University of Alberta

The Effect of a Three-week Multisensory Training Program for Postural Sway Control

by

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ABSTRACT

Evaluating postural sway parameters can play an integral part in a rehabilitation program. One device capable of quantifying postural sway measures is the Chattecx Dynamic Balance System (CDBS). The purpose of the Study 1 was to determine the test-retest reliability and the discriminant validity of the CDBS. Forty non-injured females, ranging in age from 20 to 49 years (mean age 30.03 ± 6.95 years) were randomly assigned according to the hours spent per week practicing sporting activities. This study demonstrated that the CDBS revealed good test-retest reliability (ICCs > 0.80), but it did not have good discriminant validity in distinguishing the effect of hours spent at sporting activities per week for postural sway control between Group 1 (exercise five hours or more) and Group 2 (exercise less than five hours) when testing static and dynamic balance.

Study 2 used a randomized controlled intervention to investigate whether a three-week multisensory training program would lead to a decrease of postural sway. Twenty four non-injured young females, ranging in age from 20 to 49 years (mean age 32.17 ± 7.70 years) and twenty four non-injured elderly females, ranging in age from 60 to 80 years (mean age 64.21 ± 4.58 years) were randomly assigned either to training groups (i.e. young training group: YTG, and elderly training group: ETG) or control groups (i.e. young control group: YCG, and elderly control group: ECG) with no training. Before and after the training program, all four study groups were measured for overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) for six training factors using the CDBS.

At posttest, the results showed significant improvement in the trained groups when compared to the untrained groups for all three postural sway measures for all six training factors in contrast with the pretest values. However, the ETG did not show significantly greater improvement when compared to the YTG. The findings also demonstrated that the trained ETG improved in their total Berg Balance Test (BBT) scores after the training program when compared to the untrained ECG.

The three-week multisensory training program successfully improved postural sway control and functional balance ability for both the non-injured young and elderly females. It is recommended that when designing such programs, specific sensory systems have to be targeted in order to expect improvement (i.e. reduced sway).

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Thank you.

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CHAPTER 1

INTRODUCTION

1.1 PROBLEM STATEMENT

Balance is a complex process involving the coordinated activities of the reception and integration of multiple sensory inputs, motor components for the planning and execution of movement, and biomechanical components. The position of the body in relation to gravity and its surroundings is sensed by combining visual, vestibular, and somatosensory inputs to achieve a goal requiring upright posture so that a fall does not happen. Optimal controls of balance in upright posture as well as postural stability are essential requirements for sports activities, daily activities, or for the prevention from musculoskeletal injury. [1,2]

Balance is defined as a state of body equilibrium or the ability to control and to maintain the center of gravity (COG) or the center of body mass over the base of support without falling in a given sensory environment with integration of the central nervous system (CNS). [3,4] Berg [5] attempted to define balance in three important components: the ability to maintain a position, the ability to voluntarily move, and the ability to react to a perturbation.

Mattacola et al. [6] stated that center of balance (COB) is the point between the feet where the "ball" (metatarsal heads) and heel of each foot has 25% of the body weight (Figure 1.1 and Figure 1.2). This point is referred to as the relative weight positioning over the four load cells as measured only by vertical forces.

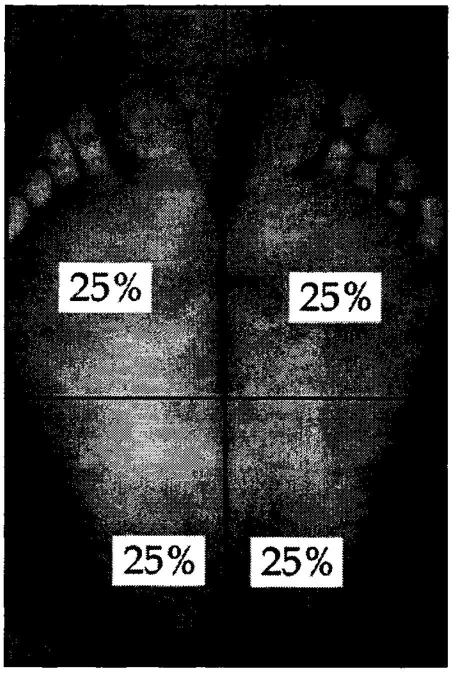


Figure 1.1: Bilateral stance: normal center of balance is the point between the feet where the "ball" and heel of each foot has 25% of the body weight.

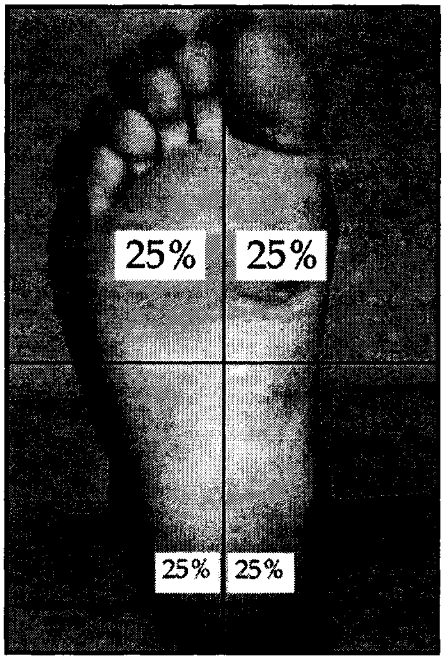


Figure 1.2: Single leg stance: normal center of balance is the point between the foot where the "ball" and heel of each foot is partitioned into four quadrants, each quadrant comprised of 25% of the body weight.

Balance reactions occur to maintain or regain the center of gravity over the base of support. These automatic reactions occur during static positions such as sitting and quiet standing (static balance), and they occur during transition phases, that is, from one position to another position (dynamic balance) (e.g., sit to stand, walk, and turn). Balance response selection is based on the conditions of the perturbation (i.e. amplitude, velocity, and direction), the initial position of the individual (the position of the individual in space and the relationship of body parts to each other), environmental conditions (e.g. the stability of support surface, objects in the environment, and the condition of the lighting), past experiences, and the goal. The goal to be achieved is to maintain or regain the center of gravity over the base of support so the individual remains balanced. [7] Variables that may affect balance and that are constantly changing include: (a) the location of the center of gravity (COG), (b) the base of support, (c) the limit of stability, (d) the surface conditions, (e) the visual environment, (f) sensory input, (g) movement, and, (h) the intentions and task choices in producing changing demands on the systems that control balance. [8]

Balance is a multi-component and highly adaptable control process. When a balance of a healthy individual is challenged, the sensory inputs determining the COG position and the pattern of movement correcting the perturbation depend on the task conditions and the person's immediate past experience. An individual with one or more impaired sensory input or motor output component will attempt to compensate by adapting both the impaired and normally functioning components to suit the demands of the balance task. Balance movements involve primarily motions of the ankle, knee, and hip joints, which are controlled by the coordinated actions of ankle, thigh, and lower trunk muscles as a task of maintaining a person's center of gravity over the base of support. [9,10]

Postural control has been defined as the ability to maintain posture equilibrium in a gravitational field by keeping or returning the center of body mass over its base of support to attain the desired positions or movement without falling. [11-13] Although postural control is taken for granted, it is a complex process involving the coordinated actions of biomechanical, sensory, motor, and central nervous system components. [3] Postural control has been functionally divided into several different activities including maintenance of posture (standing and sitting), controlled movement of the body's center of mass, and response to external disturbances. [5] Postural control is an integral component of all movement. [11] The ability to maintain postural control under dynamic conditions is an important underlying component of physical activity or performance. [14] Dysfunction in postural control may cause functional loss as well as restricted mobility. Fluctuations in displacement also indicate the response of the central nervous system (CNS) to correct the body's COG to prevent imbalance. [15] Deviation from this center of balance in any direction represents postural sway. Postural sway is the distance expressed in centimeters that an individual travels away from his or her center of balance. [12]

The goal of postural control is to orient the body parts relative to one another and the external world without loss of balance. Unstable environments place greater demands on the postural control systems. [8] The more stable the environment, the lower the demand on the individual for balance and postural control. [8] Posture must be controlled both while the body is still (static equilibrium) and during movement (dynamic equilibrium). Stabilization of postural equilibrium is achieved by continuous afferent and efferent control strategies within the sensorimotor system with feedback from somatosensory, vestibular and visual inputs. [2] The afferent information is processed in the brainstem and cerebellum, and then motor commands are initiated. [16] If any of the sensorimotor feedback loops is suppressed or defective, body sway increases and concurrently, muscle activity increases to maintain balance. [17] In the dynamic states of natural behavior, voluntary movement can perturb postural equilibrium, but knowledge of these potential perturbations is built into the motor program and used to offset their adverse effects ahead of the event by anticipatory (feed-forward) motor action. [18] The anticipatory postural responses are controlled by multi-sensory feedback such as visual, somatosensory, and vestibular inputs. They are also controlled by the postural strategies for correction includes ankle, hip, and stepping strategies. [19] These postural adjustments act in advance to compensate for changes in posture and balance caused by the movement. Anticipatory responses are adaptable to task conditions and must be learned, but eventually, they operate automatically after being triggered by specific intended movements. The postural system is also equipped with stereotypical response patterns that are rapidly corrected for unexpected perturbations. Some of these responses are innate, while others have to be acquired through motor learning that involves the cerebellum. These responses are characteristically driven by immediate feedback from visual, vestibular, and somatosensory information. Postural control is complex and context dependent. Postural control is not organized as a single unit. Independent control of the position or orientation of segments such as the head, trunk, and forearm has been shown to exist.

Nashner [9] stated that the ability to maintain postural control and balance depends on information provided by visual cues, vestibular function, and somatosensory feedback (proprioceptive neural input) from structures in the lower extremities. The integrity and interaction of postural control mechanisms (i.e. visual receptors, vestibular systems, and proprioceptive mechanoreceptors) allow a wide range of movement and functions to be achieved without loss of balance. [8] If balance and postural control are not established following injury, then the individual will be susceptible to recurrent injury and balance and postural performance may decline.

Balance abilities are heavily influenced by higher level neural circuitry and by multiple body systems such as the cognitive, sensorimotor, and musculoskeletal systems. [20] The nervous system is influenced by and responsive to the demands placed on it by the tasks being accomplished and the environment in which those tasks are performed. [21-23] The ability to maintain balance requires the integration of proprioceptive input from the periphery with afferent information from the eyes (visual) and the vestibular apparatus in the inner ear. [24] Therefore, proprioception is a distinct component of balance. Numerous investigators have provided definitions regarding the terminology of joint sensation, or proprioception and kinesthesia. Most contemporary authorities define proprioception as a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position sense. [25,26] They refer to proprioception as the inborn kinesthetic awareness of body posture including movement, tension, and changes in equilibrium. [27] Irrgang et al.[14] have defined proprioception (somatosensory) as the ability of the central nervous system to process received input from muscles, tendons, and joints and to translate the information in a meaningful way.

Proprioceptive input is the cumulative neural input from the mechanoreceptors in the muscles (i.e. muscle spindle receptors and Golgi tendon organs), joint capsules, ligaments, tendons, and skin (i.e. cutaneous receptors) that is conveyed to the central nervous system (CNS) through afferent neural pathways. [6,27] Proprioceptive feedback to the brain contributes to the body's ability to maintain postural stability. In addition, a loss of somatosensory function may lead to a loss of balance (i.e. increased postural sway) in otherwise healthy individuals. Normal balance is a combination of coordination and the individual's ability to maintain the body upright against the forces of gravity. Posture varies based on such factors as musculoskeletal structure, neurological functioning, heredity, and personality. [28]

Maintaining balance is a function of a number of sensory inputs to the CNS, including visual, vestibular, and somatosensory components. These three sensory inputs are required because no single sense can measure the COG position directly relative to gravity and the base of support. Vision measures the orientation of the eyes and head in relation to surrounding objects. The somatosensory input provides information on the orientation of body parts relative to one another and to the support surface. The vestibular input does not provide orientation information in relation to external objects. Rather, it measures gravitational, linear, and angular accelerations of the head in relation to inertial space. There is no single combination of the three senses that provides accurate COG information under all performance conditions. This is because one or more of the senses may provide information that is misleading or inaccurate for purposes of balance and postural control.[29] For instance, when a person stands next to a large bus that suddenly begins to move forward, momentary disorientation or unsteadiness may result. A fraction of a second is required for the brain to determine whether the resulting visual stimulus indicates backward sway or forward movement of the bus. Similarly, a downward tilting support surface may be confused with a backward swaying of the body.[29]

During sensory conflict situations, the CNS must quickly select the sensory inputs providing accurate orientation information and must ignore the other misleading ones. Failure to ignore conflicting sensory inputs can lead to instability or surface and surrounding motion illusions. The process of selecting and combining appropriate sensory information has been termed sensory organization.[29] Sensory organization is a process by which all three senses receive input and a determination is made whether any of the input is misleading.[30]

Vision plays significant role in balance when a support surface is unstable.[31] For instance, when toes-up and toes-down tilting of a surface disrupts somatosensory input useful for balance, COG sway is significantly less with the eyes open than with the eyes closed.[32,33] When functionally useful somatosensory and visual inputs are available under fixed support and visual surround conditions, the vestibular input plays a lesser role in direct control of the COG position.[32] This is probably because the somatosensory and visual inputs are more sensitive to body sway than the vestibular system. Vestibular input, however, is critical for balance under sensory conflict conditions and when somatosensory and visual inputs are unavailable. In addition, the vestibular input plays a critical role when conflicting visual or somatosensory information requires a person to identify and quickly ignore a misleading input. [33] The primary role of the vestibular system is to signal the sensation of acceleration of the head in relation to the body and to the environment. It allows independent control of head and eye positions. [30,34]

Somatosensory inputs (i.e. feet in contact with the support surface, and detection of joint movement) provide information concerning the orientation of all body parts for the maintenance of postural stabilization. [32,34] Under fixed support surface conditions, somatosensory input derived from the contact forces and motions between the feet and the support surface dominates the control of balance and posture. [35,36] According to Dietz and colleagues,[37] healthy individuals normally rely more on visual and somatosensory input to control postural sway. Healthy normal individuals are able to ignore the conflicting visual information if the somatosensory input is available. In addition, somatosensory inputs will compensate for the loss of visual and vestibular information. [9] The strength of the somatosensory input allows a well-compensated patient with a bilateral vestibular loss to maintain sway well within the limit of stability with the eyes-closed. [32,33] Horak et al. [34] demonstrated that neither vestibular nor somatosensory loss resulted in delayed or disorganized postural responses. However, both types of sensory deficits altered the type of postural responses selected under a given set of conditions. For instance, somatosensory loss resulted in an increased hip strategy for postural correction while standing across a shortened surface (e.g. a balance beam). Vestibular loss resulted in a normal ankle strategy but lacked a hip strategy, even when required for a task of maintaining equilibrium on a shortened surface. The authors concluded that cutaneous and joint somatosensory information from the feet and ankles may play an important role in assuring that the form of postural movements are appropriate for the current biomechanical constraints of the surface and / or foot. They also suggested that vestibular information is necessary to control equilibrium in a task requiring use of a hip strategy and somatosensory information is sufficient in controlling equilibrium in a task requiring utilize of the ankle strategy. Thus, both somatosensory and vestibular sensory information play important roles in the selection of postural movement strategies appropriate for their environmental context. [34]

There are three commonly identified postural strategies: (a) ankle strategy, (b) hip strategy; and, (c) stepping strategy. [3,38] The ankle strategy shifts the center of gravity (COG) while maintaining the placement of the feet by rotating the body as an approximately rigid mass about the ankle joint. The head and hips travel in the same direction at the same time, with the body moving as a unit over the feet. This is accomplished by contracting the ankle joint muscles to generate torque about the ankle joints. [9] This strategy is used whenever sway is small, slow, and near midline. It occurs when the support surface is broad and stable enough to allow pressure against it to produce forces that can counteract sway to stabilize the body. [8,9,39] The ankle strategy is most effective in executing relatively slow COG changes when the base of support is firm and the COG is well within the limit of stability perimeter. This strategy is also effective in maintaining a static posture with the COG offset from the center. [8,9] The utilization of the ankle strategy requires adequate surface somatosensory information. Movements organized into the hip strategy are centered about the hip joints with smaller opposing ankle joint rotations. [9] This strategy describes postural sway control from the pelvis and trunk. The head and hips travel in opposite directions, with body segment movements counteracting one another. This strategy is observed when sway is large, fast, and, nearing the limit of stability, or if the support surface is too narrow (e.g. a balance beam) or unstable to permit effective counter-pressure from base of support. [40] The utilization of the hip strategy requires adequate vestibular information. The stepping strategy describes steps in any direction with the feet in an attempt to reestablish a new BOS with the active limbs when the COG has exceeded the original base of support. The stepping strategy is the only movement strategy effective in preventing a fall when the perturbation displaces the COG beyond the limit of stability perimeter. [8,9] It is important to understand strategies do not occur in sequence with every balance disturbance. Postural strategies that emerge in any situation are limited by both external and internal constraints. In addition, these strategies are further constrained by the availability of sensory information inherent in the environment and perceived by the individual. [41] The normal response of balance disturbance is the emergence of the single strategy best suited to the particular perturbation, the limitations of the individual, or the conditions in the environment. Despite the availability of multiple sensory inputs, the CNS generally relies on only one sense at a time for orientation information. [32,34]

Aging is a progressive and usually irreversible diminution of the ability of an organism or one of its parts to perform efficiently or to adapt to changes in its environment with the passage of time. The consequence of the process is manifested as decreased capacity to function and to withstanding stresses. [42] As people age, they go through physiological processes that are natural and likely enhanced by certain conditions (e.g. inactivity and environmental factors). Aging has impact on virtually all aspects of the individual sensory and motor components of the balance system. [10,43]

Dysfunction in the sensory and motor systems contributes to an increased risk of falling among people who are 65 years of age or more.[44] Adequate postural control requires intact sensory and motor systems to enable detection of center of gravity deviations and to generate appropriate and prompt muscle responses to effect postural corrections.[45]

With aging, there is a decline in visual acuity, depth perception; contrast sensitivity, sensitivity to glare, and alteration dark adaptation, which means to adjust the vision sensitivity fully to the reduced level of illumination. Normally, adaptation to a sensory loss in one function is accomplished through an increased sensitivity of the other senses. For example, a young blind patient can adapt by using vestibular input and somatosensory input and usually learns to function well in spite of the loss of the visual input. The older the patient is when blinded, however, the more difficulty she or he will have in making this adaptive crossover to other senses. The vision losses or disturbances are contributing to the functional impairments.[46] A major cause of balance difficulties in older adults may also be related to central and peripheral visual impairments and to visual perceptual impairments. Defective horizontal and vertical visual perception has been implicated in falling in older adults. Declining peripheral vision may also contribute to falls.[47]

Degenerative changes due to generalized atrophy in the vestibular system are seen in the otolithic organs, vestibular neuroepithelium, vestibular nerve, vestibular nuclei, and areas of the vestibulo-cerebellum. Lalwani[48] points out that the changes include demineralization and fragmentation of the otoconia along with a slow decline in the number of hair cells and ganglion cells in the peripheral system. Since the specialized neural hair cells of the mammalian peripheral vestibular system are nonmitotic, the loss of sensory elements throughout the life span cannot be replaced. Therefore, the effects of aging together with external factors such as ear injuries that cause hair cells to be damaged for instance, can be responsible for dramatic changes in the vestibular system over time. [10]

The somatosensory system has also been shown to undergo degenerative changes with aging including changes in positioning sense, general sensation, and threshold for motion detection at a joint. These declines may lead to postural instability, which means ineffective sensory processing. The elderly who has ineffective sensory processing was unable to adjust and does not demonstrate anticipatory postural reactions in cooperate with the degree of perturbation. The deficits in proprioceptive and kinesthetic processing may cause inefficiencies in altering postural disturbance, hence leads to increased episodes of falling in elderly. [49] Although postural sway has been found to increase with advancing age, [50,51] there is considerable variability among subjects and this appears to be unrelated to functional ability. Experimental and clinical evidence suggests that a decline in the ability to integrate the three sensory inputs for maintenance of posture is seen in elderly. [52] Conversely, Baloh et al. [53] demonstrated age related decreases in vestibular, visual, and somatosensory functions in normal older people, but these changes were only weakly correlated with changes in gait and balance. The amplitude of sway alone has been reported not to be a good predictor of the likelihood of falls. [53]

Muscle mass declines with age, resulting in decreased muscular strength especially in the lower limbs as measured by isometric and isokinetic torque. Muscles force, endurance, and grip strength decrease significantly with age. [52,54] Loss of power and work output of the muscle is also apparent. These declines, together with a reduction in the rate of development of maximum muscle force, and additional complicating musculoskeletal system factors include decreases in the range of motion and increases in the stiffness at various joint [52] could certainly impact on many aspects of postural control.

The aging effects on musculoskeletal such as loss of muscle mass, strength, contractile speed, and power have been attributed to changes and the decreased use of the neuromuscular system. [54] These declines will defeat the efficacy of CNS integration to select and adjust muscles' contractile patterns, thus slowing the process of sending the decision to peripheral motor components such as muscles acting on ankle, thigh, trunk, and neck for the generation of body movement to maintain upright posture and balance control. The slow reaction and response of the peripheral motor component will risk the aging to fall. [55]

With age, loss of bone density causes the bones to become more fragile, [56] hence increased risk of osteoporosis, frailty, fractures, arthritis, and decreased flexibility. These declines will defeat the volitional posture movements and anticipatory postural responses to perturbations that may cause posture imbalances in an aging population. [55]

Aging affects the deficits of central nervous system leading to decreased cognition, memory, learning ability, and reaction time. As age advances, performance of tasks requiring cognitive processing slows. This finding is especially true for information integration and the preparation of responses. As decision points in a task requiring motor output are approached, slowing is again noted with increasing age. [57]

Decreased cognition and reaction time will slow the motor and sensory input processes thus increasing the risk of falls after perturbations. Deficits in memory and learning ability impede motor learning processes for the relearning and retraining of balance skills. [10]

The impact of aging on the deficits of the central nervous system is to alter balance, partly due to impaired hearing and sight. Impaired hearing and sight will decrease sensory inputs from vision, and the vestibular region to interact with an environmental disturbance to determine the body position needed to execute the best choice of body movement, thus increased the risk of a fall or imbalance. [10,43]

One of the differences observed between younger and elderly subjects has been in the manner in which the body sways about the feet in standing. Amiridis et al. [58] suggested that increasing postural demands during quiet standing results in greater sway and active hip movement in the elderly that is compensated for by increased hip muscle activity (hip strategy), a finding not noted in younger adults. In addition, Horak and colleagues, [20] and Manchester et al.[59] have suggested that on normal size support surfaces (i.e. not on a narrow beam), elderly adults make greater use of a hip strategy than do young adults. The younger individuals tend to sway at the ankle (ankle strategy) when the support surface is perturbed or smaller than the base of support. [60] The different responses in elderly individuals could reflect insufficient muscle strength to generate the necessary movement about the ankle or poor sensory feedback from, for instance, the plantar surface of the feet. Deterioration in cutaneous, visual, and vestibular input has been reported in elderly individuals. However, it seems that it is the interaction between these systems that is critical for balance and postural control. [34] Elderly adults (as well as the young) can shift from one sensory input to another if one input is disturbed but it appears that if two inputs are disturbed, the elderly adults have more difficulty balancing and control their postural sway. [29]

Impaired postural control indicates that the risk of ankle joint injury is increased even in previously uninjured soccer players. [61] Freeman's findings [62] demonstrated that there was a decrease in proprioception following an ankle sprain. The majority of therapeutic exercises used for ankle sprains call for proprioceptive training, functional progressions, and early mobilization. There has been increased attention on the development of balance and postural control in the rehabilitation and reconditioning of individuals following injury. The young adults prefer to use an ankle strategy to compensate perturbations. Therefore, proprioceptive rehabilitation following injury to structures of the lower leg is an integral element in the rehabilitation of lower extremity especially for the young adults.

It is believed that injury results in altered somatosensory input that influences neuromuscular control. If balance and postural control are not established following injury, then the individual will be susceptible to recurrent injury and balance and postural performance may decline. Poor postural control is one of the factors that may contribute to reinjury in ankle sprains. It is strongly recommended by Goldie and colleagues [63] that rehabilitation following inversion ankle injuries include balance training to minimize the risk of further injury. The integrating of balance training into rehabilitation and prevention programs could improve neuromuscular control and force-couple co-activation as well as decrease the incidence of ankle pathology.

Characterizing postural control abilty for differing test conditions of non-injured individuals are essential to provide clinicians with a reference for comparison when examining injured individuals. Before designing a rehabilitation protocol for lower extremities injuries, postural sway control evaluation is essential. Evaluating postural control characteristics can play an integral part in the rehabilitation of injury. In clinical practice, postural sway evaluation is frequently used to measure an individual's ability to maintain posture equilibrium. When evaluating postural control, clinicians often focus on the assessment of the motor and biomechanical systems. In a clinical setting, postural control is usually assessed using non-standardized clinical observation. [64] Normally, the assessment consists of noting whether there is a presence or absence of equilibrium and protective reactions, decreased balance in standing or sitting, and includes a general description of the size of base of support. Occasionally, the length of time one can maintain a static posture is recorded. [64] To date, no population-based reference material of postural sway has been presented in the literature. [65] There have been no quantitative studies of normal either young or elderly adults that could serve as a database for clinical use. The measurement of postural sway may be taken for a patient serially over time and possibly by more than one clinician. A reliable measurement tool will not only enable clinicians to make objective, quantifiable recommendations for the treatment and rehabilitation management but will also allow them to assess a patient's progress with treatment. Therefore, evaluating postural sway consistently plays an integral part in the rehabilitation of injury. Both validity and test-retest reliability of postural sway measures must be known if they are to be used in clinical decision making to ensure clinicians use this instrument more confidently in order to determine postural sway control characteristics for injured individuals. It is essential to question the reliability of any evaluative procedure that is to be used in clinical practice or research.

There are not many standardized measurement tools that measure postural sway exclusively. One of the devices capable of quantifying postural sway measurements is the Chattecx Dynamic Balance System (CDBS) (Chattanoogo Group, Inc, Hixson, TN) (Figure 1.3).

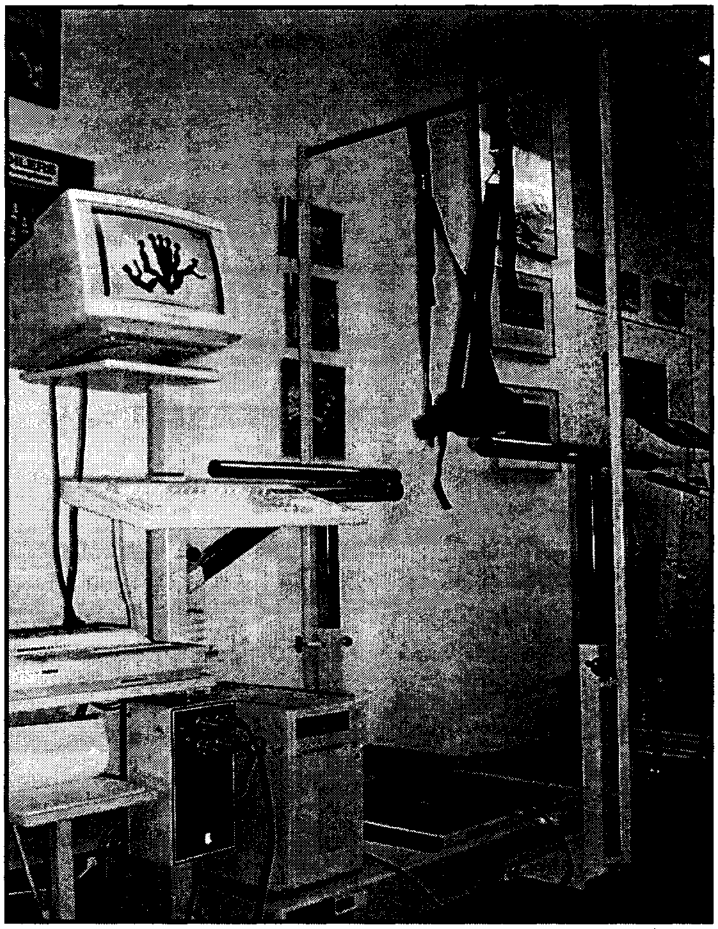


Figure 1.3: The Chattecx Dynamic Balance System

The CDBS is a computer-interfaced force platform that permits the examination of balance under static and dynamic conditions. This instrument has a limited amount of published data regarding its use. [66-72] Relatively few studies have examined the reliability of the CDBS. A review of the literature indicates that reliability studies of postural sway or dynamic measures of balance using the CDBS on healthy individuals revealed a wide range of reliability values from poor to excellent (ICCs = 0.06 to 0.90). Hence, a researcher is advised to retest the reliability of the particular instrument each time it is used by different raters for various intended purposes of the measurement. [73] Thus, Study 1 was conducted to retest the reliability of the CDBS prior to its use for evaluating the effectiveness of a three-week multisensory training program (Study 2).

To the researcher's best knowledge, no quantitative study regarding the determination of the effectiveness of a postural balance training program using postural sway measures of non-injured subjects is currently available to serve as a starting point using the CDBS and its effect on postural sway control. Therefore, the researcher was interested in developing a three-week multisensory training program that was perceived would have a significant effect on postural sway (decreased sway) among non-injured young (age range: 20 to 49 years) and elderly (age range: 60 to 80 years) females (i.e. Study 2).

1.2 OBJECTIVES OF THE STUDIES

1.2.1 Study 1

Before evaluation protocols are considered for use in the clinical setting to evaluate postural sway, the ability to obtain reliable and valid measurements should be demonstrated. The demonstration of acceptable levels of reliability and validity for such testing protocols would strengthen the ongoing use of similar protocols in clinical and research settings. Therefore, the purposes of Study 1 were as follows:-

1. To determine the test-retest reliability of the Chattecx Dynamic Balance System in measuring postural sway on non-injured females.

2. To estimate discriminant validity by determining whether the postural sway measures (i.e. overall sway [OS], medial-lateral sway [MLS], and anterior-posterior sway [APS]) produced by static and dynamic balance testing were able to discriminate between females who vigorously practiced sporting activities five hours or more per week (Group 1) from females who moderately practiced sporting activities less than five hours per week (Group 2) including competition or as an active pastime for pleasure or exercise using the CDBS.

Postural sway measures for static and dynamic balance consisted of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) in six combinations of conditions: visual (eyes-open and eyes-closed), stance (bilateral and unilateral) and support surface (stable, toe up-down, and linearly moving platform). This investigation addressed measurement reliability and validity, and added to the limited pool of normative data for postural sway, as well as increasing clinicians understanding of the importance of selecting a valid and reliable measurement tool in a clinical setting.

1.2.2 Study 2

Numerous balance training protocols are presently being utilized for rehabilitation testing and research. There is no quantitative record concerning which types of balance training are effective in decreasing postural sway for non-injured individuals. Therefore, non-injured young (age range: 20 to 49 years) and elderly (age range: 60 to 80 years) females were used for this study to demonstrate postural sway control training effects.

The objectives of Study 2 were as follows:-

1. To determine the effectiveness of the three-week multisensory training program, particularly its impact on postural sway measures (i.e. OS, MLS, and APS) of non-injured young and elderly females using the CDBS.
2. To examine and to compare the training effects between young and elderly training groups for all three postural sway measures when considering training factors such as: (a) types of balance with the eyes conditions (i.e. static and dynamic balance; eyes-open and eyes-closed conditions), (b) types of stance (i.e. unilateral and bilateral stance), and, (c) leg dominance (i.e. dominant and non-dominant leg).
3. To examine whether the improvement in postural sway measures of the elderly training group shown by the CDBS would indicate the same trends on the Berg Balance Test (BBT).

To meet these goals, all three postural sway measures (OS, MLS, and APS) were evaluated before (pretest as baseline) and immediately after (posttest) the three-week postural balance training (three weeks apart from pretest) for both young and elderly training groups (YTG and ETG) and both young and elderly control groups (YCG and ECG) to identify the effectiveness of the three-week multisensory training program. All three postural sway outcomes measures were analyzed independently to examine the training factors (i.e. types of balance with the eyes conditions, types of stance, and types of leg dominance) on postural sway control. In addition, it was hypothesized that the outcome measures produced by the CDBS could indicate similar training effects on the BBT scale as a field measure of functional balance ability.

1.3 RESEARCH HYPOTHESES

1.3.1 Study 1

The following research hypotheses were evaluated in Study 1:

1. It was hypothesized that by using a standardized protocol, good clinical reliability of postural sway measures for test-retest reliability coefficient (i.e. ICC > 0.80) could be obtained across sessions in non-injured individuals.
2. It was also hypothesized that the CDBS was a valid instrument device for evaluating postural sway and was able to discriminate between Group 1 and Group 2.

1.3.2 Study 2

The following research hypotheses were evaluated in Study 2:

1. It was hypothesized that the trained non-injured females in the young and elderly training groups (YTG and ETG) would have significant differences on postural sway measures (decrease of sway dispersion) in OS, MLS, and APS immediately after the three-week multisensory training program using the CDBS when compared to the untrained non-injured females in the young and elderly control groups (YCG and ECG) when considering the static and dynamic balance with the eyes-closed and the eyes-open conditions; bilateral and unilateral stance; and, the dominant and non-dominant leg.
2. It was hypothesized that a greater training effect would be demonstrated in the ETG when compared to the YTG for all three postural sway measures with all six training factors.

3. It was hypothesized that the trained ETG would show increasing BBT scores when compared to the untrained ECG.

1.4 SIGNIFICANCE OF THE STUDIES

1.4.1 Study 1

Because the CDBS revealed a wide range of reliability, the researcher wanted to establish reliability and validity of the CDBS to enlarge its normative data pool. This study was the pioneer study to examine the discriminant validity of the CDBS in distinguishing hours spent on sporting activities per week between Group 1 and Group 2 using postural sway measures (i.e. overall sway, medial-lateral sway, and anterior-posterior sway).

This study was unique because it included six specific combined conditions of the eyes-open and the eyes-closed; bilateral and unilateral stance; stable and moving platform as evaluation protocols for postural sway measures. In addition, to the researcher's best knowledge, no studies have used the same conditions to measure postural sway, and to investigate discriminant validity of the CDBS by postural sway measures to distinguish between females who vigorously practiced sporting activities for five hours or more per week (Group 1) and females who moderately practiced sporting activities for less than five hours per week (Group 2) included competition or as an active pastime for pleasure or exercise. [74]

1.4.2 Study 2

This study was undertaken to create a baseline data for postural sway control training program for future research that could use young and elderly subjects with previous injury or injured athlete populations. This study also provides preliminary data for effective postural sway control training program that could enable clinicians to make comparisons between rehabilitation programs. Additionally, if the postural sway control training program successfully indicated a positive effect (i.e. improved balance and postural sway control), it might be possible to adapt the program to train previously injured general populations and injured athlete populations in their rehabilitation programs.

This is the first study using the CDBS as a training device as well as an evaluation device to determine the effectiveness of a postural sway control training program. This study was unique in that it had a specifically designed postural sway control training program that consisted of nine training variations. The nine training variations were specifically designed by the researcher to incorporate manipulation of somatosensory and visual inputs.

Non-injured young and elderly females were trained and evaluated after training on the CDBS so the researcher could view the changes that occurred in a controlled setting in the absence of pathology. Effective postural sway control training is thought to improve the control of postural sway. [75] The positive effect of the postural sway control training revealed the need for clinicians to explore more effective functional rehabilitation programs and postural sway prevention training programs.

1.5 DEFINITION OF TERMS

1.5.1 Operational Definitions

A significant challenge in interpreting studies on postural control is the variation of terminologies utilized by different researchers. Generally, the terms such as postural control, postural stability, postural sway, and balance are often used synonymously. Two research groups [11,76] have attempted to create standardized definitions. For clarity and specificity, the following definitions were applied in both Study 1 and Study 2.

Anterior-posterior Sway

The distance expressed in centimeters that an individual travels away from his or her center of body mass anterior-posteriorly. [12]

Balance

A state of body equilibrium or the ability to control the center of gravity (COG) over the base of support (BOS) in a given sensory environment without falling. [3,4]

Base of Support (BOS)

The surfaces of the body that experience pressure as a result of body weight and gravity, and the projected area between them. [77]

Center of Balance (COB)

Center of balance (COB) is the point between the feet where the "ball" (metatarsal heads) and heel of each foot has 25% of the body weight (refer Figure 1.1 & 1.2). [6]

Center of Body Mass

The point at which the total mass of a body is assumed to be centered and upon which the sum of external forces can be considered to act. [76]

Center of Gravity (COG)

The point through which the vector of total body weight passes. [76]

Center of Pressure (COP)

The location of the vertical ground reaction force on the forceplate. It is equal and opposite to all the downward acting forces. [78]

Dominant Leg

The leg used to kick a ball. [79]

Eyes-closed Condition

Both eyes closed while being blindfolded using a blindfold to make sure visual input is totally eliminated.

Group 1: Vigorously Active in Sporting Activities

Vigorously active in practicing sporting activities five hours or more per week included competition or as an active pastime for pleasure or exercise (refer Appendix 1.A for examples of sporting activities suggested by Sallis et al.). [74]

Group 2: Moderately Active in Sporting Activities

Moderately active in practicing sporting activities less than five hours per week included competition or as an active pastime for pleasure or exercise (refer Appendix 1.A for examples of sporting activities suggested by Sallis et al.). [74]

Medial-lateral Sway

The distance expressed in centimeters, that individual travels away from his or her mean center of balance (COB) medial-laterally. [12]

Postural Control

The ability to maintain posture equilibrium in a gravitational field by keeping or returning the center of body mass over its base of support to attain the desired position without falling. [12]

Postural Sway

Postural sway is the distance expressed in centimeters that individual travels away from his or her mean center of balance (COB). [12]

Proprioception

A specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position sense. [25]

Romberg Stance

Standing with feet together. [80]

Somatosensory Input (Proprioception Neural Input)

Somatosensory input is the ability to receive input from muscles, tendons, and joints and to process that information in a meaningful way in the central nervous system. [9]

Sporting Activities

Physical activities occurring while participating in competition or as an active pastime for pleasure or exercise. Examples of sporting activities listed by Sallis et al. were referred in both studies (refer Appendix 1.A). [74]

Sway Index

Sway index (dispersion index) is a single number, which expresses the sway pattern (the degree of scatter of data about the mean center of balance).[6]

Tandem Romberg

One foot in front of the other, heel touching the first toe, and both heels and both the first toes approximately on a straight line.[81]

Visual Feedback

Information provided by vision on the orientation and motion of the body with respect to global space.[82]

1.6 LIMITATIONS AND DELIMITATIONS OF STUDY 1

1.6.1 Limitations of Study 1

Limitations of Study 1 included:-

1. the ability of the researcher to apply standardization protocols to each subject during each evaluation session;
2. the inability to control or measure all variables (i.e. subjects' concentration, attention, motivation, and fatigue) during evaluation process.

1.6.2 Delimitations of Study 1

This study was delimited to:-

1. non-injured females with age ranging from 20 to 49 years;

2. subjects with normal ankle stability and postural control with no known pathology;
3. the limited number of test repetitions;
4. the six specific combination of static balance and dynamic balance testing conditions;
5. the eyes-open and eyes-closed (blindfolded) conditions; bilateral and unilateral stance; and, stable and platform moving settings.
6. postural sway measures of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) using the CDBS.

1.7 LIMITATIONS AND DELIMITATIONS OF STUDY 2

1.7.1 Limitations of Study 2

Limitations of Study 2 included:-

1. the ability of the researcher to apply standardization protocols of the training and evaluation sessions to each subject across sessions;
2. the inability to control or measure all variables (i.e. subjects' concentration, attention, motivation, and fatigue) across training and evaluation sessions.

1.7.2 Delimitations of Study 2

This study was delimited to:-

1. non-injured females (age range: 20 to 49 years for young adults, and 60 to 80 years for elderly adults);

2. subjects with normal ankle stability and postural control with no known pathology;
3. the specially designed multisensory postural balance training program;
4. the limited number of test repetitions and training conditions;
5. the six specific combination of static balance and dynamic balance testing conditions;
6. the eyes-open and eyes-closed (blindfolded) conditions; bilateral and unilateral stance; dominant and non-dominant leg; and, stable and platform moving settings;
7. postural sway measures of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) using the CDBS;
8. the BBT scale only pertained to measure training effects in the elderly groups.

1.8 ETHICAL CONSIDERATIONS

Eligible subjects were initially contacted to participate in these studies by the researcher. Information letters were given to each subject to provide her with the details of the studies (see Appendix 1.B and 1.C for details). Before the baseline evaluation and training, the researcher asked all the subjects to read, and ensure they understood what was happening in the study, and than signed informed consent forms (Appendix 1.D) for both studies which guarantee confidentiality. All personal information given by the subjects was treated confidentially. For Study 1, the subjects were grouped to Group 1 or Group 2 according to the hours spent doing sporting activities per week. In Study 2, the subjects were informed that they would be randomly assigned (drawing from an envelope) to either control groups (YCG and ECG) or training groups (YTG and ETG). In addition, all subjects were informed about the potential benefits of the research through the purpose stated in the consent forms. Every subject was reminded that her participation was voluntary. Subjects had the right to withdraw from the study at any time. The researcher explained the evaluation protocols and the postural balance training program to all the subjects involved and clarified that the activities carried out in these studies were not harm the participants physically or psychologically. However, a safety harness (Figure 1.4) was used to protect them from unnecessary physical harm.

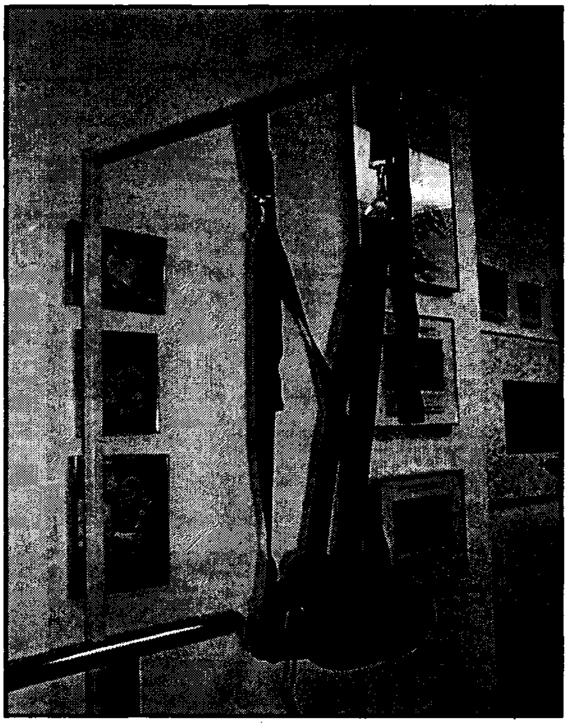


Figure 1.4: Safety Harness for Protection

These investigations were reviewed and approved by the Health Research Ethics Board: Panel B, University of Alberta before being implemented.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW OF STUDY 1

The literature review was divided into three sections:

2.1.1 Theoretical framework of postural control;

2.1.2 Related studies on postural control;

2.1.3 Concepts of reliability and validity measures.

2.1.1 Theoretical Framework of Postural Control

Historically, assessment of human postural control has developed using two complementary methodologies. The first method had its beginning with the nineteenth century work of Romberg, [83] who compared spontaneous sway under eyes-open and eyes-closed body conditions to identify peripheral somatosensory system deficits. Implicit in Romberg's interpretation of the eyes-open and eyes-closed performance of the patient was the assumption that the somatosensory input should dominate the control of balance whenever one is standing on a fixed support surface, and that visual input is the primary backup whenever the somatosensory input is disrupted. [84] Based on this assumption, a substantial increase in sway under eyes-closed relative to eyes-open conditions is indicative of impairment of the dominant somatosensory input.

Contemporary theories contend that postural control emerges from a complex and dynamic interaction of multiple systems within the individual, the task, and the environment. [32,78] Early research by Nashner and Cordo [85] investigating anticipatory postural movement provide further evidence of the importance of the task and the environmental context in postural control.[86] Their research revealed that automatic postural adjustments were made prior to voluntary actions to provide a stable base to support the primary movement. They also suggested that postural control mechanisms were not only reactive but also anticipatory in nature.

Mattacola et al.[6] noted that the ability to maintain postural control came from the integration or coordination of visual, vestibular, and somatosensory (proprioceptive neural input) to the CNS. Postural control is achieved by the interaction of many systems within the person and the demands of the special task and environment.[11,78] The important systems that influence a person's postural control are the sensory system, the motor system, and the biomechanical system.[9,11,12] Under the current theoretical framework, the sensory system is an essential component in postural control as it permits perception of body position in relation to the task and the environmental context.[32] The sensory system is composed of the visual, somatosensory, and vestibular input. Each component provides the individual with unique orientation information about the environment to sense the position of the COG relative to gravity and the base of support.[9] An individual relies on a combination of these three components from both sides of the body to perceive and interpret conditions from the environment necessary for postural control. Although multiple sensory inputs are available, the central nervous system (CNS) relies on only one sense at a time for orientation information despite the availability of multiple sensory inputs.[32,34] An individual with one or more impaired sensory input or motor output component will attempt to compensate by adapting both the impaired and normally functioning components to suit the demands of the postural control task.[9] Somatosensory input will compensate for the loss of visual information, and the vestibular input becomes critical for balance when both somatosensory and visual inputs are misleading or unavailable. [9,36] Proprioceptive information arises from mechanoreceptors in the muscles, tendons, ligaments, joint capsules, and skin. It includes information concerning muscle forces, static position, and movement. This information is relayed to the CNS and back to the effector muscles, [87,88] which reflexively assist in controlling joint position. Deficits in proprioception may adversely affect postural sway. [62] Ankle injuries may lead to partial joint deafferentation, thus interfering with proprioceptive reflexes that are mediated by articular mechanoreceptors. [62]

Currently, with force plate technology, the use of so-called "static" posturography has expanded Romberg's original concept by enabling examiners to acquire more quantitative measurement and analysis of the patient's postural sway. [89-94] The typical force plate consists of a flat, rigid surface supported on three or more points by independent force-measuring devices. As the patient stands on the force plate surface, the vertical forces recorded by the measuring devices are used to calculate the position of the center of the vertical forces exerted on the force plate surface over time. [84] The force plate can also be utilized to measure the horizontal shear forces exerted by the individual's feet against the support surface. Horizontal shear forces measure the accelerations of the body COG in the anterior-posterior and medial-lateral directions. These acceleration forces are extremely small when the body moves slowly, but increase dramatically as the frequency of COG motion increases. For this reason, horizontal shear forces are useful in identifying the pattern of body motion being used to produce COG sway. [95]

Perrin et al. [96] conducted a study using posturographic tests on a vertical force platform to determine the effects of practicing physical and sporting activities on balance control in elderly people. The study finding demonstrated significant differences in postural control between elderly subjects who practiced physical and sporting activities and those who did not. The authors concluded that practicing physical and sporting activities had a positive effect on balance and postural control (i.e. improved dynamic qualities and good control coordination in elderly subjects), thus reducing the risk of falling significantly.

A study conducted by Sallis et al. [74] has classified individual physical activity levels as vigorously active and moderately active. According to this study, individuals who regularly practiced sporting activities five hours or more per week were classified as vigorously active. Those who regularly practiced sporting activities less than five hours per week were classified as moderately active. Sallis et al. [74] classifications for levels of sporting activities were referred in the present study to classify subjects' level of sporting activities. Therefore, in this study, subjects who vigorously practiced sporting activities five hours or more per week were classified as Group 1. Subjects who moderately practiced sporting activities less than five hours per week were classified as Group 2. Sporting activities referred in this study included competition or as an active pastime for pleasure or exercise.

To provide clearer theoretical and conceptual framework that was referred through out the whole process of these studies, the researcher has defined and delimited the scope of the studies according to the research focus as indicated in the research theoretical and conceptual framework as displayed in Figure 2.1.

The Research Theoretical and Conceptual Framework
Training Normal People to Decrease Postural Sway

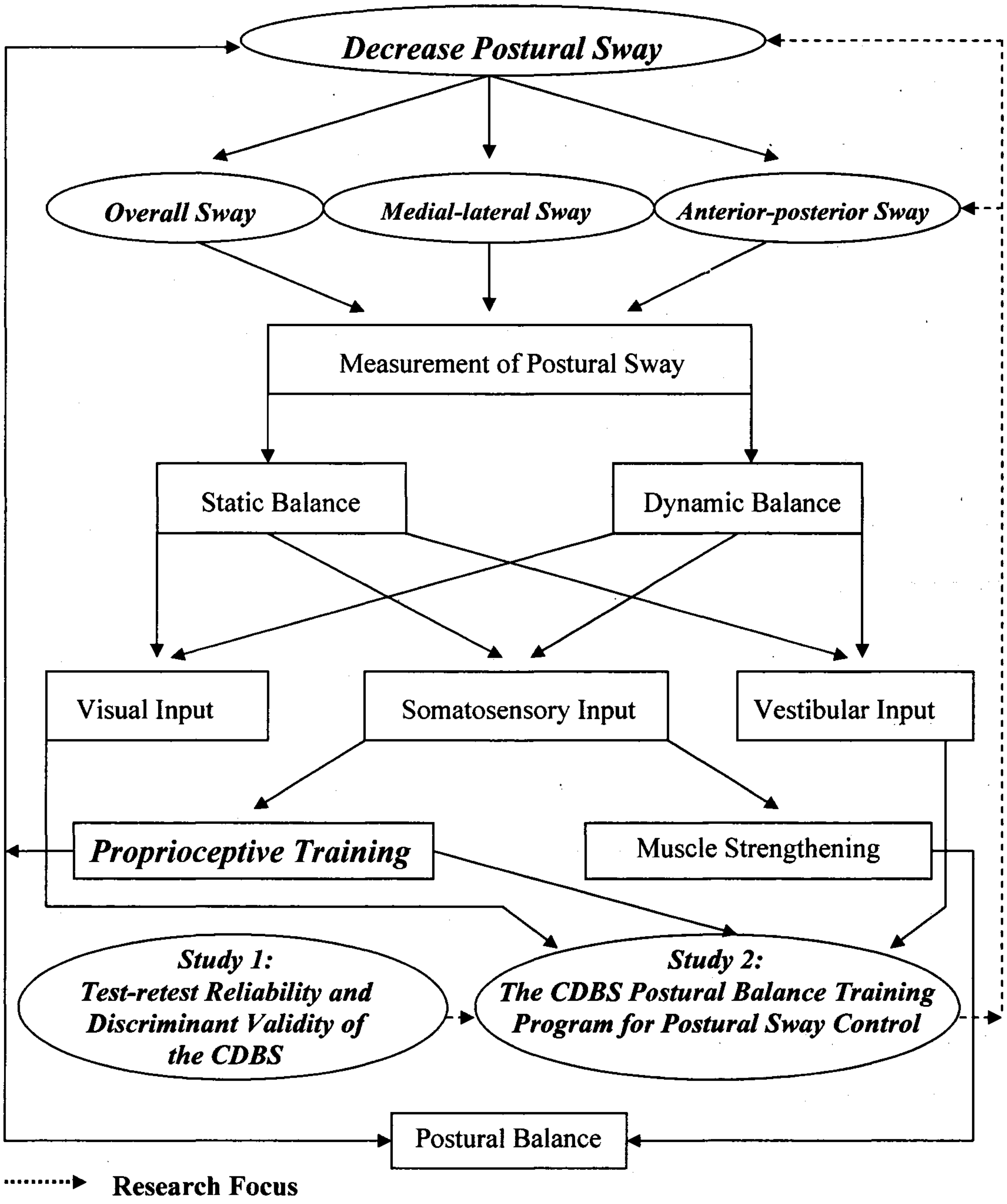


Figure 2.1: The Research Theoretical and Conceptual Framework

2.1.2 Related Studies on Postural Control

Traditionally, measurements of static balance and dynamic balance have been treated as the essential measurements of postural control. [97] In the static balance tests, subjects either do not move or do not have their balance challenged in any way. Researchers usually measure static balance with the subjects under different sensory conditions to differentiate sensorimotor impairments from neuromuscular or musculoskeletal dysfunction. [97] Some of the most frequently cited measures of static balance are variations on the Romberg test. Differences in body sway are observed with subjects' eyes-open and eyes-closed, as they stand with their feet together in a heel-to-toe position (tandem), or on one leg (unilateral). [98] The length of time that subjects can maintain these positions is often used as the measurement factor. Other examples of static balance tests include unilateral stance time, the Functional Reach Test, and the Postural Stress Test. [99,100]

For dynamic balance tests, patients either move or have their balance challenged in some way. Wolfson et al. [101] developed a relatively simple dynamic measure called the Postural Stress Test. In this test, a belt is attached to a patient, and weights of different proportions of the body weight are dropped to cause a predictable displacement force to the subject. Chandler and colleagues [102] found that the Postural Stress Test differentiated between elderly subjects who fell and young and elderly subjects who did not fall.

A performance test called the Time Up and Go Test is another type of dynamic balance test developed by Mathias and colleagues, [103] which required patients to perform a sequence of maneuvers (i.e. rising from a chair, walking, turning, and sitting down).

Tests such as the Sensory Organization Test and the Berg Balance Scale are widely used to assess both static and dynamic maneuvers. [99,100]

Documentation of sway in standing has also been used to quantify postural control. [104] Sway can also be documented with a force platform. A force platform is a device that allows for the measurement of changes in vertical or horizontal forces placed on the surface of the plate. Patients use the force plate as the floor support surface, and changes in their weight distribution over their feet are reflected in changes in the forces detected by the platform. [10] A force platform to quantify postural stability in patients with hemiplegia was utilized by Dettman and colleagues. [105] The use of force platform for evaluating postural control has been supported by evidence provided by Goldie et al. [63] to the selection of force variability measures.

There were numerous research reports establishing the reliability and validity of balance devices in assessing balance and postural control. For instance, Shepard et al. [43] have conducted a study to address the validity of assessing postural sway using only information available from floor reaction forces. In their study, the performance on EquiTest for normal young and elderly were compared using an experimental laboratory device that monitored multiple points on the body from the head to the feet. The conclusions were that the general characterization of movements made by a platform analysis system such as EquiTest was accurate, except that the platform could not account for head movement. [43]

The Clinical Test of Sensory Interaction and Balance (CTSIB) is a timed test that was developed for systematically testing the influence of visual, vestibular, and somatosensory input of standing balance.[106] The CTSIB appears to obtain high ($r = 0.99$) test-retest and inter-rater reliability.[106]

A study conducted by Schmitz et al.[107] to determine the inter-rater and intra-rater reliability scores of dynamic balance protocol, indicated that the single-leg, gradually decreasing platform stability test appears to be highly reliable (ICC = 0.70 for inter-rater and 0.82 for intra-rater) when performed on the Biodex Stability System (BSS). Similarly, Hinman[108] reported that test-retest reliability of the overall stability index produced by the BSS for balance measurement is acceptable for clinical testing and is comparable to other balance measures currently in use.

Rogind et al.[81] have conducted a study comparing the CDBS with Kistler 9861 (a force platform) for measurement of postural sway. They demonstrated that the CDBS is equally reliable and reproducible as Kistler force platform in their laboratory setting. Unfortunately, none of the reliability coefficient values was reported.

The study conducted by Mattacola et al.[6] on healthy individuals to determine the inter-rater reliability of assessing postural sway using the CDBS revealed a wide range of reliability values from poor to excellent (ICCs = 0.06 to 0.90). However, they reported that intraclass correlation coefficients (and standard errors of measurement in centimeters) ranging from 0.41 (0.21 cm) to 0.90 (0.06 cm) for inter-rater reliability of the CDBS during single-leg static and dynamic testing. Therefore, they concluded that variability existed for the measure of postural sway for static and dynamic testing conditions. This study finding has been supported by Hill et al.[109] They demonstrated low retest reliability and high intra-subject variation on the CDBS for static measures contrasting with high reliability for dynamic measures.

Conversely, Byl and Sinnott [110] investigated intra-rater and inter-rater reliability of the CDBS and reported correlation coefficients of 0.92 and 0.90 respectively. Irrgang et al. [70] measured postural sway of normal individuals during unilateral stance on a stable platform using the CDBS. Their results indicated moderate to high reliability (ICCs = 0.47 to 0.81) reliability within and between days for stable non-moving measures of balance. Similarly, Ghent et al. [72] assessed the reliability of the CDBS by testing on 54 subjects (age range: 15 to 79 years) using four conditions of stable or moving platform and eyes-open or eyes-closed conditions, their results were moderately reliable (ICCs = 0.45 to 0.63).

Condron et al. [111] suggested that the CDBS was a reliable (ICCs > 0.65) and valid measure ($r > 0.47$) that discriminates well between healthy young adults (mean age 26.4 ± 6.1 years), healthy older adults (mean age 73.8 ± 6.0 years) and those with a mild increase in risk of falling (mean age 74.8 ± 7.3 years) in dynamic balance testing. Their study findings also indicated that the best discrimination occurred with platform tilting in the anterior-posterior direction, and with concurrent performance of a cognitive task on the CDBS. Similarly, Liao et al. [112] found that the sway index and sway ratio measurement from the CDBS proved to be objective and sensitive indicators that could be used to distinguish children with cerebral palsy from normal peer groups.

Related studies as referenced on the validity and reliability of postural sway measurements using computerized devices were summarized in Table 2.1.

Table 2.1: Related Studies on the Validity and Reliability of Postural Sway Measurements using Computerized Devices

Researcher	**Study Topic**	**Balance Device**	**Results**
Rogind et al.[81]	Comparison of Kistler 9861A force platform and Chattecx Dynamic Balance System for measurement of postural sway: correlation and test-retest reliability. (on healthy female)	Chattecx Dynamic Balance System	Reliable and reproducible but reliability coefficient values were not reported.
Mattacola et al.[6]	Intertester reliability of assessing postural sway using the Chattecx Dynamic Balance System. (on healthy individuals)	Chattecx Dynamic Balance System	Wide range of reliability coefficient values from poor to excellent: Stable platform: ICCs = 0.41 to 0.57. Dynamic platform: ICCs = 0.63 to 0.90
Hill et al.[109]	Retest reliability of center of pressure measures of standing balance in healthy older women.	Chattecx Dynamic Balance System	Low test-retest reliability for static measures; high reliability for dynamic measures. But reliability coefficient values were not reported.
Byl and Sinnott[110]	Variations in balance and body sway in middle-aged adults.	Chattecx Dynamic Balance System	Intrarater reliability: $r = 0.92$ Interrater reliability: $r = 0.90$
Irrgang et al.[70]	Reliability of measuring postural sway during unilateral stance in normal individuals using the Chattecx Dynamic Balance System.	Chattecx Dynamic Balance System	Moderate to strong reliability: ICCs = 0.47 to 0.81

Researcher	**Study Topic**	**Balance Device**	**Results**
Ghent et al. [72]	Assessment of the Reliability of the Chattecx Dynamic Balance System.	Chattecx Dynamic Balance System	Moderate reliability ICCs = 0.45 to 0.63
Condron et al. [111]	Reliability and Validity of a Dual-Task Force Platform Assessment of Balance Performance: Effect of Age, Balance Impairment, and Cognitive Task.	Chattecx Dynamic Balance System	Moderate to high retest reliability (ICC > 0.65) for all platform conditions with and without the cognitive task. Moderately high concurrent validity ($r > 0.47$) between performance on clinical measures of balance (step test and timed up and go), activity levels and gait measures. Discriminative ability in dynamic balance (anterior-posterior direction) between healthy young adults, healthy older adults, and older adults with mild increase in risk of falling.
Liao et al. [112]	Differences in seated postural control in children with spastic cerebral palsy and children who develop normally.	Chattecx Dynamic Balance System	Showed objective, sensitive, and discriminant validity.
Shepard et al. [43]	Postural control in young and elderly adults when stance is challenged: clinical versus laboratory measurements.	EquiTest	Valid and accurate.

Researcher	Study Topic	Balance Device	Results
Black et al. [106]	Effects of visual and support surface orientation reference upon postural control in vestibular deficit subjects.	Clinical Test of Sensory Interaction and Balance	Test-retest and interrater reliability, $r = 0.99$.
Schmitz et al. [107]	Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System.	Biodex Stability System	Intertester reliability: ICC = 0.70 Intratester reliability: ICC = 0.82
Hinman [108]	Factors affecting reliability of the Biodex Balance System: A summary of four studies.	Biodex Stability System	Acceptable test-retest reliability, but reliability coefficient values were not reported.

2.1.3 Concepts of Reliability and Validity Measures

Within the rehabilitation setting, the instruments used to assess functional outcomes have been designed more rigidly and tested in clinical trials, assessing the instrument's psychometric properties, which determine their reliability and validity. Any instrument must be reliable in order to serve the purposes of measurement. When one uses tests or other instruments to measure outcomes, it is essential to make sure that these tools provide consistent data. If the outcome measure is not reliable, then one will not able to accurately evaluate the results. This is supported by Rothstein [113] who stated that a poorly constructed instrument can produce data that are questionable, if not worthless. If reliability and validity of an instrument is not established, little faith can be put in the results obtained as well as in the conclusions drawn from the results. [113] Rothstein [113] stated that a measure does not yield information if it does not show validity and reliability. The results obtained will be numbers or categories that give a false impression of meaningfulness. [113]

To properly assess the success of rehabilitation, clinicians must be sure that assessment instruments are measuring both accurately and truthfully. Furthermore, consumers of professional literature and research need to know that studies are based upon the use of valid and reliable assessment methods. The components of reliability and validity determine the degree of credibility that will be given to the findings. [114,115] Established reliability and validity therefore are essential for any measurement tool to be used clinically.

2.1.3.1 Components of Reliability

Reliability is most important when criterion measures and measurement tools are used. Despite the type of scale used to obtain a measure, the reliability of the information collected is a key component of the assessment process. [116]

Reliability addresses whether an instrument consistently reflects the status of the variable examined. [113] Reliability tells us something about the error associated with a measurement. A reliable instrument measures a phenomenon dependably, time after time, accurately, predictably, and without variation. [117] Portney et al. [118] stated that "reliability is fundamental to all aspects of clinical research, because without reliability, cannot have confidence in the data collect, nor can draw rational conclusions from those data" (p.53).

Reliability is the consistency or repeatability or reproducibility of measurements over time (test-retest reliability / intra-rater reliability) or by different rater (inter-rater reliability), that is, the degree to which measurements are error-free and the degree to which repeated measurements will agree and yields the same results. [119,120]

A. Test-retest Reliability or Instrument Reliability

Test-retest reliability is one of the most common methods used to assess reliability. Sometimes it is referred to as a coefficient of stability [113] or the stability of measure over time. [113] Thus, a reliable instrument will obtain the same results with repeated administrations of the test. [118] To establish that an instrument is capable of measuring a variable with consistency, test-retest reliability assessment is commonly used. Test-retest reliability assesses the degree to which results are reproducible when the same clinician tests the same subject at two different times. [113] All testing conditions should be kept as constant as possible. If the test is reliable, the subject's score should be similar on multiple trials. [118]

B. Rater Reliability

B.1 Intra-rater Reliability

Intra-rater reliability means the degree to which one person can replicate the measurements obtained which also refers to the stability of data recorded by the one individual across two or more trials. [113,118] Intra-rater reliability is usually assessed using trials that follow each other with short intervals. In a test-retest situation, when a rater's skill is relevant to the accuracy of the test, intra-rater reliability and test-retest reliability are essentially the same estimate. The effects of rater and the test cannot be separated out. [118] If the rater is reliable, then tests of intra-rater reliability will also tell if the variable or characteristic being measured or the measurement tool itself is stable over time. [113,121]

B.2 Inter-rater Reliability

Inter-rater reliability is important for longitudinal assessment of patients by two different clinicians. Inter-rater reliability concerns variation between two or more raters who independently measure the same group of subjects, thus refers to consistency of measurement between two or more raters. [118,121] Both types of test-retest and rater reliability are important in clinical settings, because several clinicians may assess the same patient at different times or the same clinician may assess a patient several times. [121]

2.1.3.2 Components of Validity

The use of a measurement for any purpose is questionable unless there is evidence for the validity of that use. Validity refers to the appropriateness, truthfulness, authenticity, or effectiveness of a study. Validity is not inherent to an instrument, but must be evaluated within the context of the test's intended use and a specific population. [118] Validity must address whether measurements obtained with a particular instrument can be used legitimately to make clinical judgments. [121] Validity is not a universal characteristic of an instrument. The researcher is always responsible for presenting evidence to support the validity of a measurement method for the specific question being investigated. [118] Validity should not be assessed before first establishing reliability. A valid test is reliable. Strong reliability does not automatically suggest strong validity, whereas, low reliability is automatic evidence of low validity. [118] Crocker [122,122] defined validity as the extent to which measurements are useful for making decisions relevant to a given purpose. Rothstein [121] stated validity as the ability of a tool to measure what it says it measures, so an instrument is valid when the test actually measures what it is intended to measure. Validity is the degree of correspondence between the concept being measured and the variable used to represent the concept. Validity implies accuracy as well as relevance of response.

A. Face Validity

If one assumes that a measurement is valid from an inference, it means the measurement has face validity. [123] The valid instrument should, “on the face of it”, appear to measure what it says it measures. In some ways, it is the public relations aspect of test giving. Patients will sometimes resist taking a test if it does not “make sense to them”, that is, if it does not appear to be related to something they can understand and accept. [123]

Many of the measurements used in physical therapy clinical practice appear to be based on the assumption of face validity. Face validity is the appearance of a justifiable use for a measurement, but this does not mean there is any data or theory to support its use. [123]

B. Content Validity

While construct validity defines what one wishes to measure, content validity regulates the sampling of that construct. A variable is “constructed” so there is a need to consider what will be measured. Content validity deals with how measurement schemes relate to how they are constructed. When one develops a measurement tool, he or she is attempting to define the variable being measured. In the balance example, the content would be different for an athlete than for an injured elderly individual. The ability of an athlete in dynamic balance is believed better than an injured elderly person. Therefore, the content of the tests of balance should reflect these differences. [121]

C. Criterion-Related Validity

The most objective and practical approach to validity testing is criterion-related validity. It is based on the ability of one test to predict results obtained on another test. The target test (the test to be validated) is compared with a gold standard or criterion measure that has already been established or assumed to be valid. [118] When both tests are administered to one group of subjects, the scores on the target test are correlated with those achieved by the criterion measure. If the correlation is high (the correlation coefficient is close to 1.00), the target test is considered a valid predictor of the criterion score. [118] Criterion-related validity is often separated into two components: concurrent validity and predictive validity.

C.1 Concurrent Validity

Concurrent validity reflects the relationship between two instruments designed to measure the same construct or concept. [116] Concurrent validity also refers to the relationship between test scores and either "criterion states" or measurements whose validity is known. Most frequently, concurrent validation is used to establish the validity of a new test in comparison to an older test (sometimes referred to as the "gold standard") for which the validity is known.

Concurrent validity may sometimes be used as a stepping stone to the development of predictive validity.

C.2 Predictive Validity

Predictive validity is verification of a relationship between the variable and an external criterion in the future. [116] Therefore, predictive validity is a future-oriented prediction based on a measure made today. Predictive validity is also criterion-related.

That is, it is related to outside objective criteria or direct measures of performance. It is important to be sure that the criterion to which the test is correlated is the correct one. If a test or measure is predicatively valid, then one can say that people who do well on this test have high probability of doing well later on in a similar situation. [123]

D. Construct Validity

Measurement must proceed from a logical understanding of the phenomena being measured. Construct validity is the conceptual (theoretical concept) argument that supports the use of a measurement based on reason. In other words, it is a theoretical form of validity. [116,121] Thomas et al. [124] defined construct validity as the degree to which a test measures a hypothetical construct and is usually established by relating the test results to some behavior. It is also reflects the ability of an instrument to measure an abstract concept, or construct. [118] Establishing construct validity, therefore, is essential when variables cannot be directly examined but only inferred. Part of construct validity is based on content validity; that is, one must be able to define the content area that represents the construct to develop a test to measure it. Beyond content, constructs must also be defined according to their underlying theoretical context. For instance, if one wants to measure balance characteristics of a patient, one must first have an idea of how balance is defined. To do this, a construct is needed. The construct guides the development of the measurement procedure and will ultimately determine the persons who can be measured and the conclusions that can be made from the measurement. [121] Therefore, construct validity also refers to the degree to which scores obtained from the use of an instrument are related to the concept of interest to the researcher. [125] Because of the abstract and complex nature of constructs, construct validation is never quite fully realized. Each attempt to validate an instrument provides evidence to support or refute the theoretical framework behind the construct. Construct validation is an ongoing process, wherein one is continually learning more about the construct and testing its predictions. This evidence can be gathered by a variety of methods. Two of the more commonly used procedures include convergence and discrimination validation. [118]

D.1 Convergent Validity

Convergent validity indicates that two measures believed to reflect the same underlying phenomenon will yield similar results or will show high correlation. [118] For instance, if two balance measurement scales are valid methods for measuring balance control ability, they should produce correlated scores. Convergent validity also refers to the extent to which the construct represents what it is intended to represent. In addition, convergence implies that the theoretical context behind the construct will be supported when the test is administrated to different groups in different places and at different times. [118]

D.2 Discriminant Validity

It is also necessary to show that a construct can be differentiated from other constructs. Discriminant validity indicates that different results, or low correlations, are expected from measures that are believed to assess different characteristics. [118] For instance, the results of a balance measurement should not be expected to correlate with results of an intelligence test. When the intelligence test scores fail to correlate with measures of postural sway from which they are supposed to be different, one could be certain that both constructs is unrelated.

The most general type of evidence in support of construct validity is provided when a test can discriminate between individuals who are known to have the trait (e.g. postural sway) and those who do not. For instance, if postural sway is chosen, the theoretical context behind the construct may be used to predict how different groups are expected to behave. Therefore, the validity of a particular test is supported if the test results document these known differences. [118] For example, Liao et al. [112] reported that the Chattecx Dynamic Balance System (CDBS) proved to be objective and sensitive indicators that could be used to distinguish children with cerebral palsy from normal peer groups. The study results demonstrated that children with spastic cerebral palsy and children who develop normally revealed significant differences of the sway index when tested in sitting.

Both studies conducted by Condron et al. [111] and Liao et al. [112] have proven that the Chattecx Dynamic Balance System (CDBS) is a reliable device and shows discriminant validity for postural sway measures. These findings have led to the investigator's interest in examining whether the CDBS is able to discriminant between individuals by hours spent per week regularly practicing sporting activities including competition or as an active pastime for pleasure or exercise.

In this study, the investigator operationally defined Group 1 as individuals who vigorously practiced sporting activities five hours or more per week and Group 2 as individuals who moderately practiced sporting activities less than five hours per week included competition or as an active pastime for pleasure or exercise. Measurement of postural sway has traditionally been divided into measurements of static balance and dynamic balance. [97] The construct of interest in this study for postural sway measurements therefore included static balance and dynamic balance measurements to quantify overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) through the CDBS. [126] An operational definition (refer to operational definitions) was included to describe specifically the way in which a construct was presented or measured within this study. Furthermore, the issue of validity was approached by discriminant validity. Evidence for discriminant (conceptual) validity was provided by the estimated differences between postural sway measures (i.e. OS, MLS, and APS) and the hours spent (i.e. five hours or more, and less than five hours) practicing sporting activities per week. Discriminant validity was demonstrated by the presence of significance differences between postural sway measures and hours spent per week in practicing sporting activities between Group 1 and Group 2.

2.1.4 Interpretation of Reliability Coefficient Values

The reliability coefficient can range between 0.00 and 1.00, with 0.00 indicating no reliability and 1.00 indicating perfect reliability. As the coefficient nears 1.00, it shows higher confidence that the observed score is representative of the true score. [118] However, reliability coefficients of 1.00 are rare because measurements are hardly ever perfect. Therefore, reliability cannot be interpreted as an all-or-none condition.

Most researchers establish limits that define “acceptable” levels of reliability. “Acceptable reliability” is a judgment call by the researcher or clinician who understands the nature of the measured variable and whether the measurements are precise enough to be used meaningfully. [118] Although such limits are essentially arbitrary, as a general guideline, coefficient values above 0.75 indicate good reliability, from 0.50 to 0.75

suggest moderate reliability, and below 0.50 represent poor reliability. [118] These reliability coefficient values were similar with Fleiss [73] interpretations. He noted that values of reliability above 0.75 might be taken to represent excellent reliability; values between 0.40 and 0.75 might be used to indicate fair to good reliability, whereas values below 0.40 might be considered as poor reliability. In contrast, Gliner, et al. [127] stated that generally for a measurement to be reliable, one would expect a coefficient between +0.70 and +1.00.

Richman et al. [128] have a different interpretation of the reliability coefficient values. They have suggested that for most purposes, instruments can be considered very reliable when reliability coefficient values fall between 0.80 and 1.00; as moderately reliable when the estimates fall between 0.60 to 0.79 and 0.59 and below is of questionable reliability. These guidelines are supported by Currier. [129] Others have suggested even stricter criteria. For instance, reliability coefficients of 0.80 are acceptable for research, but 0.90 is necessary for clinical measurements that will be used to make decisions about individuals to ensure reasonable reliability. [118] Currier [129] has referred to reliability coefficients offered by Blesh [130] as a scheme for comparing correlation coefficients to levels of acceptance on tests of physical performance. The criteria suggested by Blesh [130] for casual operation:

Reliability Coefficient Values by Blesh [130]
0.90 to 0.99 as high reliability; 0.80 to 0.89 as good reliability; 0.70 to 0.79 as fair reliability, and 0.69 and below considered as poor reliability.

Because no universally accepted values have been established for reliability coefficient, the reliability coefficient values proposed by Blesh [130] were used to interpret the reliability coefficient values for the results of this study. The interpretation of Blesh [130] was chosen because the measures of postural sway were tests of physical performance. In addition, stricter criteria are necessary for clinical measurements that will be used to make decisions about individuals to ensure reasonable reliability. [118]

2.1.5 Summary of Literature Review of Study 1

Findings from the literature review revealed that postural control measurement should involve both static balance and dynamic balance measurements. There is a general agreement among the researchers that for the measurement of postural control, various testing conditions would be utilized to examine the existing variability for static balance and dynamic balance. The eyes-open and the eyes-closed conditions would be use to identify the role of visual input on postural control. A stable and moving platform could indicate the contribution of somatosensory input toward postural control. Bilateral and unilateral stance would be performed to differentiate static and dynamic balance. In general, postural control is measured by postural sway that involves overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) through various testing protocols using a combination of visual and support surface conditions. [126] A review of the literature also clearly established the importance of a reliable and valid postural control measurement that assesses the postural sway through static balance and dynamic balance measurements. In the review, it was noted that studies conducted by various researchers for varying intended purposes on different populations using the CDBS for the measurements of postural control showed a wide range of reliability coefficient values (refer to Table 2.1).

Although the measurements of postural control using high-tech computerized devices such as Chattecx Dynamic Balance System (CDBS), Biodex Stability System (BSS), The Berg Kinesthetic Activity Trainer (Berg KAT), and Neurocom Balance Master, have gained wide acceptance in current clinical use, and most manufacturers have claimed that these devices are reliable and valid, the reliability and validity evidence for the use of a research instrument must be reexamined each time it is used with a different type of sample or for a different purpose.[125] To show evidence of validity and reliability, the researcher reexamined both the validity and reliability of the CDBS in evaluating postural sway control of non-injured females by measuring overall sway, medial-lateral sway, and posterior-anterior sway through static and dynamic balance conditions. The test-retest reliability and discriminant validity of the CDBS were examined concurrently through this study. Only the research focus identified in the research theoretical and conceptual framework (refer to Figure 2.1) were targeted through out the whole process of this study.

2.2 LITERATURE REVIEW OF STUDY 2

2.2.1 Studies on Postural Sway and Balance in Young Adults

The effectiveness of a postural balance training program could be important in helping to reduce the risk of lower limb injuries and could allow sports medicine professionals to target populations of high-risk players with specific training prevention protocols to prevent reinjury besides saving health care costs. An effective postural balance training program must develop the balance strategies necessary for safe and efficient balance performance. It is recommended that postural balance training should be a routine part of rehabilitation. [63]

Brandt et al. [131] had conducted several experiments in their study to determine the effect of postural balance training. They trained 28 healthy subjects (20 untrained student and 8 gymnasts) age ranging from 17 to 33 years by manipulating the visual input (eyes-open and eyes-closed) and vestibular input (head normal upright and maximally extended) for an hour in their first experiment. They found that the intermittent practice caused a remarkable improvement of balance. The mean reduction in sway amplitudes for all subjects was 20% to 30% and represents an exponential short-term training effect. In their second experiment, subjects were trained for five days of postural balance training by manipulating visual, somatosensory and vestibular inputs, indicated a 40% to 50% reduction of the initial sway activity. The training effects of one foot balance indicated a 20% exponential rapid improvement within the first training interval and up to 50% improvement within the five days of training. Their third experiment suggested that the newly acquired balance skill is stored and preserved for weeks (40 days) after termination of practice or training. Overall, the authors reported that the healthy subjects improved their postural balance up to 50% within the five-day period of training; trained gymnasts achieved weaker training effects than untrained student, due to their better initial stability. In addition, with the eyes-open condition, there was a 15% to 20% reduction for sway. These study results convincingly supported simple training of postural balance with either head extension or standing on one foot to improve body sway activity (lesser sway) within five days by 30% to 50%. [131]

The proprioceptive ankle disc training has demonstrated improved postural control on healthy young subjects and in subjects with functional ankle instability. [62,132-134] Tropp et al. [135] and Wester et al. [136] established that wobble board training could improve ankle stability and was effective in reducing the number of recurrent injuries and in preventing functional instability of the ankle in patients with primary ankle sprains. Similarly, the six-week coordination training performed on an ankle disk was found to significantly decrease postural sway as measured by stabilometry in male soccer players (aged 23 to 33 years) who had a history of previous ankle injury and functional instability of one or both ankles. [61] Goldie et al. [63] found that untrained subjects had poor postural control when on the injured leg. The essential difference between the two groups of subjects was the practice of specific balance exercises. Tropp and Askling [133] found that balance training with single-legged stance on an unstable surface, such as that provided by a rocker board, had a significant effect for improving postural steadiness. It was found that a ten-week training period was sufficient and that further training was not beneficial.

Blackburn et al. [137] trained on physically active young adults' age range from 18 to 25 years for static balance, semi-dynamic balance, and dynamic balance. Significant improvements were observed for all three groups (1) a strength training group, (2) a proprioception training group, and, (3) a combination of strength and proprioception training group for both semi-dynamic and dynamic balance from pre-training to post-training balance assessment after six-week balance and joint stability training.

Bernier et al. [138] demonstrated that postural sway can be improved in subjects with functional instability of the ankle following six weeks of coordination and balance training. The authors suggested balance and coordination training should continue to be an integral part of rehabilitation protocols.

Conversely, a four-week agility training program did not objectively improve static single-leg balance although subjects did report that they felt more stable and were able to perform better after training. [139] The results of an four-week unilateral balance training program on the Chattecx Dynamic Balance System (CDBS) revealed no significant post to pre mean gain score differences within and between groups although they showed a consistent pattern of decreases in postural sway posttest and pretest. [66] The finding is accordance with Verhagen et al. [79] study results. The authors concluded that no difference in changes of center of pressure excursion were found between trained and untrained young adults over the 5.5-week training period after a balance training program on center of pressure excursion in one-leg stance.

Baker and colleagues [140] concluded that a six-week resistive tubing kick training program using unilateral stance did not significantly improve postural stability in healthy collegiate wrestlers. The researchers suggested that the lack of improvement might have been due to the brevity of training frequency and duration. Another limitation of the study was the use of elite athletes (collegiate wrestlers) with high levels of fitness in a sport that frequently challenges postural stability. The authors suggested that a greater intensity and duration of training (more than six weeks) or using subjects who have a greater potential for improvement should be used in conjunction with proprioception training.

Several research findings demonstrated that there was no quantitative difference between males and females for postural sway. [141,142] Hageman et al. [143] stated that no gender differences could found on the selected postural sway outcome measures. Their finding was supported by Stribley et al. [141] who demonstrated that no differences between men and women for sway area measures on force platform. Similarly, Maki et al. [144] did not find gender differences during standing sway and mild perturbations. Their finding was in accordance with Wolfson et al. [145] Black et al. [90] have reported that sex and age did not have a statistically significant effect upon seven of eight Romberg test trials for normal subjects between the age ranging from 20 and 49 years. In general, it appears the amount of sway is constant for subjects' age ranging from 15 to 60 years and larger sway for younger and older subjects. [141,146]

Interestingly, McGuine et al. [142] demonstrated in a study of high school basketball players (210 subjects), the preseason balance assessment by quantifying postural sway, served as a predictor of ankle sprain susceptibility.

It is interesting to note that in a study of younger healthy subjects who were assigned to either strength or balance training regimens demonstrated significant increases in the balance performances outcomes when compared with baseline for both groups. [147] Motor skill training, including balance training, increases the sensitivity of feedback pathways and shortens the onset times of the selected muscles by improving the sensitivity of the position sense of both agonistic and antagonistic muscles. [2] The muscle, as the termination of the final pathway of the sensorimotor system, particularly contributes to the maintenance of body balance.

2.2.2 Studies on Postural Sway and Balance in Elderly Adults

Falls are one of the major problems in the medical care of the aged. The incidence of falls in aging populations has been studied in various circumstances, from patients in geriatric hospitals wards to community-based elderly. [148]

Sheldon [149] first suggested that the inability to control postural sway in advancing years plays an important part in the tendency of old people to fall. Overstall et al. [150] intended to relate postural sway to falls and suggesting that the amount of sway amplitude of fallers were more than non-fallers, when the cause of the fall is other than a trip or slip. They also reported an increase in postural sway with age, especially in females. Compared to individuals with no history of falls, Overstall et al. [150] noted significantly greater amplitude of sway in individuals who fall because of loss of balance, and in women who reported “postural falls due to giddiness, drop attacks, loss of balance, turning the head or rising from a bed or chair”. They found no difference for sway in those who fell due to tripping compared to the non-fallers. These findings were in accordance with the study conducted by Fernie et al. [151] They demonstrated that the average speed of sway was significantly greater for those who fell one or more times in a year than for those who did not fall. They suggested that postural sway was an indicator of a tendency to fall, but stated that no trend of increasing postural sway correlating with the increased frequency of falls was found. In addition, they reported that there was no sex-related difference in the mean speed of sway. This is in accordance with Hawken et al. [152] who noted that there was no significant difference in sway amplitude based on gender.

Postural control is an emergent property that involves the interactions of a number of sensory systems. According to Woollacott et al., [153] as long as two sensory inputs are available, both young and elderly adults can easily shift from the use of one sensory input to another. However, when only one sensory input i.e. the vestibular system remains, the sway of the older adult is sufficiently impaired to cause loss of balance in many instances.

Stelmach et al. [154] noted that elderly adults had significantly slower postural muscle responses than young adults and they were less responsive to the demands of the voluntary task. In addition, they stated that young adults had consistent distal to proximal responses to perturbations, while elderly adults had less stereotypical responses. When postural responses were inappropriate for the voluntary task, they were suppressed in the young adult, whereas there was less inhibition in the elderly adults. In addition, voluntary sway movement, which shifted the center of mass of the subjects away from their normal base of support, and thus placed them at the greater risk of fall, was correlated with faster postural responses in young subjects, but not in the elderly adults. [153] Stelmach et al. [154] concluded that the slowness and potential lack of reliability of postural responses in elderly adults may lead to their hesitancy to make voluntary sway movements which may put their balance in jeopardy. The authors suggested that if elderly adults move too far from their normal base of support, their slower, less coordinated postural responses may not be adequate to prevent a fall. Several authors reported increasing postural sway with age. [104,149,150,152,155] The authors noted that there was a tendency for elderly adults to have larger sway scores than younger adults. However, there was no trend in the mean speed of sway with age. [151]

An additional body system that contributes to balance and postural control is the musculoskeletal system, and one characteristic of the musculoskeletal system (i.e. muscle strength) decreases significantly with age. Whipple et al. [156] found that elderly nursing residents with the history of falls had severe impairments in overall ankle muscle strength when compared with age-matched controls. They noted that ankle dorsiflexion strength was most severely impaired in nursing home residents with a history of falls. These findings are similar to those reported by Woollacott et al., [157] who showed a significant slowing in onset latency for the tibialis anterior muscles in response to external threats to balance. Furthermore, studies on the elderly indicate small, but significant, increases in the onset latencies and disruptions in the temporal organization of postural muscle responses when subjects are given external threats to balance. In addition, elderly adults, like young children, use antagonist muscles more often in coactivation with agonist muscles when balancing. [157] Elderly adults also have more difficulty balancing when sensory inputs contributing to balance and postural control are reduced, so that they have less redundancy of sensory information. Thus, when both somatosensory and visual inputs are made incongruent with postural sway, the elderly adult shows significantly increased sway compared with the young adult, and many elderly adults lose balance completely. This characteristic is also similar to that seen in young children. Muscle (i.e. ankle dorsiflexor) weakness may also be a factor in balance dysfunction in the older adult. Conversely, the longitudinal study conducted by Baloh et al. [53] showed age related decreases in vestibular, visual, auditory, and somatosensory in normal older people, but these changes were only weakly correlated with changes in gait and balance.

Interestingly, it has been demonstrated that aged subjects are able to decrease the amplitude of postural sway with practice and training. [104] Altered postural responses in elderly subjects, such as delayed onset latencies, intermittent reversal of muscle activation sequence and occasional co-contraction in lower leg muscles, have shown a tendency to improve with practice. [158] This is supported by Hawken et al. [152] suggested that the tendency to lose balance could indicate a failure of central integrative mechanisms to adapt to sensory conflict, and they reported that when repeated trials were given, all elderly subjects except one were able to balance under moving platform with eyes-closed condition.

Hu and Woollacott [159] conducted a multisensory training of standing balance in older adults (age range: 65 to 90 years) using one leg stance incorporated with selectively manipulated sensory inputs from the visual, vestibular, and somatosensory systems. The study results demonstrated that balance training designed to improve intersensory interaction could effectively improve balance performance in healthy older adults after receiving a ten-hour balance training program. Additionally, Kammerlind et al. [160] study findings supported the findings that an eight-week balance training in elderly people with vertigo and unsteadiness seemed to improve both objectively measured and perceived balance. This is in agreement with previous studies, which noted that balance training had shown positive effects in healthy elderly people. [161,162] Johansson and Jarnlo [162] trained healthy 70 years old women and found significant improvement in standing on one leg with the eyes-open but not with the eyes-closed. Similarly, Stones and Kozma [163] supported that standing on one leg with the eyes-open had greater sensitivity to the effect of physical training than the eyes-closed condition. This is in accordance with Judge et al. [164] who suggesting that a six-month combined exercise training (i.e. resistance training, 20 minutes brisk walking, and flexibility and balance training) demonstrated 17% improvements in single-stance postural sway in healthy older women (age range: 62 to 75 years) but not in double-stance.

Studies related to the ankle appear to support the idea that strength of the dorsiflexors is a key element of balance in the elderly. Previous studies have shown positive effects of an eight-week balance training in healthy elderly people [161,162] and elderly people with vertigo and unsteadiness. [160] Wolf and colleagues [165] reported that tai chi exercise improved balance control on older adults. Although tai chi exercise uses slow movements, the beneficial effect of tai chi exercise on balance control could be due to the dynamic nature of this activity, in that it requires complex whole-body coordination.

It is interesting to note that the strength exercises contribute to better balance and gait in women aged equal or greater than 57 years. [166] In a separate study, the mean increase in balance scores in a balance training group was 146% and 34% in the strength training group. [167] A prospective, blinded, randomized trial of moderate intensity strength exercise was conducted on 132 older adults. The investigators stated that gait stability improved significantly more in the resistance exercise group than in control group. These results show that even moderate strength gains (17.6%) may benefit gait and balance, thus providing a sound basis for the encouragement of low-intensity strength training for individuals with functional limitations. [168] This is in accordance with the finding indicated that a strength training program can improve measures of balance among adults aged equal or greater than 65 years. [169] However, the effect of strength and endurance training on balance in older adults (age range: 65 to 85 years) with reduced balance showed that short-term strength and endurance training had no restorative effect on balance of the study cohort. [170] A study conducted by Judge et al. [164] found that double stance measurements were unchanged after the strength training for healthy older women (age range: 62 to 75 years). However, in single stance, the center of displacement of the center of pressure improved by 17%. [164]

2.2.3 Summary of Literature Review of Study 2

Over the past few decades, research into postural sway control and their disorders has shifted and broadened. The definition of postural sway control has changed, as well as the understanding of the underlying neural mechanisms. In rehabilitation science, the conceptual theory to describe the neural control of posture has shifted from reflex / hierarchical theory to the systems theory. The systems approach suggests that action emerges from an interaction of the individual with the task and environment. The systems approach implies that the ability to control body position in space emerges from a complex interaction of musculoskeletal and neural systems, collectively referred to as the postural sway control system [78] (Figure 2.2).

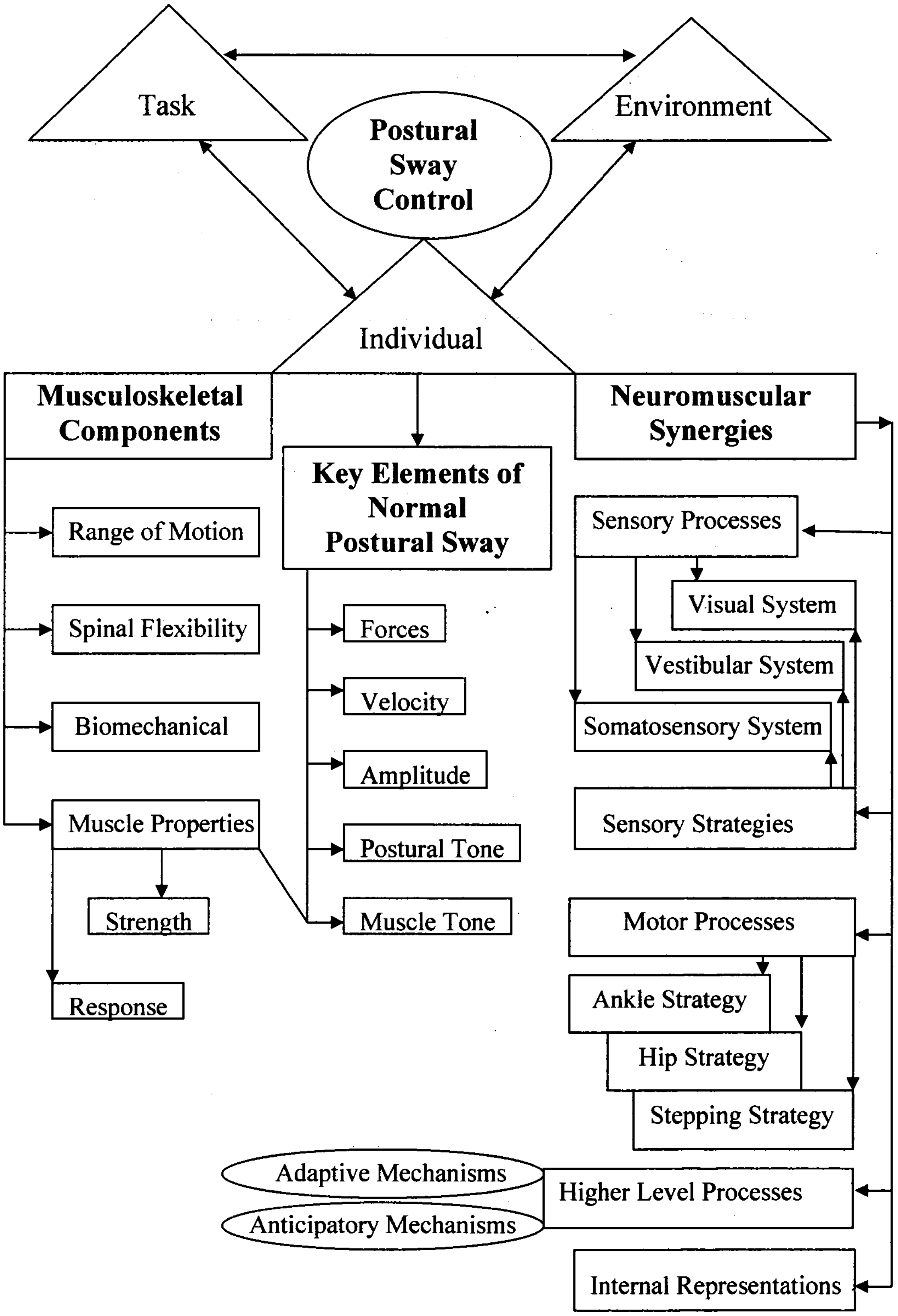


Figure 2.2: Conceptual Theory Representing Postural Sway Control Systems

CHAPTER 3

METHODOLOGY -- STUDY 1

3.1 SUBJECTS

3.1.1 Sampling

It appears that the amount of sway is constant for subjects ranging in age from 15 to 60 years with greater sway for those younger than 15 years or older than 60 years. [141,146,149] Also, several research findings have demonstrated that there were no quantitative differences between normal males and females for postural sway. [65,141,142] Black et al. [90] have reported that sex and age did not have a statistically significant effect for normal subjects between the ages of 20 to 49 years. Due to these findings, both sex and age were not chosen as variables for comparison in this study. A homogeneous group of non-injured females ranging in age from 20 to 49 years with no known lower extremities' injuries as determined by the inclusion criteria, and who had body mass index (BMI) less than 30 (i.e. in the range of 18.5 to 29.9) [171] were recruited for this study. The reason of choosing the comparable BMI (<30) was to eliminate cases of obesity.

3.1.2 Sample Size

A sample of 40 participants from the non-injured females (age range: 20 to 49 years) was used for test-retest reliability and discriminant validity. The sample size calculation was based on a study power of 0.80 at an alpha level of 0.05 for a two-tailed test. The effect size (*d or r)* of an experiment is one of the factors that influences the statistical power of an experiment. Due to no prior research looking at sample means and variances, the effect size was fixed according to a set of conventions proposed by Jacob Cohen.[172] The researcher decided to set a large effect size for both reliability and validity studies. The effect size of the validity study was *d* of 0.70 (N=33) and the effect size of reliability study was *r* of 0.50 (N=28).[172] An additional 20% was included to allow for attrition, and to enlarge the normative data pool (see Table 3.1 and 3.2 for sample size calculation in Appendix 3.A). Because the reliability and validity studies were conducted concurrently, the researcher decided to use the sample size required by a validity study in the reliability study (i.e. recruited 40 subjects for both studies).

3.1.3 Inclusion and Exclusion Criteria

Interested subjects were screened using a questionnaire (Appendix 3.B) either conducted by an interview via telephone or self-report via email. Appointments were set up if they met the following inclusion criteria:

a. females 20 to 49 years of age;
b. normal lower limbs with no known injuries;
c. normal visual function;
d. normal vestibular (balance) function;
e. normal musculoskeletal function of all joints in lower extremities;
f. vigorously active in sporting activities five hours or more per week including competition or as an active pastime for pleasure or exercise in the past three months;
g. moderately active in sporting activities less than five hours per week including competition or as an active pastime for pleasure or exercise in the past three months.

Subjects were excluded if they had any of the following exclusion criteria (Appendix 3.B):

a. injuries to either ankle and foot;

b. past history of surgery to either lower extremity;

c. ankle pain while at rest;

d. lower extremities (thigh / knee / hip) injuries within six months of the study;

e. any history of neurological conditions affecting balance (e.g. trouble balancing, multiple sclerosis, dizziness, nausea, motion sickness, light-headedness);

f. abnormal posture (e.g. bony deformity, soft tissue tightness, inability to assume a normal upright posture);

g. abnormal body mechanics (e.g. cannot assume foot flat position);

h. physically impaired (e.g. lower extremities amputation);

i. taking any prescription or over-the-counters medications that could affect normal balance (refer to Appendix 3.B for a list of medication examples).

3.1.4 Subject Recruitment

A non-probability convenience sample was used to recruit subjects from the Edmonton community. A non-probability convenience sample means each element in the population did not have an equal chance of being included, because it did not involve random selection. The advantages of this choice were: (a) near at hand, (b) easy to obtain the desired sample size, (c) likely to respond, (d) fewer refusals than a random sample of students, (e) takes less time to recruit subjects, and, (f) less cost. Volunteers were solicited through posted advertisements around campus and the surrounding commercial buildings (Appendix 3.C).

The first 40 females who met the inclusion criteria and agreed to participate were recruited. Personal demographic and anthropometric data (Appendix 1.A) including height (meter) and weight (kilogram) from these qualified subjects were collected for BMI calculation in order to eliminate subjects with obesity. The self-report information regarding average hours spent in practicing sporting activities in a week (Appendix 1.A) were utilized to define and to classify subjects into two groups. Subjects were asked to recall sports activities they practiced regularly each week for the past three months. Examples of sporting activities [74] were listed in the self-report questionnaire. Subjects were asked to recall their sporting activities during the previous seven days and quantified the time spent at each activity as precisely as possible during the testing period to control variability. Average hours spent at sporting activities per week had to be consistent (i.e. either five hours or more, or less than five hours) throughout the previous three months. Subjects were grouped into Group 1 or Group 2 according to hours spent at sporting activities per week. Group 1 included subjects who vigorously practiced sporting activities five hours or more per week, and Group 2 included subjects who moderately practiced sporting activities less than five hours per week in competition or as an active pastime for pleasure or exercise.

An information letter (Appendix 1.B) about the nature of the study was given to each subject. The issues of confidentiality and freedom to withdraw were explained. Subjects were asked to initial the information letter to indicate that they had read and understood the study information. The rater explained and demonstrated the evaluation protocols (Appendix 3.D). If the subject agreed to participate, she read and signed a consent form approved by the university's ethics committee who approves all such investigations (Appendix 1.D).

3.2 STUDY DESIGN

The study was a methodological research design that involved the testing of measuring instruments for use in research or clinical practice (Appendix 3.E). The goals of this type of research were to document and to improve the reliability and validity of clinical and research measurements.[97] Methodological studies make major contributions to research efforts, as it is virtually impossible to conduct meaningful research or clinical examinations without adequate measurement tools. For many years, clinicians have moved forward to examine reliability and validity within a context that will serve as a guide for clinical decisions. The measurement methods must test an intended population under clinical conditions, so that the findings will be meaningful to practice on the same population studied. Methodological studies on healthy subjects represent the beginning of a process to determine the measurement properties of a test, whether they are relevant to specific patient conditions and treatment choices. [118] In a research context, this approach does not involve the evaluation of treatment effectiveness, but rather, contributes to establishing the methods used to carry out that research. [118]

In recent years, the realization of the importance of documenting reliability has increased considerably among clinicians and researchers. As clinicians work toward establishing the reliability and validity of clinical measurement tools for evidence based practice, this approach is used extensively in health care research, so that there is greater confidence in the accuracy of the test measurements.

However, methodological research is not intended as an end in itself; that is, the purpose of a methodological study is to develop instruments that can be used in practice or for further testing, not to establish reliability or validity for its own sake. Sometimes it is important to evaluate instruments to determine their scope of applicability.

In this study, instrument reliability also known as test-retest reliability, was assessed to determine whether the CDBS was consistent and reliable in quantifying postural control over time. The test-retest method is an excellent approach to assessing the reliability of mechanical or electronic instruments used in experimental research. [129] To quantify postural control, the measurements of postural sway were included. The measurements of postural sway that consisted of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) were evaluated through static and dynamic balance tests. The repetitions of these measurements were made on the same group of subjects and under similar testing protocols to assure standardization (Appendix 3.E).

The time interval between test-retest must be considered carefully. To accurately examine test-retest reliability, intervals between tests should be far enough apart to avoid fatigue, learning, or memory effects, but close enough to avoid genuine changes in the measured variable, maturation, or learning occurring between the two test administrations. [118,124] Realizing the stability of a response variable is such a significant factor, a sufficient lapse in time between the first and repeated administrations were arranged appropriately to reduce or prevent the effects of memory and practice on the testing protocols. The two identical test and retest sessions were scheduled approximately at the same time of the day, separated by at least a day or more between tests. Moreover, this time interval controls for maturation as a potential confounder in test-retest results.

Appointment times for both of the evaluation sessions were made at times convenient for the participants. The participants were informed of the dates and times after they have scheduled them according to their preference. However, both evaluation sessions were scheduled between 8 a.m. and 6 p.m. from Monday through Sunday. The evaluation sessions were set and the time was controlled in order to diminish the external disturbances such as climate, temperature, subject's freshness, and circadian rhythms.

Perrin et al. [96] found significant differences in postural control between elderly (over 60 years of age) who practiced sporting activities and who did not, using posturographic tests on a vertical force platform. They concluded that sporting activities had a positive bearing on postural control. The present researcher was interested in investigating whether hours spent on sporting activities resulted in significant differences in postural control between vigorously active and moderately active non-injured young females (20 to 49 years of age) using the CDBS. According to literature, [111,112] the CDBS has good discriminat validity for discriminating the differences in postural control. Therefore, the postural sway measures (i.e. OS, MLS, and APS) produced by the CDBS during static and dynamic balance tests were examined. The researcher wanted to ensure that the CDBS was able to show discriminate validity in distinguishing between non-injured young females (20 to 49 years of age) who vigorously practiced sporting actvities five hours or more per week (Group 1) and females who moderately practiced sporting activities less than five hours per week (Group 2).

3.3 DATA COLLECTION

The overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) were assessed during the postural sway evaluation. Subjects were tested twice for each evaluation protocol and average scores from the two trials for all three postural measures were calculated based on the sway index in centimeters. A high sway score for OS, MLS, and APS values indicated increased postural sway, which indicated the subjects had more difficulty maintaining a constant position, while a lower sway score indicated a relatively better ability to maintain a constant position.

3.3.1 Instrumentation

In this study, the Chattecx Dynamic Balance System (CDBS) (Figure 1.3) was used to assess postural sway measures. The CDBS was designed to help the clinician identify and document disturbances in balance and postural stability, as well as provide multiple retraining strategies helpful in balance and postural sway control training.

To quantify postural sway, four independent force-measuring transducers were used in the CDBS (Figure 3.1). The CDBS measures vertical reaction forces through two footplates each containing two force transducers, which were placed under the subject's heel and forefoot of each lower extremity (Figure 3.2).

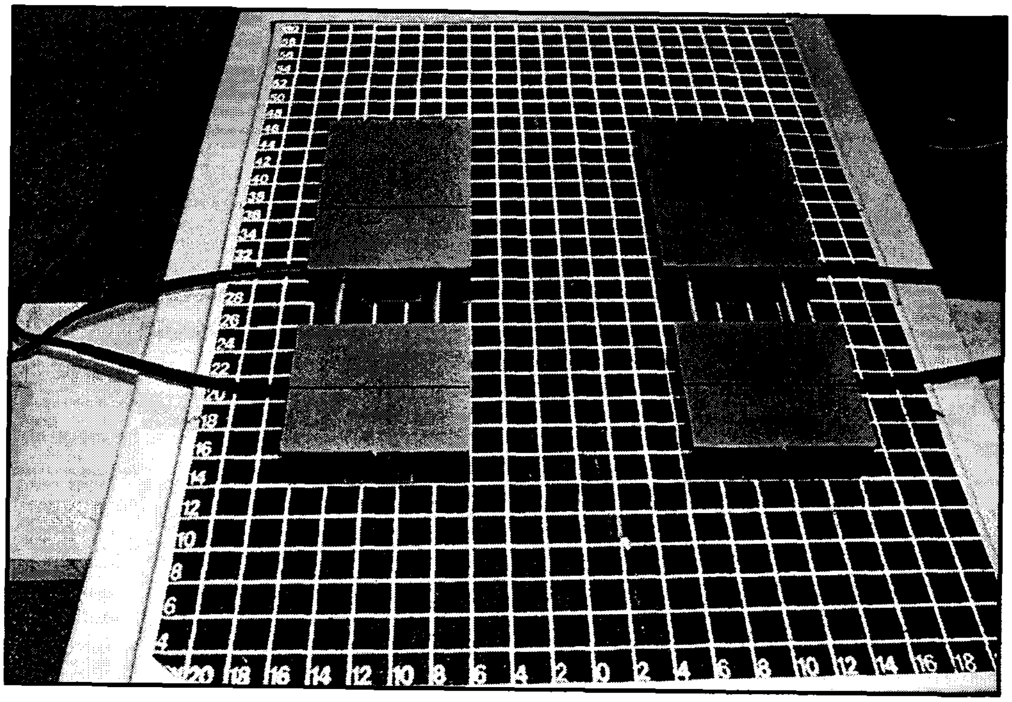


Figure 3.1: Four Independent Force-measuring Transducers

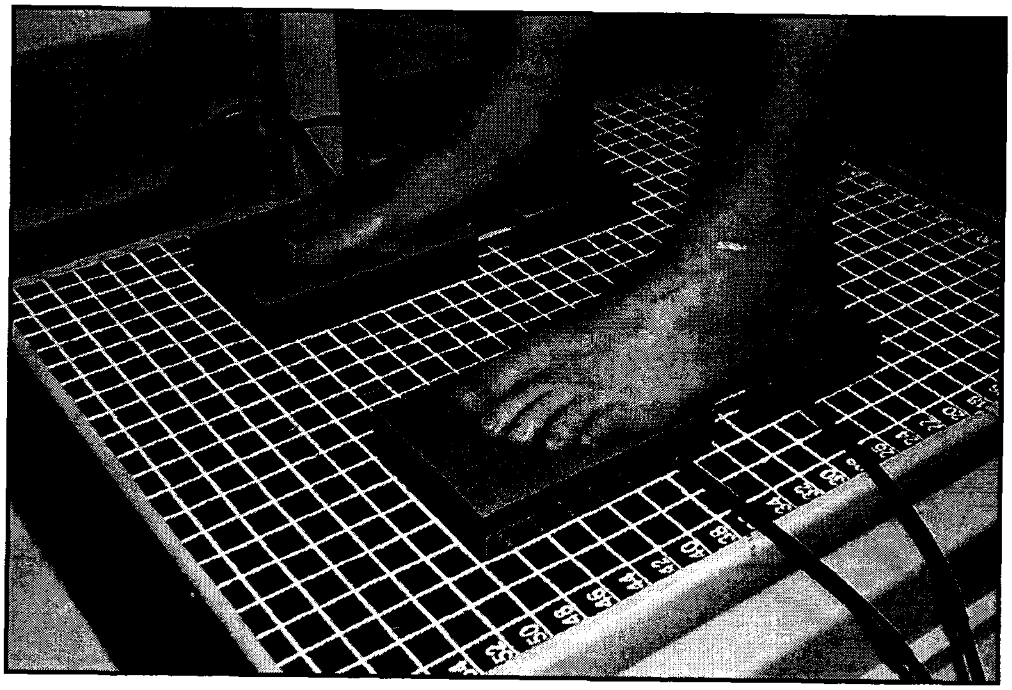


Figure 3.2: Feet Placement on Footplates

The footplates were placed on a rigid platform. The platform contained a grid to enable consistency of foot placement (Figure 3.1 - 3.2). The footplates can be separated gradually from the heel and forefoot portion for different foot sizes (Figure 3.1).

The subject placed the "ball" (metatarsal heads) of the foot or feet just above the center line of the toe plate. The individual heel position was then adjusted by adjusting heel plate so the subject's heel was bisected by the center line (Figure 3.3). By adjusting the footplates, the subject's bare feet were centered on the footplates. In this position, the "ball" (metatarsal head) and heel of each foot has 25% of the body weight [6] (refer Figure 1.1). The position of the footplates for each subject was recorded using the x and y axis numerical values printed on the base platform. This information was stored for the retest condition.

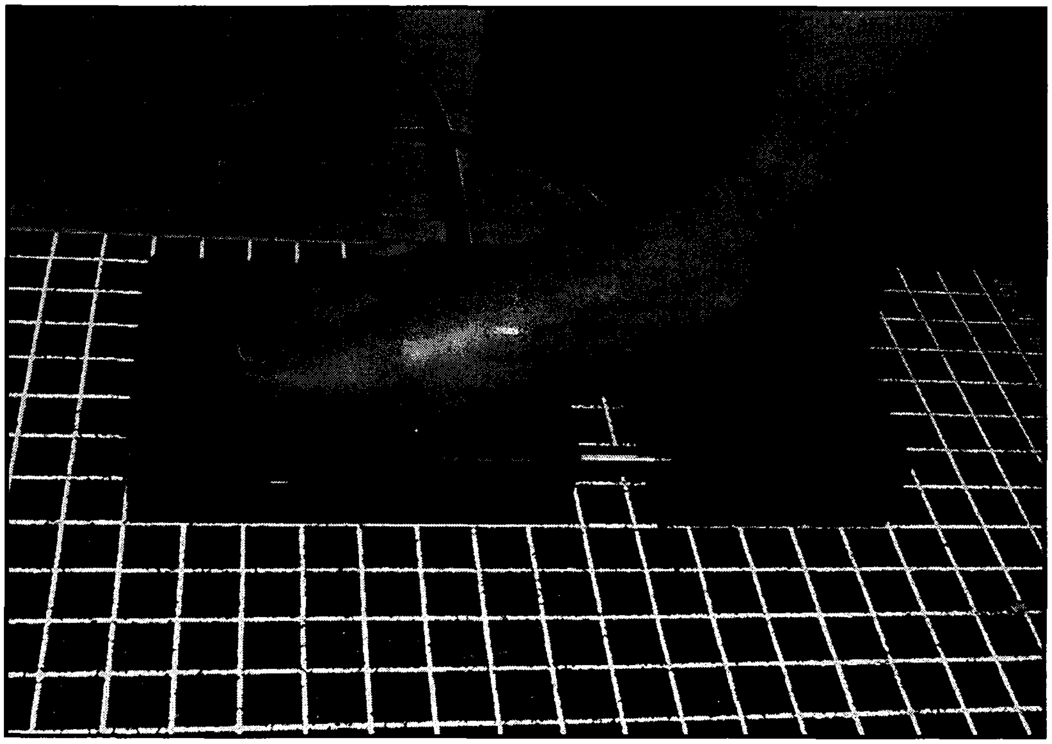


Figure 3.3: "Ball" of the Foot and Heel above the Center Line of Footplate

A subject's center of balance (COB) was indicated graphically on the monitor screen by a red "+" and numerically by the *x* and *y* coordinates. The sway index was used as the measure of postural sway. The sway index, which is calculated by the CDBS, reflects the degree of data scatter about the subject's COB. The data from the force platform measurements was interfaced with software that filters and samples the data at approximately 15 cycles per second. The sway index was calculated by determining the distance from the subject's COB for each of the data points. Each of the four transducers samples analog data, which was then amplified and converted into digital data. The output from the CDBS included:

1. the dispersion index, or sway index (SI) which was calculated as the standard deviation around the mean of 1000 normalized points gathered during a 10-second test;
2. ML – the maximal amplitude of the movement of center of pressure (CP) in the medial-lateral (*x*) direction (cm);
3. AP – the maximal amplitude of the movement of center of pressure (CP) in the anterior-posterior (*y*) direction (cm).

These data are then transformed by the software (ver. 4.00) to the coordinates (x_i, y_i) of the CP.

Formula Calculation

$$\text{SI} = \surd \sum(x_i - \bar{x}^{2}) + \sum(y_i - \bar{y}^{2}) \; / \; 1000 \text{ (100 Hz x 10-second test)}$$

* where: 100Hz means sampling frequency rate
x_i is the coordinate of the medial-lateral direction of center of pressure (CP)
y_i is the coordinate of the anterior-posterior direction of CP
$\bar{x}$, $\bar{y}$ are the coordinates of the average of CP

3.3.2 Postural Sway Evaluation Protocols

The development or testing of a measurement instrument typically involves specification of a protocol that maximizes the reliability of the instrument. Procedures were detailed to ensure consistent application and scoring (Appendix 3.D).[118] In developing the study protocol, the researcher tried to address known or expected sources of error that could limit the reliability of the test. Generally, measurement errors can be attributed to three components in the measurement process:-

1. the individual taking the measurements (tester or rater, in this case, the researcher);
2. the measuring instrument (the CDBS);
3. the variability of the characteristic being measured (overall sway, medial-lateral sway, and anterior-posterior sway).

These sources of error were minimized through careful planning, training, clear operational definitions, and inspection of equipment. [118] The researcher tried to control or to eliminate these identified sources of error although these contributions to error may not be controllable. To serve this purpose, the researcher had carefully planned the study by setting clear operational definitions; understanding the theoretical and practical nature of response variables; trained to use the instrument correctly and consistently before acting as a rater, and performed the inspection of the equipment at the beginning of each day of evaluating (i.e. recalibrate if necessary). Isolating and defining each element of the measure was believed to reduce the potential for error, thus improving reliability. [118]

The evaluation protocols were carefully planned and designed by the researcher according to the principle of operation and terminology used by the CDBS. [126]

All evaluation protocols were performed with the eyes-open and the eyes-closed. The eyes-open conditions were chose to focus on visual contributions. The eyes-closed conditions were chose to concentrate on proprioceptive neural input contributions. These dynamic evaluations with a moving platform more effectively mimic everyday activities, unlike the traditional evaluations of posture (e.g. static Romberg test or stork standing test).

The designed evaluations to quantify postural sway included six 10-second sequence tests with the eyes-open and the eyes-closed on a stable and a moving platform at maximum speed (8.3 seconds / cycle). The moving platform tilted anteriorly and posteriorly 4^0 in each direction resulting in ankle plantar flexion and dorsiflexion as the movement necessary to maintain the body in an erect and stationary position. The six postural sway evaluation protocols were as follows:

1.	Bilateral parallel stance on stable platform (eyes-closed and blindfolded) (Figure 3.4)
2.	Bilateral parallel stance on platform moving up and down (eyes-open) (Figure 3.5)
3.	Unilateral stance (right leg) on stable platform (eyes-closed and blindfolded)
4.	Unilateral stance (left leg) on stable platform (eyes-closed and blindfolded) (Figure 3.6)
5.	Unilateral stance (left leg) on platform moving forward and backward (eyes-open)
6.	Unilateral stance (right leg) on platform moving forward and backward (eyes-open) (Figure 3.7)

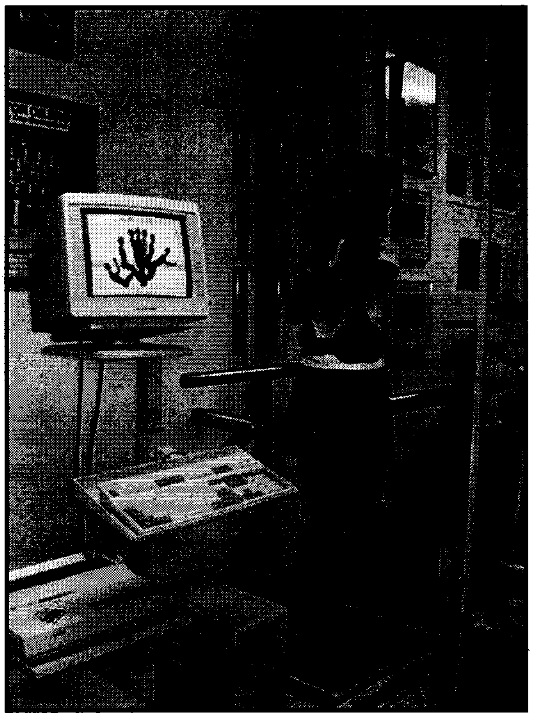


Figure 3.4: Bilateral Parallel Stance with the Eyes-closed (blindfolded)

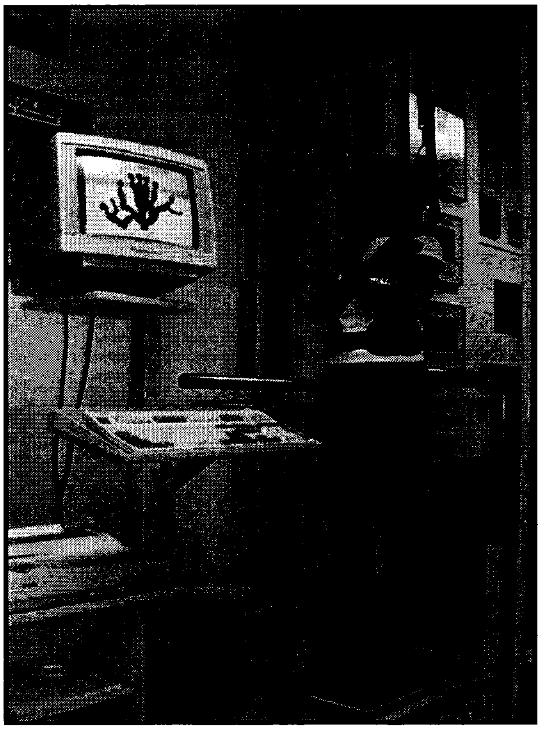


Figure 3.5: Bilateral Parallel Stance with the Eyes-open

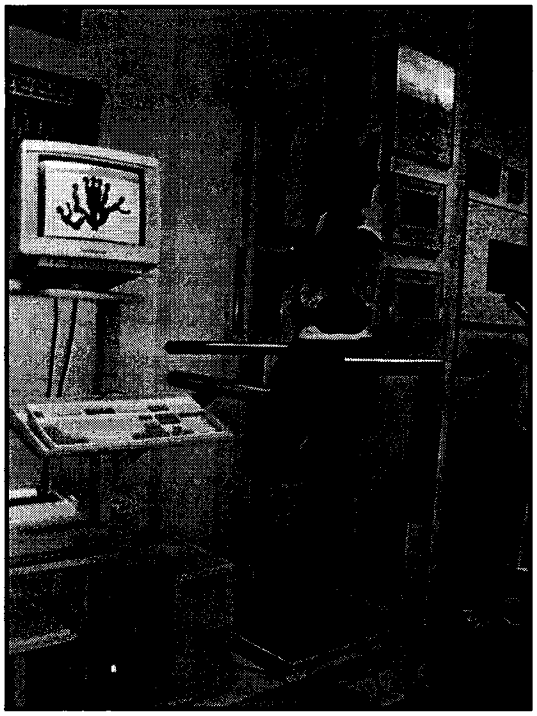


Figure 3.6: Unilateral Stance (left leg) with the Eyes-closed (blindfolded)

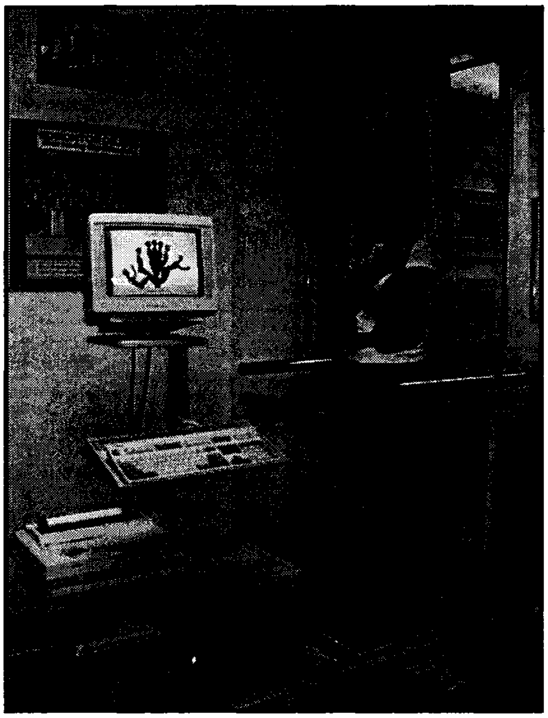


Figure 3.7: Unilateral Stance (right leg) with the Eyes-open

3.3.3 Test Administrations

To control for series effects, to avoid a learning effect, and to eliminate any fatigue that might have resulted from the testing process, the sequences of the six test protocols were administered at random order (Appendix 3.F). [137] Each subject was required to perform two repetitions for each test (12 repetitions in total). To familiarize subjects with testing protocols, and to allow for potential learning effect with repeated testing,[173] a practice trial for each test variation was performed prior to initial data collection. Subjects were allowed to rest for a minute in between each repetition. At each visit, subjects spent approximately 45 minutes participating in the evaluation process, which included completing a self-report of the previous seven days of sporting activities along with postural sway test. All measurements took place in CH1-81, Sport Therapy Research Laboratory, Corbett Hall, University of Alberta. This room was a quiet, well-lit, solitary room in order to minimize external disturbances of environmental factors such as noise and temperature during evaluation. The CDBS was placed on a flat, stable floor to diminish the influence of vibrations from the surroundings.

The researcher was aware that test score variability might be higher in a less controlled setting. The used of a standardized test protocol (Appendix 3.D) therefore was advocated to minimize measurement errors and maximize performance in this study. Testing protocols that thoroughly described the method of measurement were uniformly performed across trials, thereby improving reliability. In a consistent manner using operational procedures (Appendix 3.D), the researcher positioned each subject on the CDBS. The researcher was then informed the subjects about the sequence of events for the evaluation protocols. Subjects were asked to cross their arms, with the hands touching the opposite shoulder in order to minimize disturbing movement of the upper extremities (Figure 3.5 - 3.7) for all measurements. Subjects were required to maintain erect posture through out the whole evaluation process.

All measurements were conducted in bare feet. Foot placement on the footplates (refer to Figure 3.2 and 3.3) had to be identical to ensure measurement consistency. The footplates were placed 12 cm apart horizontally using the y-axis as a center point (Figure 3.8) to maintain the standardized alignment for the bilateral (two-legged) stance protocol.

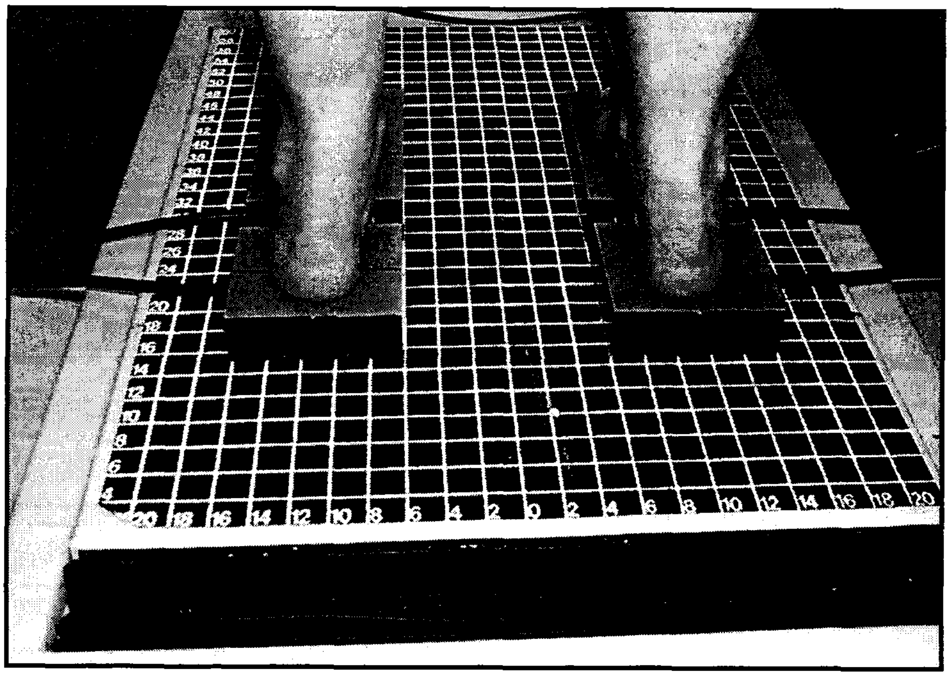


Figure 3.8: Bilateral Stance Feet Placement (12 cm apart)

During the evaluation protocol of unilateral (one-legged) stance, recordings were made with each subject standing with knee extended (0^0) on the tested leg, and the untested leg had the knee flexed to 90^0, and the hip flexed to 20^0 (Figure 3.9). To avoid injury from falling, each subject wore a safety harness that was not impeding body sway (refer to Figure 1.4).

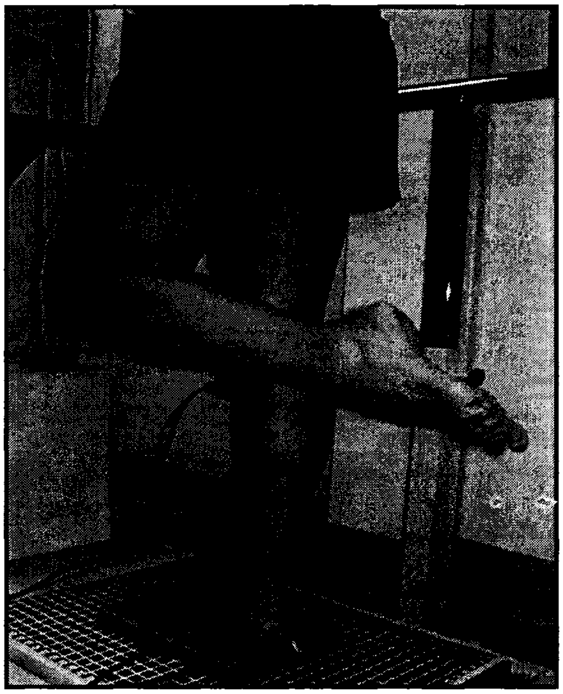


Figure 3.9: Unilateral Stance with Tested and Untested Leg Position

A practice trial was permitted for every subject for all six evaluation tests to familiarize with testing protocols. Before the evaluation began, the subject was asked to say "ready" to indicate she was balanced. As soon as the subject had indicated that she was balanced, the researcher started the evaluation recordings. During the process of evaluation, all subjects were instructed to stand as still as possible. Subjects were asked to provide their best efforts for the entire evaluation process. To avoid undue fatigue, each subject was asked to sit down during the minute rest between each assessment. A faulty trial occurred if the subjects: a) opened the blindfold in the eyes-closed condition; b) leaned onto the harness; c) grabbed hold of the handrails; d) touch down to regain balance (in unilateral stance); e) flexed the extended knee (in unilateral stance) or knees (in bilateral stance) more than 30^0; and f) moved the hip into more than 30^0 of flexion or abduction during both unilateral stance and bilateral stance tests to regain balance. If a faulty trial occurred, the subject was required to redo the trial.

There were six tests for the evaluation protocols, which took approximately 45 minutes to complete. The evaluation process for test and retest sessions for all subjects required approximately 60 hours (1.5 hours in two sessions for 40 subjects).

The researcher as the only rater collected data. Average scores from both trials in first test session and retest session were calculated for test-retest reliability. Only the average scores from first test session were collected to analysis on discriminant validity in order to minimize the possible learning effects due to multiple testing. The discriminant validity was determined by comparing postural sway measures (i.e. OS, MLS, and APS in centimeters) when testing static and dynamic balance across the subjects between Group 1 and Group 2.

The postural sway measures for two groups were recorded on identical forms (Appendix 3.G). The data calculations of postural sway measures were done by the CDBS computer interface (refer to Figure 3.10 - 3.11 in Appendix 3.H). The data was copied from results reported by the CDBS onto a data collection sheet. The average scores for OS, MLS, and APS from both trials in each test were used for data analysis. Average scores from both trials were used as the unit of analysis, as means are considered better estimates of true scores, theoretically reducing error variance, thus increasing reliability estimates.[118] The researcher entered the data manually into a statistical software package – SPSS version 15 for Windows (SPSS, Inc., Chicago). All three postural sway measures of OS, MLS, and APS were used in the analysis of test-retest reliability and discriminant validity.

3.4 STATISTICAL ANALYSIS

Descriptive statistics such as the means (M) and standard deviations (SD) were calculated for subject characteristics such as age, height (m), weight (kg), BMI, and hours spent per week in sporting activities for both Group 1 and Group 2. Independent *t*-tests were used to determine differences at baseline among the subject characteristics between Group 1 and Group 2.

Test-retest reliability has traditionally been analyzed using the Pearson product-moment coefficient of correlation (for interval-ratio data) or the Spearman *rho* (for ordinal data). Correlation coefficients have limitations as estimates of reliability. [174] The intraclass correlation coefficient (ICC) has become the preferred index, as it reflects both correlation and agreement.

Intra-class correlation coefficients (ICCs) were the statistics used to assess test-retest reliability on postural sway measures because they produce a coefficient of agreement while accounting for random effects of examiners. [174] They were calculated using variance estimates obtained through an analysis of variance. Therefore, ICCs reflect both degree of correspondence and agreement among ratings. [118]

The ICC can take several forms (Appendix 3.I). Shrout and Fleiss [174] describe three models of the ICC. They distinguish these models according to how the raters are chosen and assigned to subjects. In Model 1, each subject is assessed by a different set of *k* raters, and raters are randomly chosen from a larger population of raters. This method is rarely used in clinical reliability studies, because typically, they involve multiple raters to measure the same group of subjects and this is not feasible. [118] In Model 2, the same raters assess each subject, and raters are randomly chosen. If it is important to demonstrate that a particular measuring tool can be used with confidence by all equally trained clinicians, then Model 2 should be utilized. This approach is appropriate for clinical studies and methodological research, to document that a measuring tool has broad application. [73,118,174] In Model 3, each subject is assessed by the same raters, but the raters represent the only raters of interest. In this latter case, it is not important to generalize findings beyond the raters involved. [118] Model 3 is appropriate if the investigator is interested in establishing the intra-rater or inter-rater reliability of a group of clinicians for one specific data collection. [73,118,174] In that case, it is of limited interest if other clinicians can perform the measurements with equal reliability. Model 3 uses repeated measures analysis of variance design. [174,175] In this model, the raters being tested are considered the only raters of interest. Shrout et al. [174] suggest that Model 3 would be appropriate for testing intra-rater reliability with multiple scores from the same rater, as it is not reasonable to generalize one rater's scores to a larger population of raters. [176]

Each of the three ICC models can be expressed in two forms, depending on whether the scores are single ratings or mean ratings. [118] The six types of ICC models are classified using two numbers in parentheses. The first number designates the model (1, 2, or 3). The second number signifies the form, using either a single measurement (*1*) or average of measurements (*k*) as the unit of analysis, where the designation of *k* equals the number of measurements (for Model 3) or number of raters (for Model 1 and 2) used to obtain the average (refer to Appendix 3.I). [118]

Since the test-retest reliability was the researcher's focus and the rater being tested was the only rater of interest, Model 3 was considered the best method for this study. The average of both measurements (*k=2*) were used as the unit of analysis, because using average scores has the effect of increasing reliability estimates, as averages are considered better estimates of true scores, theoretically reducing error variance. [118] Therefore, the appropriate ICC form for this study was ICC (*3*, *k*) where *k* was equal to two measurements (i.e. measurements of trial 1 and trial 2).

$$\mathrm{ICC}\,(3, k) = \frac{\mathrm{BMS} - \mathrm{EMS}}{\mathrm{BMS}}$$

*where:
BMS = the between-subjects mean square
EMS = the error mean square
k = the number of measurements

ICCs were utilized to examine test-retest reliability of postural sway measures (i.e. OS, MLS, and APS) for Group 1 and Group 2 independently. Meanwhile, the data from both Group 1 and Group 2 were collapsed (i.e. reported as Total Group), in order to examine test-retest reliability without splitting data from Group 1 and Group 2. The ICCs were interpreted based on Blesh's [130] interpretation of reliability correlation coefficient which was as follows: high reliability (ICCs=0.90 to 0.99), good reliability (ICCs 0.80 to 0.89), fair reliability (ICCs=0.70 to 0.79), and poor reliability (ICCS=0.69 and below).

ICCs were calculated from the ANOVA data to determine the reliability of the testing. Reliability focuses on the degree of random error that is present within a measurement system. Random error is a type of measurement error or "noise" that hinders the finding of true score. [118] Random errors of measurement are due to chance.

It can affect a subject's score from trial to trial in an unpredictable way. Random errors occur from unpredictable factors such as mechanical inaccuracy, fatigue, and inattention from subjects, or even simple mistakes. [118] The observed score will be closer to the true score once random errors are diminished.

Interclass correlation coefficients provide unitless estimates of the reliability of measurement but do not provide estimates of the precision of measurement. The standard error of measurement (SEM) provides an estimate of the precision of measurement. [177] Stratford [178] demonstrated that the SEM and ICC reveal different information concerning measurement consistency. He stated that because the ICC is a numerical representation of classical test theory's version of reliability, it does not directly portray consistency, whereas the SEM represents consistency between repetitions because it is reported in the same units as the actual measurement. [178] Furthermore, Stratford [178] recommends that both the ICC and the SEM be reported for reliability studies. Standard error of measurement (SEM) therefore was calculated to determine the actual amount of variation present for each dependent variables [179] in this study (Appendix 3.I).

The concept of response stability is related to measurement error. The differences of the measurement responses from trial to trial on an infinite number of times from an individual would be a function of random measurement error. [118] The SEM describes the range in which a single subject's true score could be expected to lie when measurement error is considered. [180] Errors will be smaller, and this distribution will be less variable with a more reliable measurement and vice versa. Generally, the interpretation of the SEM is according to the properties of the normal curve. For instance, at a 95% confidence interval, the true score for an individual would lay within ± 2 SEM, and there is a 68% chance that the true score falls within ± 1 SEM at a 68% confidence interval when measurement is obtained on similar individuals by raters with similar backgrounds to those participating in the study.

The interpretation of standard error of measurement is dependent on the type of reliability coefficient that is used in its computation, [181] and the choice of reliability coefficient for calculating the SEM must be based on the ultimate purpose of predicting reliability. [118] If rater reliability is used, the SEM reflects the extent of expected error in different raters' scores. If the estimate is based on test-retested reliability, then the SEM is indicative of the range of scores that can be expected on retesting. The latter case will be the ultimate purpose of predicting reliability for this study.

Confidence interval (CI) is a range of scores with specific boundaries or confidence limits, that should contain population mean. The boundaries of the confidence intervals are based on the sample mean and its standard error. [118] In general, the confidence interval is used to estimate how the population behaves and to use the range as information for decision making or as a foundation for further research. [118] Confidence intervals are helpful in the description and interpretation of reliability too. A confidence interval gives an estimated range of values, which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data (Appendix 3.I). The width of the confidence interval gives some idea about how uncertain one is about the unknown parameter. A very wide interval may indicate that more data should be collected before anything very definite can be said about the parameter. [182] The calculation of these intervals for difference levels depends on how precise a researcher wants to be.[182] Although the size of the range of values is arbitrary, the confidence intervals are usually calculated as 90%, 95%, and 99% for the unknown parameter. If a 95% CI was determined for each dependent variable, the 95% CI contains the "true score" 95% of the time.[183] That means, if the researcher interprets an interval calculated at a 95% level as, he or she is 95% confident that the interval contains the true population mean.

Discriminant validity was assessed by determining differences across each classification group (Group 1 and Group 2) through the independent *t*-test. The independent samples *t*-test was used when two independent groups of subjects were compared. Groups were considered independent because each was composed of an independent set of subjects, with no inherent relationship derived from repeated measures or matching.[118] The unpaired t-test was based on the assumption that the variances of the two groups were not different. This was called the assumption of equality of variance or homogeneity of variance. The two tests used most often for this purpose are Levene's test and Bartlett's test, both based on the F statistic.[118] If variances shown by Levene's test are not significantly different ($p > 0.05$), they are considered equal. Then, t-test for equal variances will be utilized. When variances are unequal, an alternative formula for *t* (i.e. *t*-test for unequal variances) is applied.

The two-tailed independent samples t-test for independent means was performed to compare postural sway measures (i.e. OS, MLS, and APS) between Group 1 and Group 2 in both static and dynamic balance tests in order to distinguish significant differences for selected variables (i.e. practiced sports activities vigorously five hours or more per week and practiced sports activities moderately less than five hours per week).

Critical value of *t* was used for a test of significance. Critical value of *t* was calculated to provide the critical value of *t* for this study using two-tailed test of significance with N - 2 degrees of freedom. The *t* critical value (t_{crit}) of this study using two-tailed tests ($\alpha_2 = 0.05$) and 38 df (40 - 2) is $t_{38} = \pm 2.021$ (Appendix 3.J). For a t-ratio to represent a significant difference, the absolute value of the calculated ratio (t_{obs}) must be greater than or equal to the critical value or $p \leq 0.05$ to reject the null hypothesis. The null hypothesis (H_O) stated that there were no significant differences between μ_1 and μ_2 in the underlying population (H_O: $\mu_1 = \mu_2$). The alternative hypothesis (H_A) suggested that there were significant differences between μ_1 and μ_2 in the underlying population (H_A: $\mu_1 \neq \mu_2$). [118]

The power of this study was estimated at 0.80 ($\beta = 0.2$) with a large effect size *d* of 0.7 for validity study and *r* of 0.50 for reliability study with two tailed test of $\alpha_2 = 0.05$ (Appendix 3.A). [172] The alpha level was set at $p \leq 0.05$ a priori for all statistical tests unless otherwise specified. An average score for all subjects was used to replace the missing data if any.

No measurement is absolutely reliable or precise. It is up to each clinician and researcher to define acceptable limits of reliability and precision. To ensure the measurement method provides data that are sufficiently consistent and precise, the researcher decided to strive toward consistency in the reporting of reliability by adopting the ICC model (*3*, *k*) of Shrout and Fleiss [174] and including SEM values together with a 95% confidence intervals (± 1.96 SEM) in reports of reliability and validity. Meanwhile, the discriminant validity was assessed by two independent samples t-test followed with a *t*-ratio for the determination of the statistical significance (refer to Figure 3.12 in Appendix 3.J).

3.5 SUMMARY STATEMENT

Validation is an ongoing process of obtaining multiple sources of information and empirical evidence to assess whether the instrument actually measures what it purports to measure. Validity places an emphasis on the objectives of a test and the ability to make inferences from test score or measurement to a specific population. [118] The determination of validity for any test instrument can be made in a variety of contexts, depending on how the instrument will be used, the type of data it will generate, and the precision of the response variables. [118] Therefore, it is essential to establish test-retest reliability and discriminant validity (Study 1) of the CDBS before it is being selected and utilized as a postural control measurement device for quantifying postural sway.

This research was useful in providing additional information about postural sway measures in healthy females. Furthermore, the findings have a direct bearing upon the design and clinical usefulness of a quantitative postural sway evaluation in normal populations. With the information provided by this study, the clinicians could be expected to gain greater confidence when using the CDBS for clinical decision making. Additionally, the CBDS was used as a basis for Study 2 to determine the effectiveness of a three-week multisensory training program on postural sway measures of non-injured females. Due to the lack of knowledge in the field of proprioception, the baseline evaluation and training effectiveness in non-injured young and elderly females would be valuable for reference and for future comparison with injured individuals.

CHAPTER 4

METHODOLOGY -- STUDY 2

4.1 SUBJECTS

4.1.1 Sampling

According to the literature, it appeared that the amount of sway is constant for healthy individuals, ranging in age from 15 to 60 years. Individuals younger than 15 years and older than 60 years showed greater sway. [141,146] Therefore, two sample populations were selected for this study. The populations of interest included non-injured females derived from two age groups, consisting of young adults (age range: 20 to 49 years) and elderly adults (age range: 60 to 80 years). Subjects were expected to be physically active and interested in decreasing their postural sway through a three-week multisensory training program. Subjects must have had body mass index (BMI) lesser than 30 to be recruited in order to eliminate cases of obesity.

4.1.2 Sample Size

Forty-eight non-injured females (24 subjects from 20 to 49 years of age, and 24 subjects from 60 to 80 years of age) were recruited for the study. The sample size calculation was set based on a study power of 0.80 at an alpha level of 0.05 by setting a medium effect size of $f = 0.35$ (Appendix 4.A). [172] As effect size is a measure of the magnitude of difference, the estimation of medium effect size of $f = 0.35$ was selected by looking at past data. [159] A medium effect size is conceived as large enough to be visible to the naked eye, so that one would be aware of the change in the course of normal observation.[118] One way to conceptualize this definition is to think of effect size in terms of variance. Using a simple framework involving two group means, the difference between means would be considered medium if it is 35% ($f = 0.35$) of one standard deviation (assuming both groups have the same standard deviation).[118] The researcher could make an informed guess at the values of postural sway that might be expected by looking at sample means and the standard deviation from other studies on similar populations. A study conducted by Rozzi et al., [184] comparing the effect of postural balance training on young adults with functionally unstable ankles and nonimpaired young adults, indicated large effect sizes ranging from 0.60 to 1.19. For the elderly population, the effect sizes obtained from past studies data, showed medium to large effect sizes on postural balance training effect, ranging from 0.45 to 0.86. [159,160,164]

Due to prior research looking at sample means and variances, the researcher decided to set a medium effect size $f = 0.35$ as a conservative estimation of effect size for both young and elderly non-injured females.

4.1.3 Inclusion and Exclusion Criteria

Interested subjects were screened using a questionnaire (Appendix 4.B) either conducted by an interview via telephone or self-report via email. Subjects were selected from a homogeneous group of non-injured young and elderly females who had body mass index (BMI) less than 30 in order to eliminate individuals with obesity (Appendix 4.C). Appointments were set up if they met the following inclusion criteria:

a. females 20 to 49 years of age and 60 to 80 years of age;
b. normal ankles with no known injuries;
c. normal visual function;

d. normal vestibular (balance) function;

e. normal musculoskeletal function of all joints in lower extremities.

Exclusion criteria of this study were:

a. ankle pain while at rest;

b. injuries to either ankle or foot within six months of study;

c. lower extremities (thigh / knee / hip) injuries within six months of study;

d. any history of surgery to either lower extremity (hip, knee, ankle) past five years;

e. any history of knee or hip replacement;

f. any history of neurological conditions affecting balance (e.g. Parkinson's disease, multiple sclerosis, vertigo, dizziness, nausea, motion sickness, light-headedness);

g. any history of falling within six months of study;

h. need for an assistive device for ambulation;

i. abnormal posture (e.g. bony deformity, soft tissue tightness, inability to assume a normal upright posture);

j. abnormal body mechanics (e.g. cannot assume foot flat position);

k. physically impaired (e.g. amputation);

l. any history of hypertension;

m. any cardio-respiratory problems;

n. taking any prescription or over-the-counter medication that would affect or alter normal balance (check Appendix 4.B for example medication list).

4.1.4 Subject Recruitment

Subjects were a sample of convenience derived from the student population at the University of Alberta and from Edmonton communities. Volunteers were solicited through posted advertisements around campus and the surrounding Edmonton communities (Appendix 4.D). The non-probability convenience sample was chosen because it was easy to derive the desired sample size, less costly, and may have less time wasted on refusals than a random sample.

The first 24 qualified non-injured young females and the first 24 qualified non-injured elderly females were contacted for the prettest session. Following an explanation of the experimental procedures and a demonstration of the evaluation protocols and training protocols by the investigator (Appendix 3.D, 4.E, 4.F, and 4.G), subjects read and signed a consent form approved by the university's ethics committee (Appendix 1.D) if they agreed to participate. This was in accordance with the University of Alberta's policies on research using human subjects.

Subjects were offered compensation for participating in the research. Due to the time commitment in the evaluation sessions (two sessions, each session took about 30 minutes), and the training sessions (six sessions, each session took about an hour), each subject from both control and training groups was paid $5 per session to compensate for transportation. Compensation was paid immediately after each session. Subjects who did not complete the study were paid according to the attended sessions.

4.1.5 Screening and Randomization Process

Each prospective subject was interviewed via telephone or self-report via email during the initial contact to identify eligibility through a screening questionnaire (Appendix 4.B). After the screening process, if the eligible subjects volunteered to participate, an appointment was arranged on the day and time of their convenience. At baseline, all eligible subjects completed a self-report questionnaire on demographic variables; documenting health-history; and types of sporting activities as well as hours spent on sporting activities per week (refer to Appendix 4.C). Subjects' anthropometric data were collected by the researcher using a weight scale and BMI was calculated. Subjects were randomly assigned (draw from envelope) to either a control or a training group according to their age groups: a) young control group (YCG), b) elderly control group (ECG), c) young training group (YTG), and d) elderly training group (ETG).

The random allocation of subjects to training groups and control groups guarded against many forms of bias, including confounding bias (e.g. personal psychological factors), selection bias (e.g. history) and measurement bias (e.g. subject error). In addition, the randomization process decreased the chance that the treatment results were influenced by other external factors.

4.2 STUDY DESIGN

This was an experimental study using a pretest-posttest control-group design. In this study, there was a treatment factor with two levels (training group and control group) and a time factor with two levels (pretest and posttest) (Appendix 4.H). The study is a randomized controlled trial to test the hypotheses that the three-week multisensory training program had significant effects on postural sway control. Three dependent variables were measured: (a) overall sway (OS), (b) medial-lateral sway (MLS), and (c) anterior-posterior sway (APS). The researcher was interested in evaluating the magnitude of differences for all three dependent variables after treatment (a three-week multisensory training program) on postural sway control across non-injured young (20 to 49 years) and elderly (60 to 80 years) females.

A baseline assessment (pretest) was conducted to ensure that the training groups (YTG and ETG) and control groups (YCG and ECG) were comparable and similar on all other factors especially for the ankle stability, and posture. After the prettest, both YTG and ETG underwent a three-week multisensory training program twice weekly for three weeks. Meanwhile, both YCG and ECG received no training (Appendix 4.H). Immediately after completing the three-week multisensory training program, both YTG and ETG were evaluated for the posttest. Both YCG and ECG also returned for a posttest after three weeks. The posttest sessions (all four groups) and the six training sessions (for YTG and ETG) were arranged according to subjects' convenience.

Overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) were evaluated before and immediately after the three-week multisensory training period for all four groups (i.e. YTG, YCG, ETG, and ECG) using the Chattecx Dynamic Balance System (CDBS)(Figure 1.3) [126] following the same six evaluation protocols conducted in Study 1 (refer to page 79). In addition, the ECG and ETG were assessed using the Berg Balance Test (BBT) as a field measure at pretest and posttest in order to determine whether the postural sway measures by laboratory measures (i.e. the CDBS) would show comparable results (i.e. if the CDBS showed a decrease in all three postural sway measures in ETG after training, the BBT scores of these people would show an increase indicating that elderly females in the training group have better functional balance ability after the training program).

4.2.1 Training Protocols

Postural control and balance represent a complex integration of mechanical sensory and motor processing strategies, which enable man to maintain upright against gravity. [14] A more recently developed systems model of balance and postural control acknowledges that multiple systems including the visual, vestibular, somatosensory, motor, and musculoskeletal systems, contribute to balance. [159] This model suggests that training programs should be customized to the needs of individuals, and a specific target physiological system should be identified for the training to be effective. [131] According to this model, a training program that would enhance neural and mechanical factors relevant to balance function could potentially improve overall balance performance. Typically, training programs with an identified target training system, such as the vestibular system or the strength of the leg musculoskeletal system, have reported significant improvement in balance performance in their training subjects. [131,161] In addition, it is believed that postural balance training programs can enhance the sensitivity of mechanoreceptors to relay reliable information to the CNS if the postural balance training programs are designed to improve an identified target system (e.g. somatosensory system or visual system). [159]

The researcher was unaware of any research that supported specific postural sway control training using the CDBS. Therefore, the researcher chose and designed this multisensory training program for postural sway control, which was modified from a series of training options recommended by the manufacturer (i.e. The Chattecx Corporation).[126] This specially designed program focused on multisensory training. This multisensory training program emphasized the manipulation or alteration of somatosensory and visual inputs. Somatosensory input was manipulated or altered by having subjects standing on a single leg or by keeping the platform moving. Visual input was eliminated by the eyes-closed and blindfolding. In addition, visual input was manipulated by watching a bull's-eye for visual feedback. The program consisted of nine sequences incorporating static and dynamic balance training. For static balance training, subjects were trained on a stable platform. For dynamic balance training, subjects were trained on a moving up or a moving down platform (four degrees of tilt) with maximum speed (8.3 seconds per cycle). The nine training protocols were performed with the eyes-open (watching a bull's-eye for visual feedback, Figure 4.1) and eyes-closed conditions; bilateral (Romberg and tandem stance) and unilateral (left and right leg) stance, using dominant (leg used to kick a ball) and non-dominant leg as follows:

1. Left leg on stable platform with the eyes-open watching a bull's-eye for visual feedback (Figure 4.1)
2. Bilateral Romberg stance on platform moving down with the eyes-closed (Figure 4.2)
3. Right leg on stable platform with the eyes-open watching a bull's-eye for visual feedback
4. Left leg on platform moving down with the eyes-open watching a bull's-eye for visual feedback
5. Bilateral tandem stance on stable platform with the eyes-closed (Figure 4.3)
6. Right leg on platform moving down with the eyes-open watching a bull's-eye for visual feedback
7. Left leg on stable platform with the eyes-closed
8. Bilateral Romberg stance on platform moving up with the eyes-open watching a bull's-eye for visual feedback
9. Right leg on stable platform with the eyes-closed

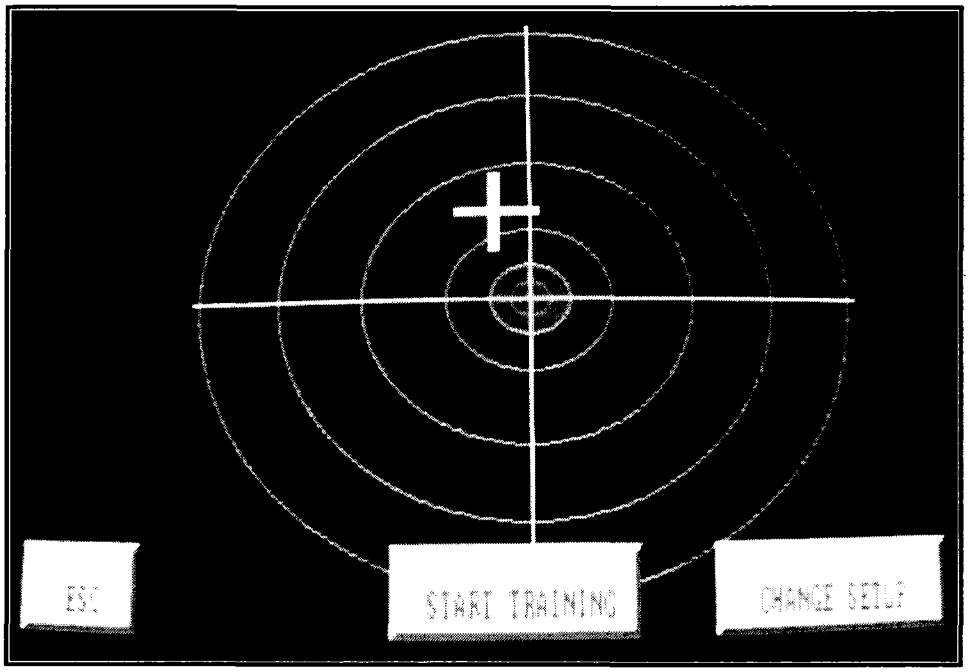


Figure 4.1: Watching a bull's-eye for visual feedback, cross-hair indicates center of gravity.

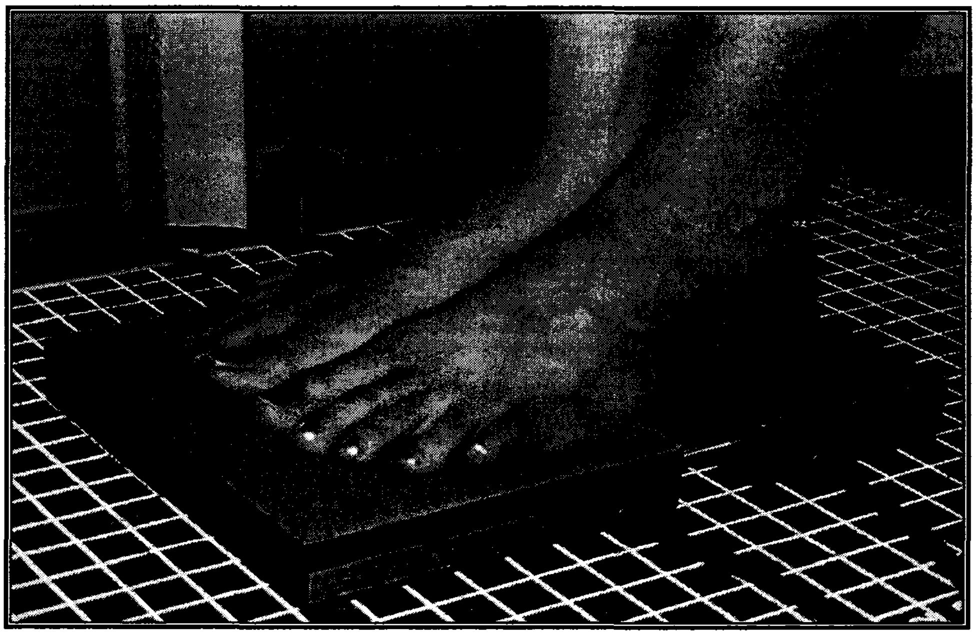


Figure 4.2: Bilateral Romberg Stance

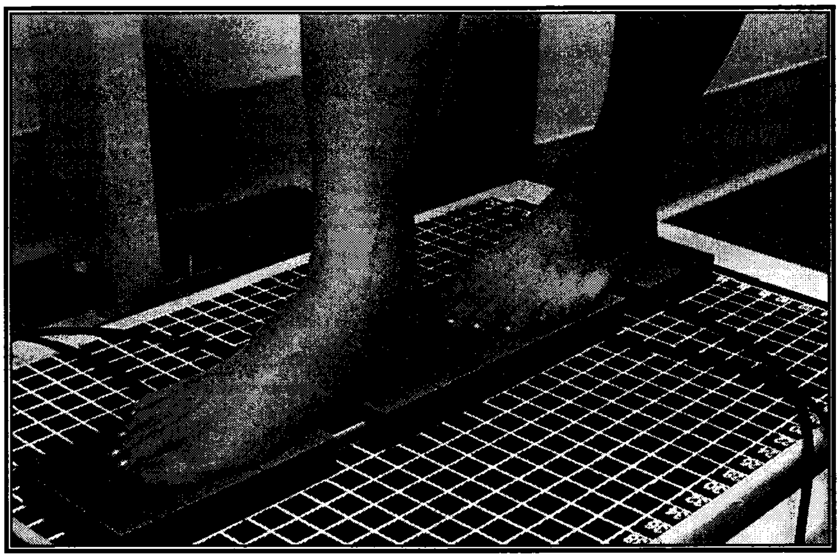


Figure 4.3: Bilateral Tandem Stance

These training protocols were designed to enhance the sensitivity of sensorimotor integration. The sensory systems (i.e. visual, vestibular, and somatosensory) were manipulated to create various stimuli to the CNS to improve the processing of inter-sensory (sensory systems and motor systems) interaction. In addition, the process of sensorimotor rearrangement with subsequent postural stability is related to the degree of the initial instability. [131] According to the literature, the greater the initial risk of falling or postural instability, the greater the training effect (percentage reduction in sway amplitudes). [131]

Therefore, this three-week multisensory postural balance training program focused on manipulating or altering one or two of the three sensory systems to create postural balance instability. Each training protocol in this study was designed to enhance specific contributions to balance and postural sway control. For instance, unilateral stance or moving platform conditions were designed to manipulate or alter the somatosensory input and produce a response. The eyes-closed condition was designed to eliminate visual input. The eyes-open condition by watching a bull's-eye for visual feedback was designed to altering visual input and creates conflict information to the CNS.

All subjects in both young (N = 12) and elderly training groups (N = 12) were trained for their static and dynamic balance. The two moving conditions of the platform for dynamic balance testing were moving with toe up, and moving with toe down (altered somatosensory input). The eyes conditions were with the eyes-open (watching a bull's-eye for visual feedback to alter visual input) and the eyes-closed (blindfolded to eliminate visual input). The types of stance were bilaterally (Romberg and tandem two-legged) and unilaterally (one-legged, left and right leg alternately) on dominant and non-dominant legs (altered somatosensory input). Once all of the four study group subjects were pretested, both training groups (YTG and ETG) performed the multisensory training program using the CDBS twice weekly for three weeks. Meanwhile, both control groups (YCG and ECG) received no training.

The researcher was the only trainer conducting the three-week multisensory training program. The program consisted of nine training protocols. Each condition was trained for one minute twice (total two minutes) for the first set (Appendix 4.E and 4.F). The duration of one minute training for each condition was chosen because it was believed to be sufficient time for the mechanoreceptors to respond to the stress of training. Subjects had a 30-second rest between repetitions. Approximately 30 minutes were required to complete all nine conditions with two repetitions. Following a five-minute break, the set of nine conditions was repeated (i.e. a second set). The entire duration of training took approximately an hour for each session. Subjects required completing six one-hour multisensory training sessions within three weeks (Appendix 4.H).

According to the literature, [131,159] the actual training time needed to show a positive training effect on balance and postural control was 130 minutes to obtain 30% to 50% improvement on young and elderly adults. In order to enhance the training effect, the researcher decided to prolong the training duration (extra 86 minutes) to allow for an over-training effect. Therefore, the actual training time that emphasized postural sway control through multisensory training was 216 minutes over the six training sessions. The time required to administer the three-week multisensory training program (an hour training for six sessions in total) for all YTG and ETG (24 subjects) and two evaluation sessions (45 minutes) for all four study groups (48 subjects) was approximately 290 hours.

Subjects were asked to report to the Sports Therapy Research Laboratory, Room 1-81, Corbett Hall, University of Alberta for six training sessions and two evaluation sessions (pretest and posttest). All six training sessions and two evaluation sessions were conducted from Monday through Sunday at 8 a.m. to 6 p.m. The evaluation protocols were identical to those described in the Study 1. Detailed descriptions of the evaluation protocols (Appendix 3.D) and the three-week multisensory training program were presented (Appendix 4.E and 4.F).

Both young and elderly control groups (YCG and ECG) performed no balance training during the three-week training period. Young and elderly subjects in both control groups were instructed to continue with their normal daily activities for the duration of three-week period after the pretest. All subjects in the study were instructed not to initiate any new training programs or activities that could affect the results of this study. This was monitored by asking all the subjects of their normal daily activities every session (i.e. training and evaluation) and they were reminded each session not to initiate any new training programs or activities until the completion of the entire study process.

4.3 DATA COLLECTION

4.3.1 Instrumentation for Training and Evaluation

4.3.1.1 The Chattecx Dynamic Balance System (CDBS)

In this study, the CDBS (refer to Figure 1.3) was used to objectively assess pretest and posttest values for all subjects before and after the three-week multisensory training program. The standardized evaluation protocols were identical as in Study 1 (see Section 3.3). In addition, the CDBS was used to train both the YTG and ETG on their postural sway control.

Healthy individuals normally rely more on visual and proprioceptive neural input to control postural sway. [37] The preferred sense for postural sway control for healthy adults comes from somatosensory (proprioception) information. [32,34] Since the subjects of this study were healthy female adults, the researcher attempted to focus on manipulation and alteration of visual input and somatosensory input contributions to postural stability for the multisensory training program. The investigator designed her own unique and specific multisensory training program. All evaluations and training protocols were performed with the eyes-open and the eyes-closed (blindfolded) to concentrate on visual and somatosensory input contributions. These dynamic evaluations and training with a moving platform more effectively mimic everyday activities than traditional evaluations of posture like the Romberg test or stork standing test. The selected dynamic balance training best meets the clinical needs of the study population for functional outcomes of stable ankles. The postural sway evaluations were conducted before and immediately after the three-week multisensory training program by the researcher for both young and elderly females.

In order to increase the researcher's confidence of using the CDBS as evaluation device, the six evaluation protocols were assessed in the previous study (i.e. Study 1) for test-retest reliability. The study finding indicated that the CDBS obtained good test-retest reliability (ICCs=0.80 to 0.83) on postural sway measures. This result suggested that the researcher gained greater confidence to use the CDBS as an evaluation device for quantifying postural sway measures especially to utilize the entire evaluation protocols to assess the effectiveness of the three-week multisensory training program for postual sway measures (i.e. Study 2).

4.3.1.2 The Berg Balance Test (BBT)

The Berg Balance Test (BBT) [185-187] is the most popular functional balance assessment tool in physical therapy which was designed to predict falls in the ambulatory elderly. [187,188] The developers hoped that the BBT scale would be used to monitor the status of a patient's balance and to assess disease cause and response to treatment. The balance assessment consists of 14 subtests performed in a standard order (Table 4.1) (Appendix 4.G). [186]

Table 4.1: The Berg Balance Test (BBT) Subtests

Item	Description	Score (0 – 4)
1.	Sitting to standing	____
2.	Standing unsupported	____
3.	Sitting unsupported	____
4.	Standing to sitting	____
5.	Transfers	____
6.	Standing with eyes-closed	____
7.	Standing with feet together	____
8.	Reaching forward with outstretched arm	____
9.	Retrieving object from floor	____
10.	Turning to look behind	____
11.	Turning 360 degrees	____
12.	Placing alternate foot on stool	____
13.	Standing with one foot in front	____
14.	Standing on one foot	____

Participants were asked to complete 14 tasks, and each task was rated by the examiner on a 5-point scale ranging from 0 (cannot perform) to 4 (normal performance). Overall scores can range from 0 (severely impaired balance) to 56 (excellent balance) (Appendix 4.G). [185-187] To achieve the maximal score of four, the subjects had to perform the movement independently and hold the position for a prescribed time or perform the action within a set time frame. Progressively fewer points were awarded as the time required was not met, and as the participants needed greater assistance in the activity. Elements of the test were supposed to be representative of daily activities that required balance (refer to Table 4.1). [187,188] The equipment used to administrate the BBT scale require a stopwatch, a tape measure, a step stool, a chair with arms, and a chair without arms. The test took about 15 to 20 minutes. [187] According to literature, the BBT scale demonstrated excellent inter-rater and intra-rater reliability with ICCs values of 0.98 and 0.99. Values on the BBT scale correlated strongly with global ratings of balance made by treating therapists (r = 0.81). [185,187,189] However, it has poor sensitivity only predicting 53% will fall at some point in future, but it has good specificity because it obtained 96% specificity for predicting who would not fall. [41,190] The BBT scale does not test for performance under conditions of altered sensory context or attentional distracters and does not include gait. [41] The lack of items that require a postural response to an external stimulus or uneven support surface is a limitation of this test. It would likely limit the utility of the test when evaluating very active persons with minimal deficits. However, the test does appear to give a range of scores for persons with identified balance impairment and in the frail and elderly.

The investigator used the Berg Balance Test (BBT) to assess the effectiveness of the three-week multisensory training program only on both elderly groups (i.e. ECG and ETG) because this field measure was developed to evaluate balance of elderly individuals above 60 years of age. Besides using laboratory measures (i.e. the CDBS) for evaluating training effect on postural sway measures, the BBT scale was used as well. The purpose of using the BBT scale to assess both ECG and ETG was to examine if similar findings (i.e. improvement in postural sway measures after training) from the force plate laboratory measures (the CDBS) was able to show on clinical field measures (the BBT). For instance, if the trained elderly swayed less (lesser sway amplitudes showed better postural control), her improvement in decreasing postural sway was hypothesized to be able to show an increase in the BBT total scores as well (higher scores showed better functional balance ability). Thus, the improvement in postural sway measures obtained from the laboratory measures (the CDBS) after training have shown the same changes as the field measures (the BBT) and indicate similar findings from both measurement tools. The rationale of using two different categories of balance measures (laboratory and field) was that the BBT scale for clinical usage was perceived to be more practical, less costly, easy to administer, reasonably short, not too complicated, and requires no sophisticated equipment, making it useful in clinical settings.

4.4 STATISTICAL ANALYSIS

The average scores (in centimeters) of the two repetitions of each evaluation protocol (six in total) were used to compute the total index of overall sway, medial-lateral sway, and anterior-posterior sway, for the pretest and posttest data. Standard error of measurement (SEM) and associated 95% confidence intervals (95% CI) were calculated to quantify measurement error or variation of individual scores. [178] The means (M), standard deviations (SDs), standard error of measurement (SEMs), and 95% confidence interveals (CI) were reported for descriptive statistics for all the control and training groups to compare the differences in overall sway, medial-lateral sway, and anterior-posterior sway (in centimeters), before and immediately after the three-week multisensory training program when considering the training factors such as: (a) static balance with the eyes-closed condition; (b) dynamic balance with the eyes-open condition; (c) unilateral stance; (d) bilateral stance; (e) dominant leg, and (f) non-dominant leg.

A multivariate analysis of variance (MANOVA) procedure was selected to determine the effectiveness of the three-week multisensory training program by detecting whether there was significant improvement (reported as percentage of change) in each of the dependent variables of postural sway measures which consisted of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS). Separate MANOVAs were conducted on the group mean scores (i.e. percentage of change) for the following six difference training factors: (a) static balance with the eyes-closed condition, (b) dynamic balance with the eyes-open condition, (c) bilateral stance, (d) unilateral stance, (e) dominant leg, and (f) non-dominant leg to compare the effectiveness of the three-week multisensory training intervention on all three postural sway measures across four study groups (i.e. young training group [YTG], elderly training group [ETG], young control group [YCG], and elderly control group [ECG]). The improvements in postural sway measures after training were reported in percentage of change instead of in centimeters because it was easier to understand and more reader friendly in terms of an explanation and elaboration of the improvement using a percentage rather than reporting the actual measurement in centimeters when groups' improvements were compared.

When significant effects were obtained, Tukey's Honestly Significant Difference (HSD) procedures were performed as follow-up tests, similar to the univariate analysis of variance (ANOVA) procedure to determine the source of difference among four study groups with an alpha level of ≤ 0.05.

Separate MANOVAs were performed to examine the differences between the pretest and the posttest scores (i.e. percentage of change) for postural sway outcome measures (i.e. OS, MLS, and APS), treating the pretest and posttest values as dependent variables and all the young and the elderly study groups as independent variables. A univariate ANOVA with Tukey's HSD post hoc analysis was conducted to determine the source of any difference identified by the MANOVA with an alpha level of ≤ 0.05.

A two-factor analysis of variance (two-way ANOVA) with repeated measures, 2 x 2 (group by training factor) mixed design with one between-subjects factor (factor A: group) and one within-subject factor (factor B: training) was utilized to analyze the differences between all three postural sway measures' (OS, MLS, and APS) means (i.e. percentage of change) at an alpha level ≥ 0.05. A mixed design was used to examine the interaction between the group (factor A) and the training (factor B). In a mixed design, the independent factor (group) was analyzed as it would be in a regular one-way analysis of variance (ANOVA), pooling all of the data for the repeated factor (training) to determine the significant difference between the groups (factor A). In this case, comparison between the two training groups (elderly and young) was a between-subject analysis, to test the hypothesis that the elderly training group would show greater improvement than the young training group for OS, MLS, and APS when incorporating the six different training factors.

The within-subjects effect included the repeated measures and the interaction of the repeated measures with the independent measure (group) to determine the significant difference within subjects for training factors (factor B) and the interaction between groups. In order to examine the different effects of the training factors on both training groups, nine separate analyses were conducted independently for each of OS, MLS, and APS, incorporating the following training factors: (a) types of balance with the eyes condition (i.e. static with the eyes-closed condition versus dynamic with the eyes-open condition); (b) types of stance (i.e. bilateral stance versus unilateral stance); and, (c) types of leg dominance (i.e. dominant leg versus non-dominant leg).

For the purposes of clarity, it is important to discuss the different training factors of balance that were chose for analysis. Static balance in this study meant that a subject attempted to maintain the center of gravity (COG) within a fixed, stable base of support. A relevant clinical example would be a single-leg stance on a level floor. In this case, it refers to a subject either standing on single leg or double legs on a stable platform of the CDBS. Dynamic balance in this study involved the attempt to maintain the COG within a moveable base of support, refers as on a moving platform of the CDBS (either standing on single leg or double legs). Unilateral stance in this study meant that a subject attempted to stand using a single leg. Bilateral stance refers to a subject attempted to stand with both legs. Leg dominance was defined in this study by the leg that each subject used to kick a ball. In the current study, the eyes-open condition refers that a subject attempted to stabilize the gaze on a scenic poster pasted a meter in front of the subject. Eyes-closed condition meant that a subject closed both eyes and was blindfolding.

A two-way ANOVA with repeated measures analysis was conducted to determine the main effect for independent factor (i.e. Factor A: Group). The main effect for group was determined by comparing the means of each type of training factor at each group (YTG and ETG); regardless of which type of training factor was compared for the overall sway measure. In addition, the within-subjects analysis lists the main effect for each type of training factor, the interaction between group and each type of training factor, and a common error term to test these two effects. If no interaction was identified, the main effect for each type of training factor was examined. The main effect for each type of training factor was calculated by determining the sum of the squares for both compared training factors (e.g. static balance with the eyes-closed condition versus dynamic balance with the eyes-open condition) for both ETG and YTG.

Because all of the training factor variables have only two levels, post hoc testing was not conducted. The *F*-test functions similar to a *t*-test. Therefore, if the *F* is significant, one need only look at the two main effect means to determine which is greater.

The two-tailed independent samples t-test for independent means was performed to compare the BBT scores between ECG and ETG before (pretest) and after (posttest) three-week multisensory training program. Critical value of *t* was used for a test of significance. Critical value of *t* was calculated to provide the critical value of *t* for this study using the two-tailed test of significance with N - 2 degrees of freedom. The *t* critical value (t_{crit}) of this study using two-tailed tests ($\alpha_2 = 0.05$) and 22 df (24 - 2) was $t_{22} = \pm 2.074$ (Appendix 4.J). For a t-ratio to represent a significant difference, the absolute value of the calculated ratio (t_{obs}) must be greater than or equal to the critical value or $p \leq 0.05$ to reject the null hypothesis. It was hypothesized that the elderly trained non-injured females (i.e. ETG) would show higher BBT scores (better postural balance ability) after the three-week multisensory training program compared with the elderly untrained non-injured females (i.e. ECG).

The SPSS version 15 was used to perform the statistical analysis of the data. The power of this study was estimated at 0.80 ($\beta = 0.2$) with a medium effect size of $f = 0.35$ [172,191] (Appendix 4.A). The significance level was set at $\alpha \leq 0.05$ a priori for all statistical tests unless otherwise specified. Therefore, results was considered to be statistically significant when $p \leq 0.05$.

4.5 SUMMARY STATEMENT

This study attempted to develop an effective multisensory training program to improve postural sway control. The researcher was not interested in using elite athletes for Study 2 because they train on a regular basis that could make it more difficult to demonstrate improvements in ankle stability and postural sway control. The use of non-injured non-athletic females would hopefully eliminate any training effect. Due to the fact that non-injured non-athletic subjects were utilized in Study 2, the results would not directly apply to injured young or elderly individuals, or healthy or injured athletic populations.

If the three-week multisensory training program showed a positive impact on decreasing postural sway, this research would be useful in providing additional information about postural sway control in healthy young and elderly females. Successful development of an effective multisensory training program on postural sway control could allow clinicians, and sports medicine professionals to adapt a rehabilitation program to compensate for balance and postural instability provided the injured individual is able to do the training protocols. This multisensory training program might also be beneficial to athletic trainers, coaches, clinicians, and individuals as a preventive training program and a daily exercise to enhance their postural sway control for long term health maintenance if it showed positive impact.

CHAPTER 5

RESULTS AND DISCUSSIONS -- STUDY 1

5.1 RESULTS

The present study examined the results of test-retest reliability and discriminant validity of the CDBS on postural sway measures of non-injured young females ranged from 20 to 49 years of age. All study participants were carefully screened according to the established inclusion and exclusion criteria. Each participating subject was informed of her rights and full disclosure of the benefits and risks of the study.

5.1.1 Subjects Characteristics

Fifty-two volunteers were screened and 40 subjects age ranging from 21 to 47 years (mean age 30.03 ± 6.95 years) were included in this study. Twelve subjects were dropped from the study because: one subject was disqualified from the retest session because she sprained her ankle doing another activity; this subject's data was excluded from all analysis. The remaining 11 subjects were excluded because they had lower extremity injuries within six months of the study.

5.1.2 Personal Demographics

The subject demographic descriptive statistics for Group 1 and Group 2 are given in Table 5.1 with the comparison of mean scores and standard deviations for age (years), height (m), weight (kg), body mass index (BMI) and hours spent on sporting activities per week. Independent *t*-tests were reported as well to determine differences among subject characteristics between Group 1 and Group 2.

Table 5.1: Descriptive Statistics for Subject Demographic Characteristics

Variables	Group 1 (≥ 5h) M ± SD	Group 2 (< 5h) M ± SD	*t*	*p*
Age (yrs)	30.25 ± 7.81	29.80 ± 6.09	0.20	0.84
Height (m)	1.66 ± 0.05	1.64 ± 0.06	1.28	0.21
Weight (kg)	60.00 ± 6.53	65.00 ± 13.12	-1.42	0.17
BMI	22.00 ± 2.03	23.85 ± 4.21	-1.77	0.85
Hours spent on sporting activities per week	11.50 ± 4.28	3.15 ± 1.37	8.29*	0.00*

** Significant*

Abbreviation= BMI: body mass index (body weight [kg] / height^2 [m^2])

As can be seen in Table 5.1, there were no significant differences found in age, height, weight, and BMI between Group 1 and Group 2. This means that the subjects from both groups were homogeneous. However, a significant difference was found in hours spent on sporting activities per week between Group 1 and Group 2. On average, individuals in Group 1 spent 11.50 hours on sporting activities per week, whereas individuals in Group 2 spent on average only 3.15 hours on sporting activities per week.

5.1.3 Test-retest Reliability

The primary goal of this study was to determine test-retest reliability of the CDBS as an evaluation device for quantifying postural sway measures. Further, the researcher wished to examine all three postural sway measures, which consisted of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) if the CDBS was a reliable measurement tool.

Decriptive statistics of means (M), standard deviations (SDs), standard error of measurements (SEMs), and 95% confidence intervals (CIs) are reported for test and retest sessions. Table 5.2 summarizes all three postural sway measures.

Table 5.2: Descriptive Statistics for Postural Sway Measures in Means (M), Standard Deviations (SDs), Standard Error of Measurements (SEMs), and 95% Confidence Intervals (CIs) for Test and Retest Sessions

Variables	**Test (cm)**	**Retest (cm)**
Overall Sway	M±SD 0.97 ± 0.15 SEM 0.02 95% CI 0.93 – 1.01	M±SD 0.94 ± 0.12 SEM 0.02 95% CI 0.90 – 0.98
Medial-lateral Sway	M±SD 1.67 ± 0.25 SEM 0.04 95% CI 1.59 – 1.75	M±SD 1.68 ± 0.19 SEM 0.03 95% CI 1.62 – 1.74
Anterior-posterior Sway	M±SD 4.12 ± 0.69 SEM 0.11 95% CI 3.90 – 4.34	M±SD 3.91 ± 0.48 SEM 0.08 95% CI 3.75 – 4.07

Figure 5.1 depicts a comparison of mean scores in centimeters for all three postural sway measures, which consisted of OS, MLS, and APS for the two test and retest sessions for all subjects in Group 1 and Group 2.

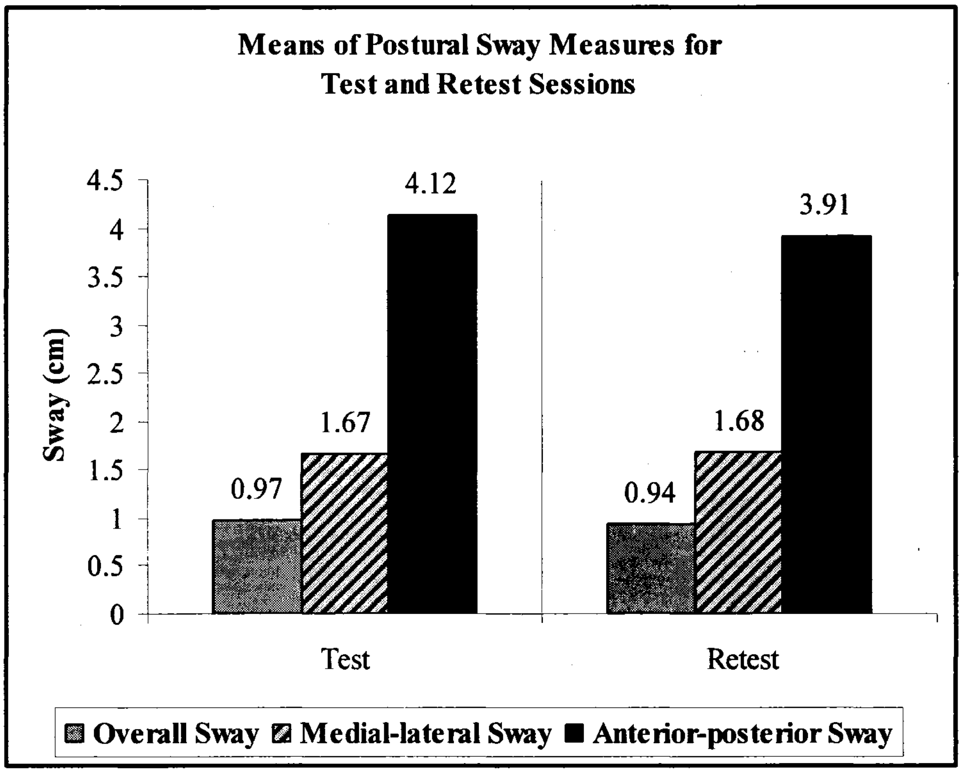


Figure 5.1: Means of postural sway measures for test and retest sessions for all subjects in Group 1 and Group 2.

As shown in Table 5.2 and Figure 5.1, mean scores of OS and APS were greater in the first test session than to MLS when compared with the retest session. For the OS, test and retest means scores were 0.97 ± 0.15 cm and 0.94 ± 0.12 cm; and the SEMs were the same for both sessions i.e. 0.02 cm. For the MLS, test and retest means scores were 1.67 ± 0.25 cm and 1.68 ± 0.19 cm; and the SEMs were 0.04 cm and 0.03 cm, respectively. For the APS, test and retest means scores were 4.12 ± 0.69 cm and 3.91 ± 0.48 cm; and SEMs were 0.11 cm and 0.08 cm, respectively. The results of the small SEM on all three postural sway measures across test and retest sessions suggests that the inconsistency of measurements occurred in an acceptably small range (0.02 cm to

0.11 cm). When errors were small and the distributions were less variable with a more reliable measurement. The test-retest measurements were reliable and precise for OS, MLS, and APS using the CDBS for this time interval. The 95% confidence intervals were determined for all variables and test-retest sessions (refer to Table 5.2). The 95% confidence intervals equal mean of the sample ± (1.96 multiplied by the standard error of measurement) (i.e. 95% CI = Mean ± 1.96 SEM).[118] For instance, if the retest score of OS was 0.94 cm with a SEM of 0.02 cm, one can be 95% confident that there exists a band of error of ± 0.04 cm around this measurement. Likewise, if the retest score of APS was 3.91 cm with a SEM of 0.08 cm, one can be 95% confident that there exists a band or error ± 0.16 cm around this measurement (Table 5.2). If the OS was 0.97 cm on first test session and 0.94 cm on retest session, the researcher can be 95% certain that the difference was due to error rather than to true change. As for this example, a change greater than 0.04 cm would be necessary to attribute the difference to change rather than to error of measurement. Thus, the researcher must be conscious that the differences observed may exist due to measurement variance alone.

The test-retest reliability resulting intraclass correlation coefficients (ICCs *3*, *k*) and SEMs (cm) on postural sway measures for total group (G1 and G2), Group 1 and Group 2 are displayed in Table 5.3.

Table 5.3: Postural Sway Measures when comparing Total Group (G1+G2), Group 1 and Group 2 for Test-retest Reliability and Resulting Intraclass Correlation Coefficients (ICC: *3*, *k*) with Standard Error of Measurements

Variables	**ICC**		**95% CI**	**SEM (cm)**
Overall Sway	Total Group	0.83	0.79 – 0.87	0.02
	Group 1	0.70	0.66 – 0.74	0.02
	Group 2	0.87	0.81 – 0.93	0.03
Medial-lateral Sway	Total Group	0.80	0.74 – 0.86	0.03
	Group 1	0.83	0.75 – 0.91	0.04
	Group 2	0.80	0.70 – 0.90	0.05
Anterior-posterior Sway	Total Group	0.82	0.64 – 1.00	0.09
	Group 1	0.72	0.52 – 0.92	0.10
	Group 2	0.86	0.59 – 1.13	0.14

The SEM is used to further evaluate the reliability following ICCs scores. The test-retest reliability revealed good reliability for total group (G1 and G2); with the ICCs scores ranged from 0.83, 0.80, and 0.82 for all three postural measures (i.e. OS, MLS, and APS, respectively). The total group yielded relatively small SEMs of 0.02, 0.03, and 0.09 for OS, MLS, APS, respectively. When compared the test-retest reliability between Group 1 and Group 2, the ICCs scores for Group 1 were slightly lower than Group 2 for OS, and APS. Group 1 obtained lower ICC scores of 0.70 for OS, and 0.72 for APS. However, the ICC value for MLS of Group 1 was higher than that of Group 2 (i.e. 0.83 and 0.80 respectively). Small SEMs ranged from 0.02 to 0.10 obtained by Group 1 indicate that there are relatively small between-subjects variations for all three postural sway measures. Group 2 yielded highest ICCs scores of 0.87, 0.80, and 0.86, with relatively small SEMs of 0.03, 0.05, and 0.14 for OS, MLS, and APS, respectively. Generally, the results of test-retest reliability appears to have greater ICCs scores values on Group 2 when compared with Group 1 on overall sway and anterior-posterior sway measures. Overall, Group 2 revealed greater test-retest reliability (ICCs=0.80 to 0.87) when compared with Group 1 (ICCs=0.70 to 0.83). However, Group 1 appear to be more consistent for all three postural sway measures when compared with Group 2, as evidenced by the relatively small amount of error variance (refer to Table 5.3).

5.1.4 Discriminant Validity

5.1.4.1 Static Balance

When testing static balance between Group 1 and Group 2, the two independent samples *t*-test was reported for discriminant validity in Table 5.4 in order to determine whether there were significant differences in all three postural sway measures. For all three postural sway measures, Group 1 showed a trend toward reduced sway for static balance when compared with Group 2. However, the *t* statistics and *p* values for OS, MLS, and APS (p=0.40, p=0.25, and p=0.41, respectively) did not indicate significant differences statistically between Group 1 and Group 2 when testing static balance.

Table 5.4: Means and Standard Deviations (M ± SD), Standard Error of Measurements (SEMs), 95% Confidence Intervals (CIs), and Two Independent Samples *t*-test for Discriminant Validity when testing Static Balance between Group 1 and Group 2

Postural Sway Measures for Static Balance				
Variables	**Group 1 (cm)**	**Group 2 (cm)**	***t****	***p***
Overall Sway	M±SD 0.88 ± 0.17 SEM 0.04 95% CI 0.80 – 0.96	M±SD 0.94 ± 0.22 SEM 0.05 95% CI 0.84 – 1.04	-0.859	0.40
Medial-lateral Sway	M±SD 1.96 ± 0.29 SEM 0.07 95% CI 1.82 – 2.10	M±SD 2.09 ± 0.38 SEM 0.08 95% CI 1.93 – 2.25	-1.162	0.25
Anterior-posterior Sway	M±SD 3.51 ± 0.77 SEM 0.17 95% CI 3.18 – 3.84	M±SD 3.76 ± 1.11 SEM 0.25 95% CI 3.27 – 4.25	-0.837	0.41

* *Observed* $t\ (38) \geq \pm\ 2.021$ *to reject* H_O

Figure 5.2 portrays a comparison of mean scores in centimeters for all three postural sway measures (i.e. OS, MLS, and APS) between Group 1 and Group 2 when testing static balance using the CDBS.

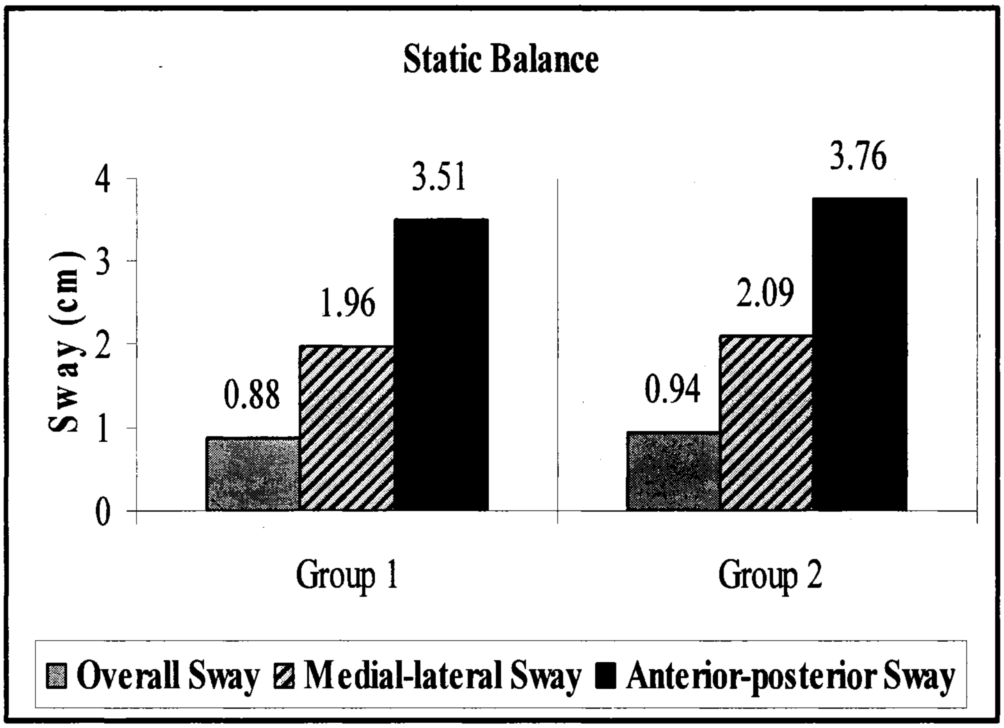


Figure 5.2: Means of postural sway measures between Group 1 and Group 2 when testing static balance.

5.1.4.2 Dynamic Balance

As can be seen in Table 5.5, Group 1 showed a trend toward reduced sway for all three postural sway measures when compared to Group 2 when testing dynamic balance. However, the observed *t*-statistics were smaller than the critical value *t* (38) = ± 2.021, and the *p* values were larger than 0.05, indicating that there were no significant differences for all three postural sway measures between Group 1 and Group 2 when testing dynamic balance using the CDBS.

Table 5.5: Means and Standard Deviations (M±SD), Standard Error of Measurements (SEMs), 95% Confidence Intervals (CIs), and Two Independent Samples *t*-test for Discriminant Validity when testing Dynamic Balance between Group 1 and Group 2

Postural Sway Measures for Dynamic Balance				
Variables	**Group 1 (cm)**	**Group 2 (cm)**	***t****	***P***
Overall Sway	M±SD 1.00 ± 0.12 SEM 0.03 95% CI 0.94 – 1.06	M±SD 1.07 ± 0.18 SEM 0.04 95% CI 0.99 – 1.15	-1.445	0.16
Medial-lateral Sway	M±SD 1.30 ± 0.19 SEM 0.04 95% CI 1.22 – 1.38	M±SD 1.34 ± 0.28 SEM 0.06 95% CI 1.22 – 1.46	-0.546	0.59
Anterior-posterior Sway	M±SD 4.59 ± 0.60 SEM 0.13 95% CI 4.34 – 4.84	M±SD 4.63 ± 0.70 SEM 0.16 95% CI 4.32 – 4.94	-0.164	0.87

* *Observed* $t\,(38) \geq \pm\ 2.021$ *to reject* H_O

Figure 5.3 depicts a comparison of mean scores in centimeters for all three postural sway measures (i.e. OS, MLS, and APS) between Group 1 and Group 2 when testing dynamic balance using the CDBS.

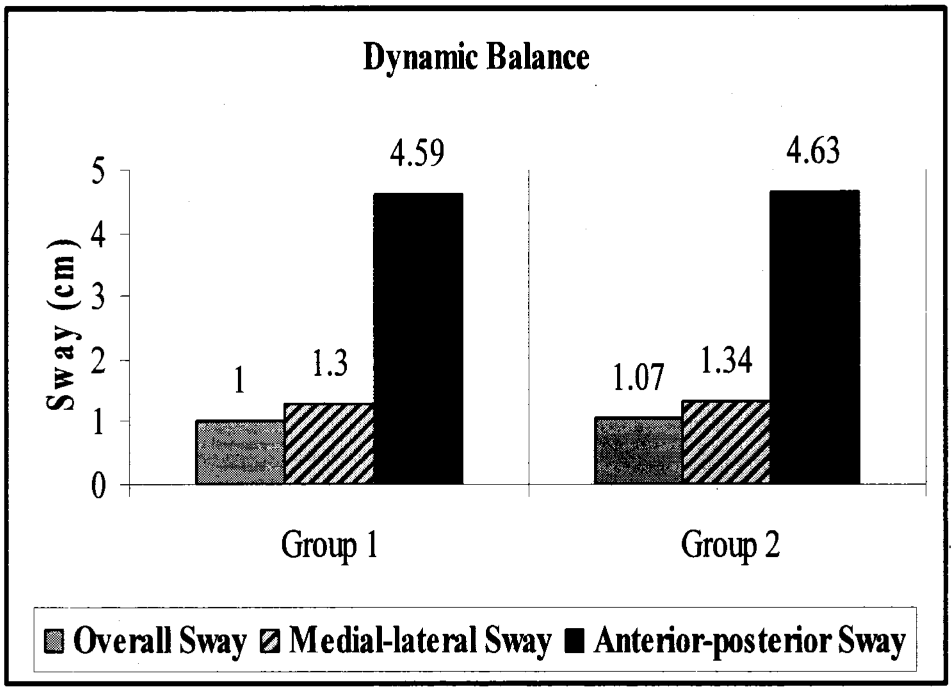


Figure 5.3: Means of postural sway measures between Group 1 and Group 2 when testing dynamic balance.

5.2 DISCUSSIONS

5.2.1 Test-retest Reliability

The present ICCs (refer to Table 5.3) describing consistency of group performances on test and retest sessions suggest that all groups demonstrated fair-to-good reliability ranged from 0.70 to 0.87. This finding is consistent with other reports in the literature for the CDBS. Irrgang et al. [70] suggested that the CDBS revealed moderate to strong reliability (ICCs=0.47 to 0.81) of measuring postural sway in normal individuals. This is in agreement with Condron et al.,[111] supporting the finding that the CDBS revealed moderate to high test-retest reliability (ICCs > 0.65) for assessment of balance performance. The present study finding is in accordance with Rogind et al., [81] suggesting that the CDBS is reliable and reproducible to use for balance measurements. Similarly, Liao et al. [112] supported that the CDBS is an objective and sensitive measurement device for postural control measurements. The ICCs values obtained by the present study showed considerably higher stability (ICCs=0.70 to 0.87) for all three postural sway measures with the smaller range of 95% CI suggesting that the CDBS yielded good test-retest reliability as an evaluation device measured on the same subjects when performed over time by the same rater.

These reliability coefficients are also comparable to those produced by other force-plate systems such as EquilTest, [10,43] Clinical Test of Sensory Interaction and Balance, [106] Biodex Stability System [107,108] for balance and postural sway measurements (refer to Table 2.1).

Nevertheless, the present study findings are contrasting with the results reported by Mattacola et al. [6] They reported that the CDBS revealed a wide range of reliability values from poor to excellent (ICCs=0.41 to 0.90) for inter-rater reliability in assessing postural sway on healthy individuals. Also, Ghent et al. [72] noted that the CDBS obtained moderate reliability (ICCs=0.45 to 0.63). Additionally, Hill et al. [109] demonstrated that the CDBS revealed low test-retest reliability for static balance measures in healthy older women, but indicated high reliability for dynamic balance measures. However, their results did not report the reliability correlation coefficient values.

The reliability correlation coefficient values found in this study (ICC > 0.80) were slightly lower than those reported by Byl and Sinnott [110] who reported that the CDBS had excellent intra-rater reliability (ICC=0.92) and inter-rater reliability (ICC=0.90) in their study of variations in balance and body sway in middle-aged adults.

The primary finding of this study confirms that the CDBS is a reliable evaluation devise to quantify postural sway measures for clinical use. It also demonstrates that the CDBS has good stability over time for testing performed between days and within a week on same subjects.

It was interesting to consider the reliability results of the total group (Group 1 combined with Group 2) and splitting the reliability results for Group 1 and Group 2 to compare which group produced better test-retest reliability. For the total group, test-retest reliability of OS, MLS, and APS demonstrate good reliability ICCs values ranged from 0.83, 0.80, and 0.82, respectively. For Group 1, OS had the lowest ICC value of 0.70, which is in the "fair" reliability according to Blesh's [130] interpretation of reliability coefficient values. For APS, Group 1 had an ICC value of 0.72, which is a "fair" reliability as well. However, for MLS, Group 1 indicated greater ICC value of 0.83, which is in the "good" reliability coefficient value. For Group 2, test-retest reliability of OS, MLS, and APS demonstrate good reliability ICCs values ranged from 0.87, 0.80, and 0.86, respectively.

The findings demonstrated that greater levels of consistency (good reliability ICC > 0.80) between test and retest sessions for the total group and Group 2, but lesser level of consistency (fair reliability ICC > 0.70) for Group 1. Therefore, the results indicate that test-retest reliability is greater when comparing females who moderately practiced sporting activities less than five hours per week (Group 2) to females who vigorously practiced sporting activities five hours or more per week (Group 1).

Intraclass correlations make it possible to distinguish between score variances that are due to differences between subjects as opposed to those due to measurement error or changes in scores over time. Generally, an ICC is a ratio of subject differences to the total score variance (including error variance). [178] If there is a relatively small between-subjects variation, ICCs will tend to be low. Therefore, scores among a group with little variance, although consistent from one time to the next, may produce low ICCs. [177] In this study, the lower ICCs for Group 1 were associated with the smallest between-subject variances.

An additional factor for lower reliability of females who vigorously practiced sporting activities five hours of more per week (Group 1) for two of the postural sway measures (OS and APS) may be attributed to the concentration, attention, effort, cooperation, and motivation of the subjects during retesting session. The six evaluation protocols appeared to not be too challenging to females in Group 1 when compared with Group 2. This can be seen by less faulty trials during the evaluation process of Group 1 than with Group 2. After the first testing session, subjects in Group 1 knowing that the evaluation protocols were less challenging to them appeared to be able to complete the testing confidently without much effort and less faulty trials. They tended to show less concentration, attention, effort, and motivation during the retest session. This might have contributed to the greater variations between test and retest session in this group, thus resulting in lower ICC values. Unlike Group 1, subjects in Group 2 showed the same concentration, attention, effort, and motivation during the retest session as in the first testing session. This was because the six evaluation protocols were considered challenging tasks for them and probably more difficult to complete the test. Subjects in Group 2 committed more faulty trials during the evaluation process. This occurred especially for the unilateral stances (left and right leg) with the eyes-closed condition on a stable platform because these tasks required greater concentration, attention, effort, and motivation from subjects. Some of the subjects in Group 2 had to redo these tests a few times to have their data collected due to faulty trials.

During each evaluation session, it was emphasized that every subject should provide her greatest concentration, attention, effort, cooperation, and motivation for every evaluation protocol. In addition, they were advised to maintain the same testing attitude for both evaluation sessions. However, the subjects' attitudes during each testing were not under control due to the inability of the researcher to control or measure the above-mentioned variables.

Interestingly, the data indicates that the APS produced proportionately greater standard error of measurement for the total group, Group 1 and Group 2 compared with OS and MLS. Notably, during the dynamic balance evaluations, whenever the platform were set to move up and down (for bilateral stance test) or anterior-posteriorly (for unilateral stance test), the subjects were driven by the CDBS to move forward and backward. Consequently, one explanation for the greater SEM found in APS, might be due to the subjects' slower reaction and the inability to compensate for the platform movement. If the subject is unable to react sufficiently and to compensate appropriately to relocate her center of balance, and remain centered on the force platform after being challenged to move anterior-posteriorly by the CDBS, she tended to produce a greater amount of anterior-posterior sway amplitudes. Subjects' APS errors of measurement were greater for Group 2 (0.14 cm) which demonstrated that the measurements were less consistent compared with Group 1 (0.10 cm). However, the measurements were still relatively as precise as a SEM of 0.14 cm is a relatively small error variance.

Stratford [178] demonstrated that the SEM and ICC reveal different information concerning measurement consistency. He stated that because the ICC is a numerical representation of classical test theory's version of reliability, it provides unitless estimates of the reliability of measurement. [177] Therefore, it does not directly portray consistency, whereas the SEM represents consistency between repetitions because it is reported in the same units as the actual measurement. For an observed score, the SEM quantifies the range in which the true score might be expected to vary because of measurement error, and therefore provides information to help evaluate physical performance more confidently. [178] In addition, the SEM provides an estimate of the precision of measurement and is useful to determine if differences between scores are due to change or error. [177] Hence, the SEM was used to further evaluate the reliability for the CDBS which, when using the ICC values, yielded good test-retest reliability. For the present study, the differences of SEM values (Table 5.2) were 0.00, 0.01, and 0.03 for OS, MLS, and APS, respectively within the test-retest sessions. One should note that the CDBS showed high consistency (ICCs > 0.80), and yielded stability over time with a small SEM (within 0.00 to 0.03). The CDBS appears to represent a stable measurement tool for clinical use. In addition, the small confidence intervals reported in this study indicate that the measurements were more precise and the rater was more certain that the true population mean should fall within these smaller ranges of scores 95% of the time (refer to Table 5.2). The small confidence intervals within all three postural sway measurements further reinforces that the CDBS, as performed in this study, is reliable to use as a clinical measurement tool for quantifying postural sway measures.

5.2.2 Discriminant Validity

When comparing the mean scores between Group 1 and Group 2 for their static and dynamic balance for OS, MLS, and APS, differences for sway in centimeters were found for all three postural sway measures. Group 1 revealed a lesser amount of sway in centimeters when compared with Group 2 for all three postural sway measures. However, an independent sample *t*-test revealed no significant differences between Group 1 and Group 2 when testing static and dynamic balance using the CDBS for all three dependent variables.

The results demonstrate that, based on postural sway measures, the CDBS did not show good discriminate validity when testing static and dynamic balance in distinguishing hours spent on sporting activities between non-injured females who vigorously practiced sporting activities five hours or more per week (Group 1) and non-injured females who moderately practiced sporting activities less than five hours per week (Group 2).

The findings are different from those found in a study conducted by Condron et al. [111] Their findings demonstrated that the CDBS was able to discriminate dynamic balance in an anterior-posterior direction with a cognitive task among healthy young adults, healthy older adults, and older adults with a mild increase in risk of falling. Likewise, Liao et al. [112] reported that the Chattecx Dynamic Balance System (CDBS) proved to be an objective and sensitive indicator that could be used to distinguish children with cerebral palsy from normal peer groups. The study results demonstrated that children with spastic cerebral palsy and children who develop normally revealed significant differences of the sway index when tested in sitting.

Contrary to these findings, this present study did not find that the CDBS was able to discriminate hours spent in sporting activities per week with postural sway measures between non-injured females who vigorously active (exercise five hours or more per week) and moderately active (exercise less than five hours per week) in practicing sporting activities. These contradictory results could be due to the homogenous study population. Both Group 1 and Group 2 had similar demographic characteristics. For instance, average age ± standard deviation for the subjects in Group 1 was 30.25 ± 7.81 years, and Group 2 was 29.80 ± 6.09 years. Average subjects' height ± standard deviation for Group 1 and Group 2 were 1.66 ± 0.05 meters and 1.64 ± 0.06 meters, respectively. Average subjects' weight ± standard deviation for Group 1 and Group 2 were 60 ± 6.53 kilograms and 65 ± 13.12 kilograms, respectively. Average subjects' BMI ± standard deviation for Group 1 and Group 2 were 22 ± 2.03 and 23.85 ± 4.21, respectively. The literature suggested that the amount of sway in healthy adults ranging in age from 15 to 60 years was constant despite any pathology problems. For these homogenous study groups, the possibility of decreasing postural sway through regular sporting activities may be mild and low. For healthy young individuals, there is less room for improvement as well, and a higher exercise threshold may be needed to gain improvement in postural sway control. Although the study results indicate varying postural sway amounts between Group 1 and Group 2, these subtle differences in performance failed to show statistical significance, to indicate discriminative ability on the CDBS.

In a study conducted by Condron et al., [111] their study population of interest consisted of healthy young adults (mean age 26.4 ± 6.1 years), healthy older adults (mean age 73.8 ± 6.0 years), and older adults with mild increase in risk of falling (mean age 74.8 ± 7.3 years). The literature indicates that for the latter group, their postural control declined primarily due to pathology or health problems, thus showing a larger amount of postural sway and differences in balance abilities. Therefore, when this group was compared with healthy young adults, and healthy older adults on their balance performance, the CBDS was able to discriminate the differences in balance performance across the three groups. Likewise, the study population chosen by Liao et al. [112] to compare differences in seated postural control in children with spastic cerebral palsy and normal developing children, demonstrated significant differences in postural control ability between the two study groups.

In a study investigating the effect of physical and sporting activities on balance and postural control, Perrin et al. [96] suggested that there were significant differences in postural sway control between elderly subjects who practiced physical and sporting activities vigorously three times a week (at least five hours) and those who did not exercise. The authors concluded that practicing physical and sporting activities had a positive effect on balance and postural control (i.e. improved dynamic balance and good control coordination in elderly subjects). The difference in the results was due to the different study population of interest. The present study population was non-injured females age ranging from 20 to 49 years, whereas Perrin et al. [96] studied elderly males and females aged over 65 years. According to the literature, the effects of balance training on postural stability are related to the degree of the initial instability. Generally, elderly adults (over 60 years of age) demonstrated poorer initial postural stability compared with young adults. Therefore, it is assumed that the elderly adults would show greater training effect because they have a greater possibility of improvement due to their initial instability. The healthy and younger adult might need to exercise to a higher threshold for improvement and to expect for any physiological changes in postural stability after exercising.

Additionally, the inconsistency of these results could be due to over-reporting by subjects in Group 1 and under-reporting in Group 2 of actual hours spent in sporting activities per week (i.e. 11.50 ± 4.28 hours and 3.15 ± 1.37 hours, respectively) because this information was gathered through a self-report questionnaire. An additional factor that may account for the significant difference in hours spent on sporting activities per week between Group 1 and Group 2 may be related to the variation of activities reported by Group 1. For instance, slow jogging; slow running; cycling to school or work; and walking the dog, walking for groceries shopping, walking to school or work, were claimed as brisk walking, although these activities were practiced in low intensity as an active daily living activities. At one point, these types of activities would have very little impact on physiological change especially for enhancing balance ability and postural control. In addition, as the subjects were asked to report the times spent on each activity per week without identifying the intensity of the activities, chances of over-reporting for longer practice time and irrelevant activities are possible (that is, reporting their active daily living activities which do not count as high intensity sporting activities). Types of sporting activities reported by subjects in Group 1 are assumed to having impact on the present study findings. For instance, sporting activities such as weight lifting, swimming, and hiking are believed have little impact on enhancing balance ability and postural control. If an individual reported that she was practicing these types of sporting activities for more than five hours per week, she might not gain much improvement in her balance and postural control compared with individuals who practiced sporting activities such as skating, skiing, snow boarding, basketball, and volleyball. The latter sporting activities involve dynamic balance that requires greater balance and postural control ability to complete the task.

In the present study, considerably intra-subject variation was seen on both static and dynamic balance tests with Group 2 having a slightly higher variation for all three postural measures when compared with Group 1. In addition, the intra-subjects variation was slightly higher for static balance measures in contrast to dynamic balance measures in Group 2 for all three postural sway measures. These study findings are in agreement with previous results.[109] Hill et al.[109] demonstrated high intra-subject variation for static balance measures contrasting with dynamic balance measures for healthy female volunteers on the CDBS.

5.2.3 Strengths of Study 1

The major strength of the study is the utilization of a wide range of evaluation protocols. The evaluation protocols consisted of six different conditions, which were a combination of bilateral and unilateral stance; the eyes-open and the eyes-closed conditions; and, on a stable and a moving platform. Furthermore, the wide range of postural sway measures that consisted of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) were measured, unlike most of the previous studies which only reported anterior-posterior sway (APS) as an outcome measure for quantifying postural sway.

The current study was the pioneer study to determine the discriminant validity of the CDBS in distinguishing non-injured young females who vigorously practiced sporting activities five hours or more per week between non-injured young females who moderately practiced sporting activities less than five hours per week including competition or as an active pastime for pleasure or exercise. Furthermore, the discriminant validity was examined by testing static and dynamic balance. To the researcher's best knowledge, there has been no research conducted on non-injured young females to discriminate the postural control ability and activity level on static and dynamic balance using the CDBS.

The researcher allowed a sufficient lapse in time between the first and repeated test sessions. The two identical test and retest sessions were conducted at least a day or more between the tests. This was to control the potential confounders in the test-retest results, such as memory effects, fatigue, maturation, and the learning effect. In addition, the researcher was aware of the potential threat of the learning effect with repeated testing. To counteract this, the sequences of the evaluation protocols were administered at random order.

In the present study, the average of both measurements was used instead of using the best score. Using the average score had the effect of increasing reliability estimates. This was because the average was considered better estimate of the true scores, theoretically reducing error variance.

Other than reporting ICCs for the reliability values, the researcher included the SEM values together with 95% confidence intervals to ensure the results were sufficiently consistent and precise. Furthermore, the ICCs were classified at a higher interpretation of reliability correlation coefficient as suggested by Blesh et al. [130] as follows: high reliability (0.90 to 0.99), good reliability (0.80 to 0.89), fair reliability (0.70 to 0.79), and poor reliability (0.69 and below); instead of referring on generally acceptable levels of: good reliability (above 0.75), moderate reliability (0.50 to 0.75), and below 0.50 (poor reliability). [118]

5.2.4 Weaknesses of Study 1

Subject groupings were based on the hours spent in sporting activities per week. Females who practiced sporting activities five hours or more per week were categorized as Group 1, and females who practiced sporting activities less than five hours per week were categorized as Group 2. The hours spent on sporting activities per week were identified by self-report questionnaire in this study. The present researcher did not directly observe the subjects' sporting activities and hours spent weekly, but only recorded the subjects' report of them. There is always some potential for bias or inaccuracy in self-report, particularly if the questions concern personal issues. In addition, the phenomenon of recall bias can be a problem when subjects are asked to remember past events. As in this study, subjects were asked to recall sporting activities which they regularly practiced weekly for the past three months and recorded their sporting activities for the previous seven days in the first evaluation session, and to quantify the actual playing time of each activity as precisely as possible. Subjects might have forgotten types of sporting activities and actual hours spent for each. They might have over-reporting or under-reporting the sporting activities and actual hours spent. This information could not be corroborated and was not verifiable. Therefore, the phenomenon of recall bias might have been a problem that confounded the results.

There was a possibility that subjects in Group 1 might have over-reporting the number of hours spent in sporting activities per week. Maximum hours spent in sporting activities reported by Group 1 were 22 hours per week and 6.50 hours at minimum. In addition, the sporting activities listed by Group 1 as active daily living activities (e.g. walk the dog, walking to work, or grocery shopping) would not be considered as high intensity sporting activities. It is suggested that detail guidelines to quantify high intensity sporting activities would be helpful to control the over-reporting possibility. Sallis et al. [74] categorized jog or run at least 16 km per week, swim at least 3 km per week, and ride a bicycle at least 80 km per week as vigorous activities. In the present study, all subjects were asked to recall and estimate, as close as possible, the distance covered during particular sporting activities. If a subject reported that she rode a bicycle to school every day for 1.5 hours for five days, she reported that she practiced sporting activities for more than five hours a week. Then, she was categorized as a vigorously active female and was grouped in Group 1. According to Sallis et al., [74] this subject would have to cycle at least 16 km to school each day (including return trip) for five days in order to be categorized as a vigorously active female.

The same limitation applied to Group 2. There was a possibility that subjects in Group 2 might have under-reporting hours spent in sporting activities per week. Some of them reported that they did not spend any time in sporting activities per week (i.e. minimum 0 hour and maximum 4.5 hours). Subjects in Group 2 did not report active daily living activities as sporting activities unlikely Group 1. The differences in hours spent in sporting activities for both Group 1 and Group 2 were significant, where on average, the Group 1 spent 11.50 hours, and Group 2 spent 3.15 hours per week in sporting activities. Therefore, possible over-reporting of the number of hours spent on sporting activities from Group 1 and under-reporting of hours spent on sporting activities from Group 2 were likely possibilities that may have lead to the CDBS failing to discriminate the postural sway measures between both groups.

The test-retest reliability and the discriminant validity of the CDBS were performed using the six specific combinations for the evaluation protocols, applicable only to the same intended purposes, since any other evaluation protocols are different.

The inability to control for subject's concentration, attention, motivation, and fatigue during the evaluation process, could increase subject variability for the test-retest sessions. Greater subject variability was found for all three postural sway measures for the first test session when compared with the retest session (refer to Table 5.2).

In order for one to stand upright with a minimal postural sway, one has to fully concentrate without any disturbances from the testing environment (e.g. noise). Otherwise, the real performance might be altered due to these extraneous factors. Since, the evaluation sessions were conducted in a shared laboratory; it is unlikely to isolate the test setting to minimize aforementioned external influences.

CHAPTER 6

RESULTS AND DISCUSSIONS -- STUDY 2

6.1 RESULTS

This randomized control trial design study examined the effectiveness of a three-week multisensory training program using the Chattecx Dynamic Balance System (CDBS) on postural sway measures of young (age range: 20 to 49 years, mean age 32.17 ± 7.70 years) and elderly (age range: 60 to 80 years, mean age 64.21 ± 4.58 years) non-injured females. All study participants were carefully screened according to the established inclusion and exclusion criteria (see section 4.1). The selected volunteers were randomized to either control groups or training groups. All of the subjects in either the two control groups or two training groups were required to attend two evaluation sessions three weeks apart.

6.1.1 Subjects Characteristics

A total of 108 volunteers responded to the advertisement and were screened. After the screening process, 58 volunteers were excluded mainly because they had injuries to either ankle or foot within six months of the study or had a history of surgery to either lower extremity in the past five years. Of the remaining 50 potential subjects, two volunteers dropped out. One qualified subject did not turn up for the pretest, and the other was unable to return for the posttest for personal reasons. Finally, 48 subjects were enrolled in this study, 24 volunteers from the young group (age range: 22 to 47 years) and 24 volunteers from the elderly group (age range: 60 to 74 years).

6.1.2 Personal Demographics

The subject demographic descriptive statistics for all four study groups are given in Table 6.1 with the comparison of mean scores and standard deviations for age (years), height (m), weight (kg), body mass index (BMI) and activity level (hours spent on sporting activities per week).

Table 6.1: Descriptive Statistics for Subject Demographic Characteristics

Variables	**YCG M ± SD**	**YTG M ± SD**	**ECG M ± SD**	**ETG M ± SD**
Age (yrs)	32.00 ± 9.20	32.33 ± 6.20	64.75 ± 4.45	63.67 ± 4.70
Height (m)	1.66 ± 0.06	1.63 ± 0.04	1.62 ± 0.06	1.60 ± 0.05
Weight (kg)	63.75 ± 8.18	57.68 ± 6.38	66.49 ±11.13	63.15 ± 11.54
BMI	23.06 ± 3.04	21.77 ± 1.83	24.93 ± 3.23	24.53 ± 3.78
Activity Level (hrs)	4.73 ± 2.40	5.31 ± 3.30	3.73 ± 2.58	4.94 ± 1.94

Abbreviation = YCG: Young Control Group; YTG: Young Training Group; ECG: Elderly Control Group; ETG: Elderly Training Group; BMI: body mass index (body weight [kg] / height^2 [m^2])

An one-way ANOVA was conducted to determine differences among all subjects' characteristics except for age. Two-separate independent *t*-tests were performed to determine differences in age of the subjects in the young control group (YCG) and the young training group (YTG), and between the elderly control group (ECG) and the elderly training group (ETG).

As can be seen in Table 6.2, there were no significant differences found in height (m) (p = 0.097), weight (kg) (p = 0.161), BMI (p = 0.057), or activity level (hrs) (p = 0.491) across all four study groups. This means that all variables tested were similar for all groups.

Table 6.2: The *F*-statistic for Subject Demographic Characteristics

Groups	**Height (m)**	**Weight (kg)**	**BMI**	**Activity Level (hrs)**
Young Control Young Training Elderly Control Elderly Training	*F*=2.241* *p*=0.097	*F*=1.798* *p*=0.161	*F*=2.690* *p*=0.057	*F*=0.820* *p*=0.491

* *Observed f (3, 44) ≥ ± 2.82 to reject Ho*

Abbreviation= BMI : body mass index (body weight [kg] / height^2 [m^2])

Table 6.3 indicates that there were no significant differences in age found between YCG and YTG (p = 0.918), nor between ECG and ETG (p = 0.568). These findings mean that the subjects in each age group were not significantly different.

Table 6.3: Two-independent Sample *t*-tests for Age Variable across the Young Groups and the Elderly Groups

Two-independent Sample *t*-tests for Age			
Groups	**Age (M ± SD)**	***t*** *	***p***
Young Control Young Training	32.00 ± 9.20 32.33 ± 6.20	-0.104	0.918
Elderly Control Elderly Training	64.75 ± 4.45 63.67 ± 4.70	0.580	0.568

**Observed t (22) ≥ ± 2.704 to reject Ho*

6.1.3 Differences in Training Effects between Study Groups

6.1.3.1 Training Effect for Static Balance with the Eyes-closed Condition

A. Comparison within Young Aged Groups and Elderly Aged Groups

Table 6.4 summarizes descriptive statistics for pretest and posttest values (in centimeters), SEMs and 95% confidence intervals for OS, MLS, and APS for static balance with the eyes-closed condition between YCG and YTG, and between ECG and ETG, respectively.

At baseline, the MANOVA analysis indicated there were no significant differences between YCG and YTG for all three measures (i.e. OS, $p = 0.934$; MLS, $p = 0.998$; and APS, $p = 0.911$) nor between ECG and ETG for all three measures (i.e. OS, $p = 0.619$; MLS, $p = 0.288$, and APS, $p = 0.664$) recorded from the three different test conditions for static balance with the eyes-closed condition (i.e. bilateral stance with the eyes-closed on stable platform, right leg stance with the eyes-closed on stable platform, left leg stance with the eyes-closed on stable platform).

In contrast to the pretest, the MANOVA analysis revealed significant differences at posttest between YCG and YTG, and between ECG and ETG for all three postural sway measures after the three-week multisensory training intervention ($p \leq 0.000$). The results indicate that the training intervention was effective in reducing the amount of sway in all three postural sway measures for static balance with the eyes-closed condition when the trained YTG and the untrained YCG, and the trained ETG and the untrained ECG were compared (refer to Table 6.4).

Table 6.4: Descriptive Statistics for Pretest and Posttest (in centimeters) for Static Balance with the Eyes-closed Condition Compared between Same Age Groups

Static Balance with the Eyes-closed Condition					
Group	**Measures**	**Pretest (cm)**		**Posttest (cm)**	
Young Control	OS	M±SD	0.89 ± 0.16	M±SD	1.06 ± 0.18
		SEM	0.05	SEM	0.05
		95% CI	0.79 – 1.00	95% CI	0.94 – 1.18
	MLS	M±SD	2.14 ± 0.30	M±SD	2.39 ± 0.27
		SEM	0.09	SEM	0.08
		95% CI	1.95 – 2.33	95% CI	2.22 – 2.56
	APS	M±SD	3.44 ± 0.67	M±SD	4.23 ± 0.86
		SEM	0.19	SEM	0.25
		95% CI	3.01 – 3.87	95% CI	3.69 – 4.78
Young Training	OS	M±SD	1.17 ± 0.22	M±SD	0.76 ± 0.12
		SEM	0.06	SEM	0.03
		95% CI	1.03 – 1.31	95% CI	0.68 – 0.83
		p-value	0.934	*p*-value	0.000*
	MLS	M±SD	2.28 ± 0.21	M±SD	1.79 ± 0.13
		SEM	0.06	SEM	0.04
		95% CI	2.15 – 2.41	95% CI	1.70 – 1.87
		p-value	0.998	*p*-value	0.000*
	APS	M±SD	4.59 ± 0.78	M±SD	2.87 ± 0.61
		SEM	0.23	SEM	0.18
		95% CI	4.10 – 5.09	95% CI	2.48 – 3.26
		p-value	0.911	*p*-value	0.000*
Elderly Control	OS	M±SD	1.92 ± 0.95	M±SD	2.24 ± 1.21
		SEM	0.27	SEM	0.35
		95% CI	1.31 – 2.52	95% CI	1.47 – 3.00
	MLS	M±SD	2.93 ± 1.17	M±SD	3.30 ± 1.34
		SEM	0.34	SEM	0.39
		95% CI	2.19 – 3.67	95% CI	2.45 – 4.16
	APS	M±SD	8.00 ± 3.73	M±SD	9.09 ± 4.44
		SEM	1.08	SEM	1.28
		95% CI	5.63 – 10.38	95% CI	6.28 – 1.91
Elderly Training	OS	M±SD	2.48 ± 2.06	M±SD	1.04 ± 0.22
		SEM	0.59	SEM	0.06
		95% CI	1.17 – 3.80	95% CI	0.90 – 1.18
		p-value	0.619	*p*-value	0.000*
	MLS	M±SD	4.30 ± 3.54	M±SD	2.24 ± 0.42
		SEM	1.02	SEM	0.12
		95% CI	2.05 – 6.55	95% CI	1.98 – 2.51
		p-value	0.288	*p*-value	0.000*
	APS	M±SD	10.00 ± 7.63	M±SD	4.18 ± 1.01
		SEM	2.20	SEM	0.29
		95% CI	5.15 – 14.85	95% CI	3.54 – 4.82
		p-value	0.664	*p*-value	0.000*

* *Significant*

Abbreviation= OS: Overall Sway; MLS: Medial-lateral Sway; APS: Anterior-posterior Sway

B. Comparison across the Four Study Groups

The MANOVA indicated that there were significant differences across the four study groups in their pretest values for static balance with the eyes-closed condition (Wilk's Lambda = 0.517, F (3, 44) = 3.547 at $p \leq 0.001$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at pretest (in centimeters) occurred across the four study groups (Table 6.5).

At the pretest session, all three dependent variables showed the same pattern of pairwise differences between ETG and YCG (OS, $p = 0.007$; MLS, $p = 0.035$; and APS, $p = 0.003$), indicate that the YCG demonstrated decreased sway for all postural sway measures in comparison to the ETG. Nevertheless, OS, MLS, and APS between YTG and ETG were significantly different on their pretest values ($p = 0.035$, $p = 0.050$, $p = 0.017$, respectively), showing that the YTG has better postural sway control before training intervention for static balance with the eyes-closed condition. There were no significant differences between ECG and ETG at pretest for OS, MLS, and APS ($p = 0.619$, $p = 0.288$, $p = 0.664$, respectively) for static balance with the eyes-closed condition (refer to Table 6.5).

Table 6.5: Tukey's HSD Multiple Comparisons at Pretest (in centimeters) for Static Balance with the Eyes-closed Condition across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG)[a]	Sig.*
Overall Sway	Young Training	Young Control	0.28	0.934
		Elderly Control	-0.75	0.388
		Elderly Training	-1.31	0.035*
	Young Control	Elderly Control	-1.02	0.141
	Elderly Training	Young Control	1.59	0.007*
		Elderly Control	0.57	0.619
Medial-lateral Sway	Young Training	Young Control	1.14	0.998
		Elderly Control	-0.65	0.832
		Elderly Training	2.02	0.050*
	Young Control	Elderly Control	-0.78	0.737
	Elderly Training	Young Control	2.16	0.035*
		Elderly Control	1.37	0.288
Anterior-posterior Sway	Young Training	Young Control	1.16	0.911
		Elderly Control	-3.41	0.222
		Elderly Training	-5.41	0.017*
	Young Control	Elderly Control	-4.57	0.057
	Elderly Training	Young Control	6.57	0.003*
		Elderly Control	2.00	0.664

* *Significant*

[a] *Negative values indicate lesser sway for the main group*

The MANOVA indicated that there were significant differences across the four study groups at posttest for static balance with the eyes-closed condition (Wilk's Lambda = 0.178, F (3, 44) = 11.730 at $p \leq 0.000$, note that the probability is never actually zero, but in this case, it is low enough that it can be rounded off to zero). Tukey's HSD multiple comparisons were conducted to determine where significant differences at posttest (in percentage of change) occurred across the four study groups (Table 6.6).

At posttest, all three dependent variables showed the same pattern of pairwise differences between YTG and YCG; between YTG and ECG; between ETG and YCG, and between ETG and ECG (refer to Table 6.6). The results indicated that both the trained young group and the trained elderly group improved significantly in OS, MLS, and APS after completing the multisensory postural balance training intervention, indicating the degree of improvement was significant enough to differentiate the trained (YTG and ETG) and the untrained groups (YCG and ECG).

None of the three dependent variable means in percentage of change were significantly different between YTG and ETG (OS, p = 0.784; MLS, p = 0.366; APS, p = 0.736, respectively), and between YCG and ECG (OS, p = 0.945; MLS, p = 1.000; APS, p = 0.358, respectively) on their posttest values for static balance with the eyes-closed condition (Table 6.6).

Table 6.6: Tukey's HSD Multiple Comparisons at Posttest (in percentage of change) for Static Balance with the Eyes-closed Condition across the Four Study Groups

Dependent Variable	**Main Group (MG)**	**Comparison Group (CG)**	**Mean Difference (MG - CG)[a]**	**Sig.***
Overall Sway	Young Training	Young Control	-53.89	0.000*
		Elderly Control	-49.84	0.000*
		Elderly Training	6.86	0.784
	Young Control	Elderly Control	4.05	0.945
	Elderly Training	Young Control	-60.75	0.000*
		Elderly Control	-56.70	0.000*
Medial-lateral Sway	Young Training	Young Control	-33.84	0.000*
		Elderly Control	-34.47	0.000*
		Elderly Training	10.07	0.366
	Young Control	Elderly Control	-0.62	1.000
	Elderly Training	Young Control	-43.91	0.000*
		Elderly Control	-44.53	0.000*
Anterior-posterior Sway	Young Training	Young Control	-61.25	0.000*
		Elderly Control	-50.09	0.000*
		Elderly Training	6.90	0.736
	Young Control	Elderly Control	11.16	0.358
	Elderly Training	Young Control	-68.15	0.000*
		Elderly Control	-56.99	0.000*

* *Significant*

[a] *Negative values indicate greater improvement for the main group*

Despite the greater percentage of change obtained by ETG for OS, MLS, and APS (40.82%, 31.32%, and 44.01%, respectively) for static balance with the eyes-closed condition after training intervention, the results demonstrated the improvement at posttest did not show a significant difference when compared with YTG (33.96%, 21.25%, and 37.10%, respectively). As for YCG and ECG, the pattern of pairwise differences for the posttest values remained consistent with the pretest values, noting no significant differences for all three postural sway measures between both the untrained groups in comparison with pretest and posttest values for static balance with the eyes-closed condition (refer to Table 6.6).

Table 6.7 presents the percentage of change at posttest across the four study groups for static balance with the eyes-closed condition. The observed effect sizes and power after the fact were calculated. The large observed effect sizes for OS, MLS, and APS (f = 0.725, f = 0.657, and f = 0.782, respectively) indicate the findings were clinically significant differences. This study obtained power after the fact of 100% for all three postural sway measures for static balance with the eyes-closed condition.

Table 6.7: MANOVA Summary Table for Percentage of Change at Posttest for Static Balance with the Eyes-closed Condition across the Four Study Groups

Group	**Overall Sway**		**Medial-lateral Sway**		**Anterior-posterior Sway**	
YCG	M±SD	19.93 ± 16.14	M±SD	12.60 ± 11.91	M±SD	24.15 ± 19.96
	Min.	3.90	Min.	28.17	Min.	2.39
	Max.	52.91	Max.	-3.89	Max.	57.82
	Med.	12.37	Med.	10.86	Med.	19.50
	SEM	4.66	SEM	3.44	SEM	4.90
	95% CI	9.68 – 30.19	95% CI	5.03 – 20.16	95% CI	13.37 – 34.92
YTG	M±SD	-33.96 ± 12.04	M±SD	-21.25 ± 7.68	M±SD	-37.10 ± 11.25
	Min.	-10.67	Min.	-6.90	Min.	-14.08
	Max.	-48.33	Max.	-32.72	Max.	-52.33
	Med.	-37.36	Med.	-21.11	Med.	-37.79
	SEM	3.47	SEM	2.22	SEM	3.25
	95% CI	(-26.34) – (-41.61)	95% CI	(-16.37) – (-26.14)	95% CI	(-29.95)– (-44.25)
ECG	M±SD	15.86 ± 12.46	M±SD	13.22 ± 9.10	M±SD	12.99 ± 8.45
	Min.	42.79	Min.	26.39	Min.	23.55
	Max.	-1.66	Max.	-1.18	Max.	-3.55
	Med.	13.16	Med.	15.75	Med.	15.06
	SEM	3.60	SEM	2.63	SEM	2.44
	95% CI	7.96 – 23.79	95% CI	7.44 – 19.00	95% CI	7.62 – 18.35
ETG	M±SD	-40.82 ± 26.81	M±SD	-31.31 ± 24.87	M±SD	-44.01 ± 25.55
	Min.	-8.62	Min.	-2.51	Min.	-12.78
	Max.	-82.61	Max.	-79.50	Max.	-76.36
	Med.	-33.94	Med.	-29.39	Med.	-42.32
	SEM	7.74	SEM	7.18	SEM	7.09
	95% CI	(-23.79) – (-57.86)	95% CI	(-15.51) – (-47.11)	95% CI	(-28.41) – (-59.60)
F Test *p-value*	*F=38.629* *p=0.000* *		*F=28.139* *p=0.000* *		*F=52.352* *p=0.000* *	
Effect Size	*f* = 0.725		*f* = 0.657		*f* = 0.782	
Power	1.000		1.000		1.000	

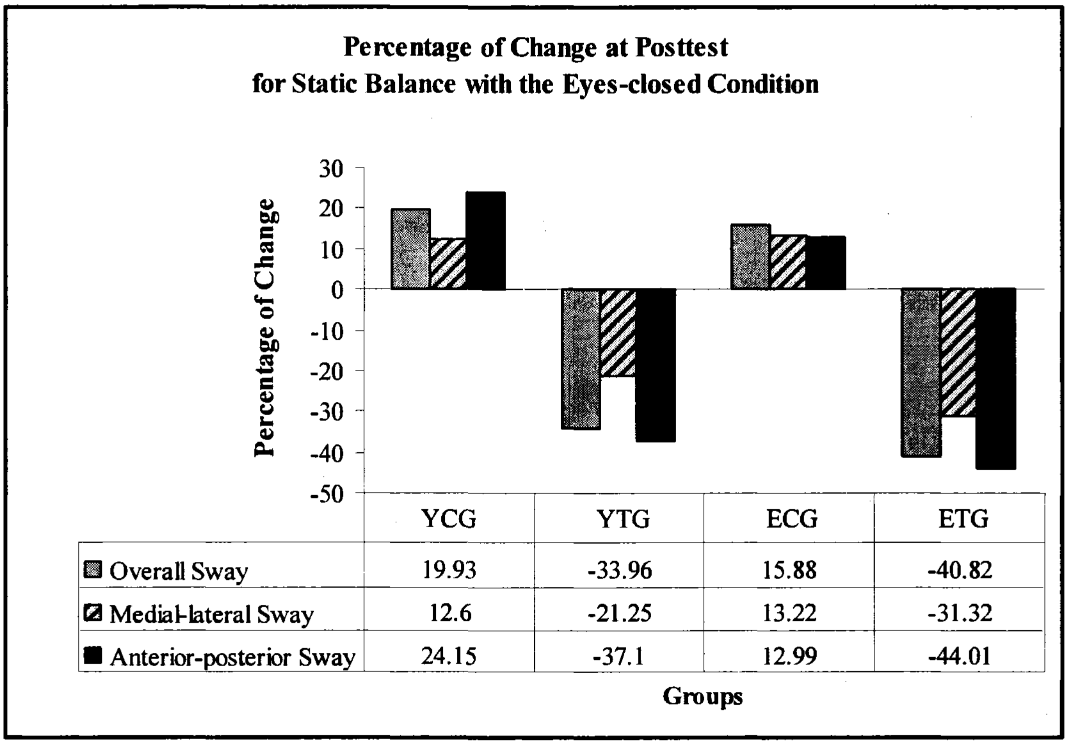
** Significant*

The F test determines the effect on the group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Negative values indicating improvement / sway reduced

Abbreviation= YCG: Young Control Group; YTG: Young Training Group;
ECG: Elderly Control Group; ETG: Elderly Training Group;
Min.: Minimum; Max.: Maximum; Med.: Median

Figure 6.1 shows the comparison across the four study groups (YCG, YTG, ECG, and ETG) for overall sway, medial-lateral sway, and anterior-posterior sway measures in comparison with mean differences in percentage of change at posttest for static balance with the eyes-closed condition.



	YCG	YTG	ECG	ETG
▩ Overall Sway	19.93	-33.96	15.88	-40.82
▨ Medial-lateral Sway	12.6	-21.25	13.22	-31.32
■ Anterior-posterior Sway	24.15	-37.1	12.99	-44.01

Figure 6.1: Percentage of change at posttest for overall sway, medial-lateral sway, and anterior-posterior sway for each group on the training for static balance with the eyes-closed condition. Lower or negative values represent a decrease in sway, thus improvements in postural sway control (i.e. YTG and ETG). Positive values indicated an increase in sway, therefore a decrement of postural sway control (i.e. YCG and ECG).

6.1.3.2 Training Effect for Dynamic Balance with the Eyes-open Condition

A. Comparison within Young Aged Groups and Elderly Aged Groups

Table 6.8 summarizes descriptive statistics for pretest and posttest values (in centimeters), SEMs and 95% confidence intervals for OS, MLS, and APS for dynamic balance with the eyes-open condition between YCG and YTG, and between ECG and ETG, respectively.

At baseline, the MANOVA analysis indicated there were no significant differences between YCG and YTG for OS, MLS, and APS (p = 0.838, p = 0.878, p = 0.936, respectively) nor between ECG and ETG for all three postural sway measures (OS, p = 0.614; MLS, p = 0.709; APS, p = 0.359, respectively) recorded from the three different test conditions for dynamic balance with the eyes-open condition (i.e. bilateral stance with the eyes-open on platform moving up-down, right leg stance with the eyes-open on platform moving linearly, left leg stance with the eyes-open on platform moving linearly).

At posttest, the MANOVA analysis revealed significant differences between YCG and YTG, and between ECG and ETG for all postural sway measures at $p \leq 0.000$. The results demonstrated that following the completion of the training period, the trained YTG and ETG revealed improvement in postural sway control by indicating the regression of sway for all three postural sway measures for dynamic balance with the eyes-open condition when compared with the untrained YCG and ECG (refer to Table 6.8).

Table 6.8: Descriptive Statistics for Pretest and Posttest (in centimeters) for Dynamic Balance with the Eyes-open Condition Compared between Same Age Groups

Dynamic Balance with the Eyes-open Condition					
Group	**Measures**	**Pretest (cm)**		**Posttest (cm)**	
Young Control	OS	M±SD	1.03 ± 0.12	M±SD	1.09 ± 0.15
		SEM	0.04	SEM	0.04
		95% CI	0.95 – 1.11	95% CI	1.00 – 1.19
	MLS	M±SD	1.37 ± 0.20	M±SD	1.46 ± 0.18
		SEM	0.06	SEM	0.05
		95% CI	1.25 – 1.50	95% CI	1.35 – 1.58
	APS	M±SD	4.58 ± 0.57	M±SD	4.81 ± 0.75
		SEM	0.17	SEM	0.22
		95% CI	4.22 – 4.95	95% CI	4.33 – 5.28
Young Training	OS	M±SD	0.97 ± 0.12	M±SD	0.80 ± 0.07
		SEM	0.03	SEM	0.02
		95% CI	0.89 – 1.04	95% CI	0.75 – 0.84
		p-value	0.838	*p*-value	0.000*
	MLS	M±SD	1.29 ± 0.16	M±SD	1.05 ± 0.07
		SEM	0.06	SEM	0.02
		95% CI	2.15 – 2.41	95% CI	1.01– 1.10
		p-value	0.878	*p*-value	0.000*
	APS	M±SD	4.39 ± 0.47	M±SD	3.61 ± 0.34
		SEM	0.13	SEM	0.10
		95% CI	4.09 – 4.69	95% CI	3.40 – 3.83
		p-value	0.936	*p*-value	0.000*
Elderly Control	OS	M±SD	1.30 ± 0.29	M±SD	1.38 ± 1.30
		SEM	0.08	SEM	0.08
		95% CI	1.11 – 1.49	95% CI	1.11 – 1.57
	MLS	M±SD	1.83 ± 0.30	M±SD	1.99 ± 0.31
		SEM	0.09	SEM	0.09
		95% CI	1.64 – 2.02	95% CI	1.80 – 2.18
	APS	M±SD	5.49 ± 1.19	M±SD	5.97 ± 1.30
		SEM	0.34	SEM	0.37
		95% CI	4.74 – 6.25	95% CI	5.15 – 6.80
Elderly Training	OS	M±SD	1.40 ± 0.19	M±SD	1.08 ± 0.18
		SEM	0.05	SEM	0.05
		95% CI	1.28 – 1.52	95% CI	0.97 – 1.20
		p-value	0.614	*p*-value	0.000*
	MLS	M±SD	1.95 ± 0.38	M±SD	1.58 ± 0.31
		SEM	0.11	SEM	0.09
		95% CI	1.71 – 2.19	95% CI	1.38 – 1.77
		p-value	0.709	*p*-value	0.000*
	APS	M±SD	6.03 ± 0.78	M±SD	4.69 ± 0.73
		SEM	0.22	SEM	0.23
		95% CI	5.74 – 6.53	95% CI	4.20 – 5.19
		p-value	0.359	*p*-value	0.000*

* *Significant*

Abbreviation= OS: Overall Sway; MLS: Medial-lateral Sway; APS: Anterior-posterior Sway

B. Comparison across the Four Study Groups

The results revealed there were significant differences for OS, MLS, and APS across the four study groups for dynamic balance with the eyes-open condition at pretest (Wilk's Lambda = 0.385, F (3, 44) = 5.462 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at pretest (in centimeters) occurred across the four study groups (Table 6.9).

At baseline, all three OS, MLS, and APS means demonstrated the same pattern of pairwise differences when compared between the young and elderly aged groups [i.e. there were significantly difference between YTG and ECG (OS, $p = 0.001$; MLS, $p = 0.000$; APS, $p = 0.008$, respectively), between YTG and ETG (OS, $p = 0.001$; MLS, $p = 0.000$; APS, $p = 0.000$, respectively), between ETG and YCG (OS, MLS, and APS, $p = 0.000$, respectively) and between YCG and ECG (OS, $p = 0.008$; MLS, $p = 0.001$; APS, $p = 0.039$, respectively)].

Meanwhile, when compared within the same age groups for dynamic balance with the eyes-open condition at baseline, OS, MLS and APS were not significantly different between YTG and YCG (OS, $p = 0.838$; MLS, $p = 0.878$; APS, $p = 0.936$, respectively), and between ETG and ECG (OS, $p = 0.614$; MLS, $p = 0.709$; APS, $p = 0.359$, respectively) (Table 6.9).

Table 6.9: Tukey's HSD Multiple Comparisons at Pretest (in centimeters) for Dynamic Balance with the Eyes-open Condition across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG)[a]	Sig.
Overall Sway	Young Training	Young Control	-0.07	0.838
		Elderly Control	-0.33	0.001*
		Elderly Training	-0.43	0.000*
	Young Control	Elderly Control	-0.27	0.008*
	Elderly Training	Young Control	0.37	0.000*
		Elderly Control	0.10	0.614
Medial-lateral Sway	Young Training	Young Control	-0.08	0.878
		Elderly Control	-0.54	0.000*
		Elderly Training	-0.66	0.000*
	Young Control	Elderly Control	-0.46	0.001*
	Elderly Training	Young Control	0.58	0.000*
		Elderly Control	0.12	0.709
Anterior-posterior Sway	Young Training	Young Control	-0.19	0.936
		Elderly Control	-1.10	0.008*
		Elderly Training	-1.64	0.000*
	Young Control	Elderly Control	-0.91	0.039*
	Elderly Training	Young Control	1.45	0.000*
		Elderly Control	0.54	0.359

* *Significant*

[a] *Negative values indicate lesser sway for the main group*

The MANOVA indicated that there were significant differences across the four study groups at posttest for dynamic balance with the eyes-open condition (Wilk's Lambda = 0.171, F (3, 44) = 12.123 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at posttest (percentage of change) occurred across the four study groups (Table 6.10).

At posttest, all three dependent variables portrayed the same pattern of pairwise differences between YTG and YCG; between YTG and ECG; between ETG and YCG, and between ETG and ECG. The results indicate that both the trained groups (young and elderly) improved significantly for OS, MLS, and APS after completing the multisensory training intervention. The degree of improvement was significant enough to differentiate the trained (YTG and ETG) and the untrained groups (YCG and ECG) for dynamic balance with the eyes-open condition.

None of the three dependent variable means were significantly different between YTG and ETG (OS, p = 0.290; MLS, p = 0.987; APS, p = 0.445, respectively), and between YCG and ECG (OS, p = 0.998; MLS, p = 0.908; APS, p = 0.555, respectively) on their posttest values in percentage of change for dynamic balance with the eyes-open condition (Table 6.10).

Table 6.10: Tukey's HSD Multiple Comparisons at Posttest (in percentage of change) for Dynamic Balance with the Eyes-open Condition across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG) [a]	Sig.
Overall Sway	Young Training	Young Control	-22.60	0.000*
		Elderly Control	-23.08	0.000*
		Elderly Training	5.38	0.290
	Young Control	Elderly Control	-0.48	0.998
	Elderly Training	Young Control	-27.98	0.000*
		Elderly Control	-28.46	0.000*
Medial-lateral Sway	Young Training	Young Control	-24.30	0.000*
		Elderly Control	-26.85	0.000*
		Elderly Training	1.26	0.987
	Young Control	Elderly Control	-2.55	0.908
	Elderly Training	Young Control	-25.56	0.000*
		Elderly Control	-28.11	0.000*
Anterior-posterior Sway	Young Training	Young Control	-21.86	0.000*
		Elderly Control	-26.03	0.000*
		Elderly Training	4.75	0.445
	Young Control	Elderly Control	-4.18	0.555
	Elderly Training	Young Control	-26.60	0.000*
		Elderly Control	-30.78	0.000*

* *Significant*

[a] *Negative values indicate greater improvement for the main group*

Despite the greater percentage of change obtained by ETG for OS, MLS, and APS (22.08%, 18.60%, and 21.95%, respectively) for dynamic balance with the eyes-open condition after training intervention, the results indicate that the differences in improvement at posttest did not show statistical significance when compared with YTG (16.70%, 17.34%, and 17.20%, respectively). As for the untrained YCG and ECG, the pattern of pairwise differences for the pretest and posttest values remained consistent, noting no significant differences for all three postural sway measures between pretest and posttest values for both YCG and ECG for dynamic balance with the eyes-open condition (refer to Table 6.10).

Table 6.11 presents the MANOVA summary at posttest in percentage of change across the four study groups for dynamic balance with the eyes-open condition. The observed effect sizes and power after the fact were reported. The large observed effect sizes for OS, MLS, and APS ($f = 0.771$, $f = 0.684$, and $f = 0.764$, respectively), indicate the findings were clinically significant differences. This study obtained power after the fact of 100% for all three postural sway measures for dynamic balance with the eyes-open condition.

Table 6.11: MANOVA Summary Table for Percentage of Change at Posttest for Dynamic Balance with the Eyes-open Condition across the Four Study Groups

Group	**Overall Sway**		**Medial-lateral Sway**		**Anterior-posterior Sway**	
YCG	M±SD	5.91 ± 5.88	M±SD	6.96 ± 4.44	M±SD	4.65 ± 7.12
	Min.	0.00	Min.	0.22	Min.	-1.16
	Max.	20.50	Max.	15.63	Max.	24.24
	Med.	4.01	Med.	6.29	Med.	1.40
	SEM	1.70	SEM	1.28	SEM	2.06
	95% CI	2.17 – 9.64	95% CI	4.14 – 9.78	95% CI	0.13 – 9.18
YTG	M±SD	-16.70 ± 8.26	M±SD	-17.34 ± 10.53	M±SD	-17.20 ± 8.65
	Min.	-4.13	Min.	-1.40	Min.	-4.83
	Max.	-28.71	Max.	-30.17	Max.	-34.15
	Med.	-16.16	Med.	-19.27	Med.	-15.28
	SEM	2.38	SEM	3.04	SEM	2.06
	95% CI	(-11.45)-(-21.94)	95% CI	(-10.65)-(-24.03)	95% CI	(-11.71)-(-22.70)
ECG	M±SD	6.39 ± 4.59	M±SD	9.51 ± 11.44	M±SD	8.83 ± 5.10
	Min.	0.81	Min.	36.62	Min.	2.10
	Max.	15.58	Max.	-4.41	Max.	20.95
	Med.	5.24	Med.	7.59	Med.	7.85
	SEM	1.33	SEM	3.30	SEM	1.47
	95% CI	3.47 – 9.30	95% CI	2.24 – 16.78	95% CI	5.59 – 12.07
ETG	M±SD	-22.08 ± 9.59	M±SD	-18.60 ± 9.32	M±SD	-21.95 ± 9.41
	Min.	-12.50	Min.	-4.01	Min.	-12.21
	Max.	-38.85	Max.	-39.65	Max.	-34.78
	Med.	-17.37	Med.	-18.09	Med.	-18.43
	SEM	2.77	SEM	2.69	SEM	2.72
	95% CI	(-15.99)-(-28.17)	95% CI	(-12.68)-(-24.53)	95% CI	(-15.97)-(-27.93)
F Test *p-value*	*F=49.429* *p=0.000 **		*F=31.708* *p=0.000 **		*F=47.481* *p=0.000 **	
Effect Size	*f*= 0.771		*f*= 0.684		*f*= 0.764	
Power	1.000		1.000		1.000	

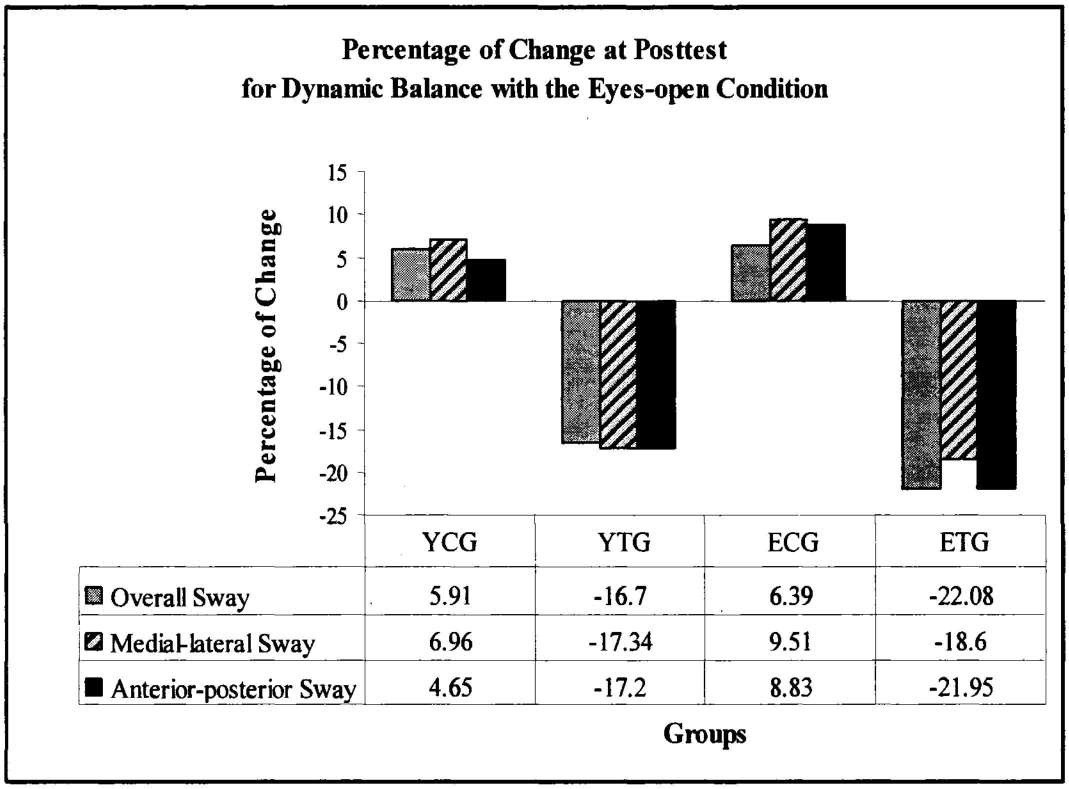
** Significant*

The F test determines the effect on the group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Negative values indicating improvement / sway reduced

Abbreviation= YCG: Young Control Group; YTG: Young Training Group;
ECG: Elderly Control Group; ETG: Elderly Training Group;
Min.: Minimum; Max.: Maximum; Med.: Median

Figure 6.2 depicts the comparison across the four study groups (YCG, YTG, ECG, and ETG) for overall sway, medial-lateral sway, and anterior-posterior sway measures in comparison with mean differences at posttest in percentage of change for dynamic balance with the eyes-open condition.



	YCG	YTG	ECG	ETG
▩ Overall Sway	5.91	-16.7	6.39	-22.08
▨ Medial-lateral Sway	6.96	-17.34	9.51	-18.6
■ Anterior-posterior Sway	4.65	-17.2	8.83	-21.95

Figure 6.2: Percentage of change at posttest for overall sway, medial-lateral sway, and anterior-posterior sway for each group on the training for dynamic balance with the eyes-open condition. Lower or negative values represent a decrease in sway, thus improvements in postural sway control (i.e. YTG and ETG). Positive values indicated an increase in sway, therefore a decrement of postural sway control (i.e. YCG and ECG).

6.1.3.3 Training Effect for Bilateral Stance

A. Comparison within Young Aged Groups and Elderly Aged Groups

Table 6.12 summarizes descriptive statistics for pretest and posttest values (in centimeters), SEMs and 95% confidence intervals for OS, MLS, and APS for bilateral stance between YCG and YTG, and between ECG and ETG, respectively.

The MANOVA analysis indicated there were no significant differences at baseline between YCG and YTG for OS, MLS, and APS (p = 0.946; p = 0.998; p = 0.863, respectively) nor between ECG and ETG for OS, MLS, and APS measures (p = 0.341; p = 0.305; p = 0.070, respectively) recorded from the two different test conditions for bilateral stance (i.e. bilateral stance with the eyes-closed on stable platform, bilateral stance with the eyes-open on platform moving up-down).

In contrast to the pretest, the results revealed significant differences at posttest between YCG and YTG, and between ECG and ETG for all three postural sway measures at $p \leq 0.000$ after the three-week multisensory training intervention. The results demonstrated that the training intervention was effective in reducing the amount of sway for all three postural sway measures for bilateral stance in comparison with the trained YTG and ETG, and the untrained YCG and ECG (refer to Table 6.12).

Table 6.12: Descriptive Statistics for Pretest and Posttest (in centimeters) for Bilateral Stance Compared between Same Age Groups

Bilateral Stance					
Group	**Measures**	**Pretest (cm)**		**Posttest (cm)**	
Young Control	OS	M±SD	0.68 ± 0.11	M±SD	0.75 ± 0.12
		SEM	0.03	SEM	0.03
		95% CI	0.61 – 0.75	95% CI	0.68 – 0.82
	MLS	M±SD	0.73 ± 0.12	M±SD	0.87 ± 0.19
		SEM	0.04	SEM	0.06
		95% CI	0.65 – 0.81	95% CI	0.75 – 0.99
	APS	M±SD	3.01 ± 0.46	M±SD	3.31 ± 0.50
		SEM	0.13	SEM	0.15
		95% CI	2.71 – 3.30	95% CI	3.00 – 3.63
Young Training	OS	M±SD	0.73 ± 0.15	M±SD	0.48 ± 0.10
		SEM	0.04	SEM	0.03
		95% CI	0.63– 0.81	95% CI	0.42 – 0.55
		p-value	0.946	*p*-value	0.000 *
	MLS	M±SD	0.72 ± 0.13	M±SD	0.58 ± 0.06
		SEM	0.04	SEM	0.02
		95% CI	0.64 – 0.80	95% CI	0.54– 0.61
		p-value	0.998	*p*-value	0.000 *
	APS	M±SD	3.25 ± 0.65	M±SD	2.12 ± 0.45
		SEM	0.19	SEM	0.13
		95% CI	2.84 – 3.66	95% CI	1.84 – 2.41
		p-value	0.863	*p*-value	0.000 *
Elderly Control	OS	M±SD	0.99 ± 0.20	M±SD	1.10 ± 0.17
		SEM	0.06	SEM	0.05
		95% CI	0.86 – 1.11	95% CI	0.99 – 1.21
	MLS	M±SD	0.91 ± 0.18	M±SD	1.07 ± 0.19
		SEM	0.05	SEM	0.09
		95% CI	0.79 – 1.03	95% CI	1.80 – 2.18
	APS	M±SD	4.04 ± 0.70	M±SD	4.54 ± 0.61
		SEM	0.20	SEM	0.17
		95% CI	3.59 – 4.49	95% CI	4.15 – 4.92
Elderly Training	OS	M±SD	1.13 ± 0.32	M±SD	0.68 ± 0.14
		SEM	0.09	SEM	0.04
		95% CI	0.93 – 1.33	95% CI	0.59 – 0.77
		p-value	0.341	*p*-value	0.000 *
	MLS	M±SD	1.04 ± 0.27	M±SD	0.79 ± 0.16
		SEM	0.08	SEM	0.05
		95% CI	0.87 – 1.22	95% CI	0.69 – 0.89
		p-value	0.305	*p*-value	0.000 *
	APS	M±SD	4.83 ± 1.10	M±SD	2.98 ± 0.63
		SEM	0.32	SEM	0.18
		95% CI	4.13 – 5.53	95% CI	2.58 – 3.38
		p-value	0.070	*p*-value	0.000 *

* *Significant*

Abbreviation= OS: Overall Sway; MLS: Medial-lateral Sway; APS: Anterior-posterior Sway

B. Comparison across the Four Study Groups

The MANOVA indicated that there were significant differences across the four study groups in their pretest values for bilateral stance (Wilk's Lambda = 0.430, F (3, 44) = 4.711 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at pretest (in centimeters) occurred across the four study groups (Table 6.13).

At pretest, all three postural sway measures of OS, MLS and APS showed the same pattern of pairwise differences between YTG and ETG (OS, $p = 0.000$; MLS, $p = 0.001$; APS, $p = 0.000$, respectively), indicating that there were significant differences among all postural sway measures. Moreover, there was a significant difference between YTG and ECG for OS ($p = 0.18$) only. The YCG and ECG showed significant differences at pretest for OS and APS ($p = 0.04$, $p = 0.10$, respectively). The results revealed that both YTG and YCG have better postural sway control for OS, MLS, and APS at pretest in comparison to ETG for bilateral stance. As can be seen in Table 6.13, there were no significant differences between ECG and ETG at pretest for OS, MLS, and APS ($p = 0.341$, $p = 0.305$, $p = 0.700$, respectively) for bilateral stance.

Table 6.13: Tukey's HSD Multiple Comparisons at Pretest (in centimeters) for Bilateral Stance across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG) [a]	Sig.*
Overall Sway	Young Training	Young Control	0.05	0.946
		Elderly Control	-0.26	0.018*
		Elderly Training	-0.40	0.000*
	Young Control	Elderly Control	-0.31	0.004*
	Elderly Training	Young Control	0.45	0.000*
		Elderly Control	0.14	0.341
Medial-lateral Sway	Young Training	Young Control	-0.01	0.998
		Elderly Control	-0.19	0.070
		Elderly Training	-0.33	0.001*
	Young Control	Elderly Control	-0.18	0.102
	Elderly Training	Young Control	0.31	0.001*
		Elderly Control	0.13	0.305
Anterior-posterior Sway	Young Training	Young Control	0.24	0.863
		Elderly Control	0.79	0.068
		Elderly Training	-1.58	0.000*
	Young Control	Elderly Control	-1.04	0.010*
	Elderly Training	Young Control	1.82	0.000*
		Elderly Control	0.79	0.700

** Significant*

[a] *Negative values indicate lesser sway for the main group*

The MANOVA indicated that there were significant differences across the four study groups at posttest for bilateral stance (Wilk's Lambda = 0.214, F (3, 44) = 10.065 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at posttest (in percentage of change) occurred across the four study groups (Table 6.14).

It is interesting to note that all three dependent variables showed the same pattern of pairwise differences between YTG and YCG; between YTG and ECG; between ETG and YCG, and between ETG and ECG. The results demonstrate that both the trained young group and the trained elderly group improved significantly in OS, MLS, and APS for bilateral stance after completing the multisensory training intervention, indicating the degree of improvement was significant enough to differentiate the trained groups (YTG and ETG) from the untrained groups (YCG and ECG).

None of the three dependent variable means were significantly different between YTG and ETG (OS, p = 0.903; MLS, p = 0.904; APS, p = 0.983, respectively), and between YCG and ECG (OS, p = 0.990; MLS, p = 0.999; APS, p = 0.980, respectively) on their posttest values in percentage of change for bilateral stance (Table 6.14).

Table 6.14: Tukey's HSD Multiple Comparisons at Posttest (in percentage of change) for Bilateral Stance across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG)[a]	Sig.*
Overall Sway	Young Training	Young Control	-43.20	0.000*
		Elderly Control	-44.89	0.000*
		Elderly Training	3.74	0.903
	Young Control	Elderly Control	-1.68	0.990
	Elderly Training	Young Control	-46.93	0.000*
		Elderly Control	-48.61	0.000*
Medial-lateral Sway	Young Training	Young Control	-37.13	0.000*
		Elderly Control	-36.24	0.000*
		Elderly Training	4.45	0.904
	Young Control	Elderly Control	0.90	0.999
	Elderly Training	Young Control	-41.59	0.000*
		Elderly Control	-40.69	0.000*
Anterior-posterior Sway	Young Training	Young Control	-44.94	0.000*
		Elderly Control	-47.18	0.000*
		Elderly Training	2.11	0.983
	Young Control	Elderly Control	-2.23	0.980
	Elderly Training	Young Control	-47.04	0.000*
		Elderly Control	-49.27	0.000*

* *Significant*

[a] *Negative values indicate greater improvement for the main group*

Despite the greater percentage of change obtained by ETG for OS, MLS, and APS (35.77%, 22.49%, and 35.76%, respectively) for bilateral stance after training intervention, the results indicated that the differences in improvement at posttest did not show statistical significance when compared with YTG (32.04%, 18.03%, and 33.65%, respectively). As for the untrained YCG and ECG, the pattern of pairwise differences for the pretest and posttest values remained consistent, noting no significant differences for all three postural sway measures between pretest and posttest values for both YCG and ECG for bilateral stance (refer to Table 6.14).

Table 6.15 presents the MANOVA summary for percentage of change at posttest across the four study groups for bilateral stance. The observed effect sizes and power after the fact were calculated. The large observed effect sizes for OS, MLS, and APS ($f = 0.763$, $f = 0.617$, and $f = 0.753$, respectively), indicate the findings were clinically significant difference. This study obtained power after the fact of 100% for all three postural sway measures for bilateral stance.

Table 6.15: MANOVA Summary Table for Percentage of Change at Posttest for Bilateral Stance across the Four Study Groups

Group	**Overall Sway**		**Medial-lateral Sway**		**Anterior-posterior Sway**	
YCG	M±SD	11.16 ± 11.42	M±SD	19.10 ± 20.80	M±SD	11.29 ± 14.85
	Min.	35.46	Min.	75.16	Min.	1.85
	Max.	-5.76	Max.	-3.18	Max.	20.72
	Med.	9.59	Med.	15.50	Med.	4.14
	SEM	3.30	SEM	6.01	SEM	4.29
	95% CI	3.90 – 18.42	95% CI	5.88 – 32.32	95% CI	-4.46 – 39.94
YTG	M±SD	-32.04 ± 12.77	M±SD	-18.03 ± 13.20	M±SD	-33.65 ± 12.37
	Min.	-18.59	Min.	-2.59	Min.	-14.08
	Max.	-61.95	Max.	-41.40	Max.	-52.33
	Med.	-29.79	Med.	-15.68	Med.	-36.43
	SEM	3.69	SEM	3.81	SEM	3.57
	95% CI	(-23.92) –(-40.15)	95% CI	(-9.64) –(-26.42)	95% CI	(-16.82) –(-57.45)
ECG	M±SD	12.84 ± 10.62	M±SD	18.20 ± 13.66	M±SD	13.52 ± 11.67
	Min.	0.83	Min.	37.09	Min.	1.05
	Max.	33.33	Max.	-3.43	Max.	34.53
	Med.	9.06	Med.	15.67	Med.	11.45
	SEM	3.06	SEM	3.94	SEM	3.37
	95% CI	6.10 – 19.59	95% CI	9.53 – 26.88	95% CI	6.10 – 20.93
ETG	M±SD	-35.77 ± 17.63	M±SD	-22.49 ± 15.42	M±SD	-35.76 ± 16.96
	Min.	-8.57	Min.	-1.81	Min.	-10.09
	Max.	-71.67	Max.	-51.74	Max.	-68.87
	Med.	-35.25	Med.	-19.51	Med.	-34.59
	SEM	5.09	SEM	4.45	SEM	4.90
	95% CI	(-24.57) –(-46.97)	95% CI	(-12.69) –(-32.28)	95% CI	(-24.98) –(-46.53)
F Test *p-value*	*F=47.215* *p=0.000* *		*F=23.650* *p=0.000* *		*F=44.620* *p=0.000* *	
Effect Size	*f* = 0.763		*f* = 0.617		*f* = 0.753	
Power	1.000		1.000		1.000	

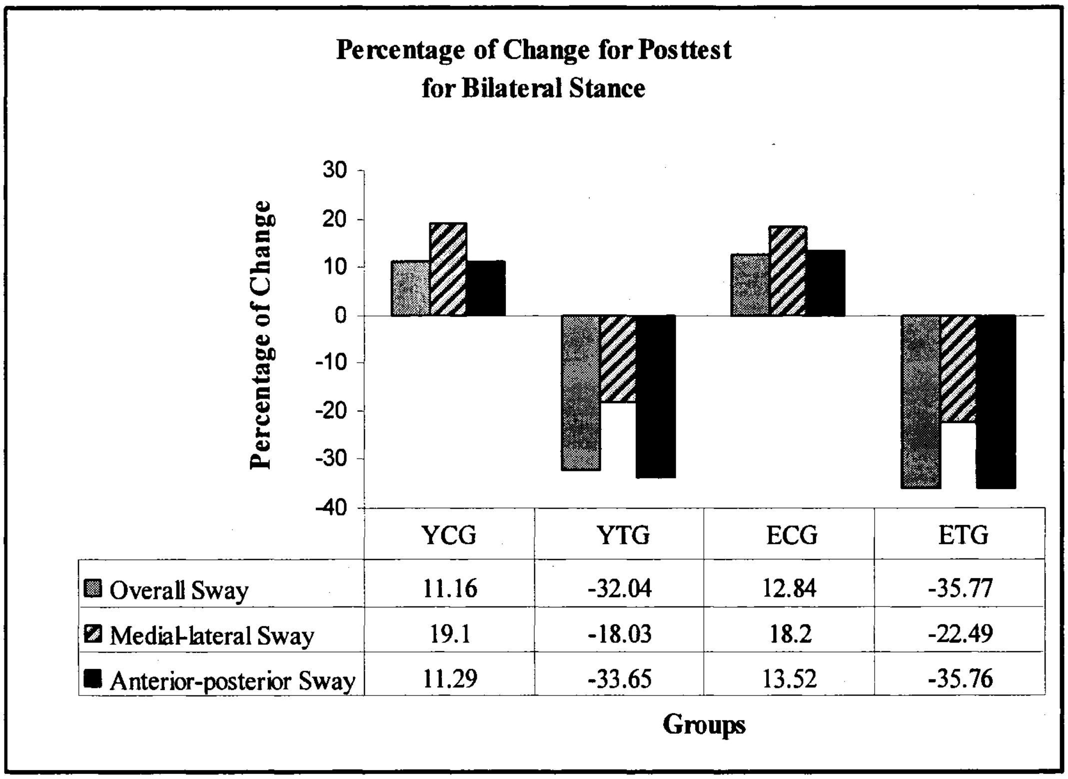
** Significant*

Negative values indicating improvement / sway reduced

The F test determines the effect on the group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Abbreviation= YCG: Young Control Group; YTG: Young Training Group;
ECG: Elderly Control Group; ETG: Elderly Training Group;
Min.: Minimum; Max.: Maximum; Med.: Median

Figure 6.3 portrays the comparison across the four study groups (YCG, YTG, ECG, and ETG) for overall sway, medial-lateral sway, and anterior-posterior sway measures in comparison with mean differences in percentage of change at posttest for bilateral stance.



	YCG	YTG	ECG	ETG
▩ Overall Sway	11.16	-32.04	12.84	-35.77
▨ Medial-lateral Sway	19.1	-18.03	18.2	-22.49
■ Anterior-posterior Sway	11.29	-33.65	13.52	-35.76

Figure 6.3: Percentage of change at posttest for overall sway, medial-lateral sway, and anterior-posterior sway for each group on the training for the bilateral stance. Lower or negative values represent a decrease in sway, thus improvements in postural sway control (i.e. YTG and ETG). Positive values indicate an increase in sway, therefore a decrement of postural sway control (i.e. YCG and ECG).

6.1.3.4 Training Effect for Unilateral Stance

A. Comparison within Young Aged Groups and Elderly Aged Groups

Table 6.16 summarizes descriptive statistics for pretest and posttest values (in centimeters), SEMs and 95% confidence intervals for OS, MLS, and APS for unilateral stance between YCG and YTG, and between ECG and ETG, respectively.

The MANOVA analysis indicated there were no significant differences at baseline between YCG and YTG for OS, MLS, and APS ($p = 0.983$; $p = 1.000$; $p = 0.972$, respectively) nor between ECG and ETG for OS, MLS, and APS measures ($p = 0.650$; $p = 0.294$; $p = 0.699$, respectively) recorded from the four different test conditions for unilateral stance (i.e. right leg stance with the eyes-open on platform moving linearly, right leg stance with the eyes-closed on stable platform, or left leg stance with the eyes-open on platform moving linearly, left leg stance with eyes-closed on stable platform).

In addition, the MANOVA analysis revealed significant differences between YCG and YTG, and between ECG and ETG for all three postural sway measures at $p \leq 0.000$ at posttest in contrast to pretest. The results indicate that the training intervention was effective in reducing the amount of sway in all three postural sway measures for unilateral stance in comparison with the trained YTG and ETG, and the untrained YCG and ECG (refer to Table 6.16).

Table 6.16: Descriptive Statistics for Pretest and Posttest (in centimeters) for Unilateral Stance Compared between Same Age Groups

Unilateral Stance					
Group	**Measures**	**Pretest (cm)**		**Posttest (cm)**	
Young Control	OS	M±SD	1.10 ± 0.16	M±SD	1.24 ± 0.17
		SEM	0.05	SEM	0.05
		95% CI	1.00 – 1.21	95% CI	1.13 – 1.35
	MLS	M±SD	2.27 ± 0.20	M±SD	2.46 ± 0.25
		SEM	0.06	SEM	0.07
		95% CI	2.15 – 2.40	95% CI	2.30 – 2.61
	APS	M±SD	4.51 ± 0.77	M±SD	5.12 ± 0.90
		SEM	0.22	SEM	0.26
		95% CI	4.03 – 5.00	95% CI	4.55 – 5.69
Young Training	OS	M±SD	1.24 ± 0.15	M±SD	0.92 ± 1.11
		SEM	0.04	SEM	0.03
		95% CI	1.14 – 1.34	95% CI	0.85 – 1.00
		p-value	0.983	*p*-value	0.000 *
	MLS	M±SD	2.32 ± 0.17	M±SD	1.84 ± 0.09
		SEM	0.05	SEM	0.03
		95% CI	2.21 – 2.43	95% CI	1.78– 1.89
		p-value	1.000	*p*-value	0.000 *
	APS	M±SD	5.12 ± 0.60	M±SD	3.80 ± 0.52
		SEM	0.17	SEM	0.15
		95% CI	4.74 – 5.49	95% CI	3.47 – 4.13
		p-value	0.972	*p*-value	0.000 *
Elderly Control	OS	M±SD	1.92 ± 0.84	M±SD	2.18 ± 1.01
		SEM	0.24	SEM	0.29
		95% CI	1.35 – 2.45	95% CI	1.54 – 2.82
	MLS	M±SD	3.11 ± 0.98	M±SD	3.46 ± 1.09
		SEM	0.28	SEM	0.31
		95% CI	2.49 – 3.74	95% CI	2.77 – 4.15
	APS	M±SD	8.10 ± 3.41	M±SD	9.05 ± 3.95
		SEM	0.99	SEM	1.14
		95% CI	5.93 – 10.27	95% CI	6.55 – 11.56
Elderly Training	OS	M±SD	2.35 ± 1.57	M±SD	1.25 ± 0.19
		SEM	0.45	SEM	0.06
		95% CI	1.35 – 3.34	95% CI	1.13 – 1.37
		p-value	0.650	*p*-value	0.000 *
	MLS	M±SD	4.16 ± 2.70	M±SD	2.47 ± 0.42
		SEM	0.78	SEM	0.12
		95% CI	2.45 – 5.88	95% CI	2.21 – 2.73
		p-value	0.294	*p*-value	0.000 *
	APS	M±SD	9.61 ± 5.82	M±SD	5.16 ± 0.95
		SEM	1.68	SEM	0.27
		95% CI	5.92 – 13.31	95% CI	4.56 – 5.77
		p-value	0.699	*p*-value	0.000 *

* *Significant*

Abbreviation= OS: Overall Sway; MLS: Medial-lateral Sway; APS: Anterior-posterior Sway

B. Comparison across the Four Study Groups

The MANOVA indicated that there were significant differences across the four study groups at pretest for unilateral stance (Wilk's Lambda = 0.576, *F* (3, 44) = 2.899 at $p \leq 0.004$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at pretest (in centimeters) occurred across the four study groups (Table 6.17).

It is interesting to note that at pretest, all postural sway measures of OS, MLS and APS showed the same pattern of pairwise differences between YTG and ETG (OS, $p = 0.021$; MLS, $p = 0.016$; APS, $p = 0.012$, respectively), and between YCG and ETG (OS, $p = 0.008$; MLS, $p = 0.013$; APS, $p = 0.004$, respectively), indicate there were significant differences for unilateral stance. The results revealed that both YTG and YCG have better postural sway control for OS, MLS, and APS at pretest in comparison to the ETG, indicating that both the young control group and the young training group demonstrated reduced sway for all three postural sway measures when compared with the ETG for unilateral stance. As can be seen in Table 6.17, there were no significant differences between ECG and ETG at pretest for OS, MLS, and APS ($p = 0.650$, $p = 0.294$, $p = 0.699$, respectively) for unilateral stance.

Table 6.17: Tukey's HSD Multiple Comparisons at Pretest (in centimeters) for Unilateral Stance across the Four Study Groups

Dependent Variable	Main Group	Comparison Group (CG)	Mean Difference (MG – CG) [a]	Sig.*
Overall Sway	Young Training	Young Control	0.13	0.983
		Elderly Control	-0.68	0.260
		Elderly Training	-1.11	0.021*
	Young Control	Elderly Control	-1.02	0.141
	Elderly Training	Young Control	1.24	0.008*
		Elderly Control	0.43	0.650
Medial-lateral Sway	Young Training	Young Control	0.05	1.000
		Elderly Control	-0.79	0.538
		Elderly Training	-1.85	0.016*
	Young Control	Elderly Control	-0.84	0.490
	Elderly Training	Young Control	1.89	0.013*
		Elderly Control	1.05	0.294
Anterior-posterior Sway	Young Training	Young Control	0.60	0.972
		Elderly Control	-2.99	0.154
		Elderly Training	-4.50	0.012*
	Young Control	Elderly Control	-3.59	0.061
	Elderly Training	Young Control	5.10	0.004*
		Elderly Control	1.51	0.699

* *Significant*

[a] *Negative values indicate lesser sway for the main group*

The MANOVA indicated that there were significant differences across the four study groups at posttest for unilateral stance (Wilk's Lambda = 0.229, F (3, 44) = 9.466 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at posttest (in percentage of change) occurred across the four study groups (Table 6.18).

It is interesting to note that at posttest, all three dependent variables showed the same pattern of pairwise differences among YTG, YCG, and ECG; and among ETG, YCG, and ECG for unilateral stance. The results demonstrate that both the trained young group and elderly group improved significantly in OS, MLS, and APS for unilateral stance after completing the multisensory training intervention, indicating the degree of improvement was significant enough to differentiate the trained groups (YTG and ETG) and the untrained groups (YCG and ECG).

None of the three dependent variable means were significantly different between YTG and ETG (OS, p = 0.507; MLS, p = 0.341; APS, p = 0.288, respectively), and between YCG and ECG (OS, p = 0.999; MLS, p = 0.927; APS, = 0.976, respectively) on their posttest values in percentage of change for unilateral stance (Table 6.18).

Table 6.18: Tukey's HSD Multiple Comparisons at Posttest (in percentage of change) for Unilateral Stance across the Four Study Groups

Dependent Variable	**Main Group (MG)**	**Comparison Group (CG)**	**Mean Difference (MG - CG)** [a]	**Sig.***
Overall Sway	Young Training	Young Control	-37.53	0.000*
		Elderly Control	-38.47	0.000*
		Elderly Training	8.43	0.507
	Young Control	Elderly Control	-0.94	0.999
	Elderly Training	Young Control	-45.96	0.000*
		Elderly Control	-46.90	0.000*
Medial-lateral Sway	Young Training	Young Control	-28.61	0.000*
		Elderly Control	-31.82	0.000*
		Elderly Training	8.66	0.341
	Young Control	Elderly Control	-3.14	0.927
	Elderly Training	Young Control	-37.34	0.000*
		Elderly Control	-40.48	0.000*
Anterior-posterior Sway	Young Training	Young Control	-39.33	0.000*
		Elderly Control	-37.05	0.000*
		Elderly Training	9.96	0.288
	Young Control	Elderly Control	2.27	0.976
	Elderly Training	Young Control	-49.29	0.000*
		Elderly Control	-47.01	0.000*

* *Significant*

[a] *Negative values indicate greater improvement for the main group*

Despite the greater improvement obtained by ETG for OS, MLS, and APS (33.32%, 28.94%, and 35.39%, respectively) in comparison with YTG (24.89%, 20.28%, and 25.43%, respectively) for unilateral stance, the results demonstrate that the differences in improvement did not show statistical significance for the percentage of change at posttest between both trained YTG and trained ETG. As for YCG and ECG, the pattern of pairwise differences of the posttest values remained consistent with the pretest values, indicating no significant differences for all three postural sway measures between both the untrained groups when compared the pretest and posttest values for unilateral stance (refer to Table 6.18).

Table 6.19 presents the percentage of change at posttest across four study groups for unilateral stance. The observed effect sizes and power after the fact were reported. The large observed effect sizes for OS, MLS, and APS (f = 0.695, f = 0.682, and f = 0.739, respectively), indicating the findings were clinically significant difference. This study obtained power after the fact of 100% for all three postural sway measures for unilateral stance.

Table 6.19: MANOVA Summary Table for Percentage of Change at Posttest for Unilateral Stance across the Four Study Groups

Group	**Overall Sway**		**Medial-lateral Sway**		**Anterior-posterior Sway**	
YCG	M±SD	12.64 ± 9.95	M±SD	8.40 ± 8.21	M±SD	13.90 ± 9.92
	Min.	2.56	Min.	20.66	Min.	1.65
	Max.	31.76	Max.	-2.82	Max.	32.75
	Med.	8.94	Med.	5.25	Med.	12.51
	SEM	2.87	SEM	2.37	SEM	2.86
	95% CI	6.32 – 18.96	95% CI	3.18 – 13.62	95% CI	7.60 – 20.20
YTG	M±SD	-24.89 ± 8.62	M±SD	-20.28 ± 6.53	M±SD	-25.43 ± 8.84
	Min.	-6.11	Min.	-5.49	Min.	-5.55
	Max.	-33.12	Max.	-27.77	Max.	-36.55
	Med.	-25.55	Med.	-22.78	Med.	-28.53
	SEM	2.49	SEM	1.89	SEM	2.55
	95% CI	(-19.42) – (-30.37)	95% CI	(-16.13) – (-24.43)	95% CI	(-19.81)– (-31.04)
ECG	M±SD	13.58 ± 11.43	M±SD	11.54 ± 7.17	M±SD	11.63 ± 8.46
	Min.	32.32	Min.	0.43	Min.	0.99
	Max.	-2.21	Max.	22.41	Max.	24.25
	Med.	8.95	Med.	11.38	Med.	14.44
	SEM	3.30	SEM	2.07	SEM	2.44
	95% CI	6.31 – 20.84	95% CI	6.98 – 16.09	95% CI	6.25 – 17.00
ETG	M±SD	-33.32 ± 23.83	M±SD	-28.94 ± 21.62	M±SD	-35.39 ± 22.10
	Min.	-7.87	Min.	-6.41	Min.	-9.50
	Max.	-75.43	Max.	-74.06	Max.	-71.46
	Med.	-27.55	Med.	-21.94	Med.	-28.82
	SEM	6.88	SEM	6.24	SEM	6.38
	95% CI	(-18.18) – (-48.46)	95% CI	(-15.20) – (-42.68)	95% CI	(-21.35)– (-49.42)
F Test *p-value*	*F=33.362* *p=0.000* *		*F=31.492* *p=0.000* *		*F=41.623* *p=0.000* *	
Effect Size	*f* = 0.695		*f* = 0.682		*f* = 0.739	
Power	1.000		1.000		1.000	

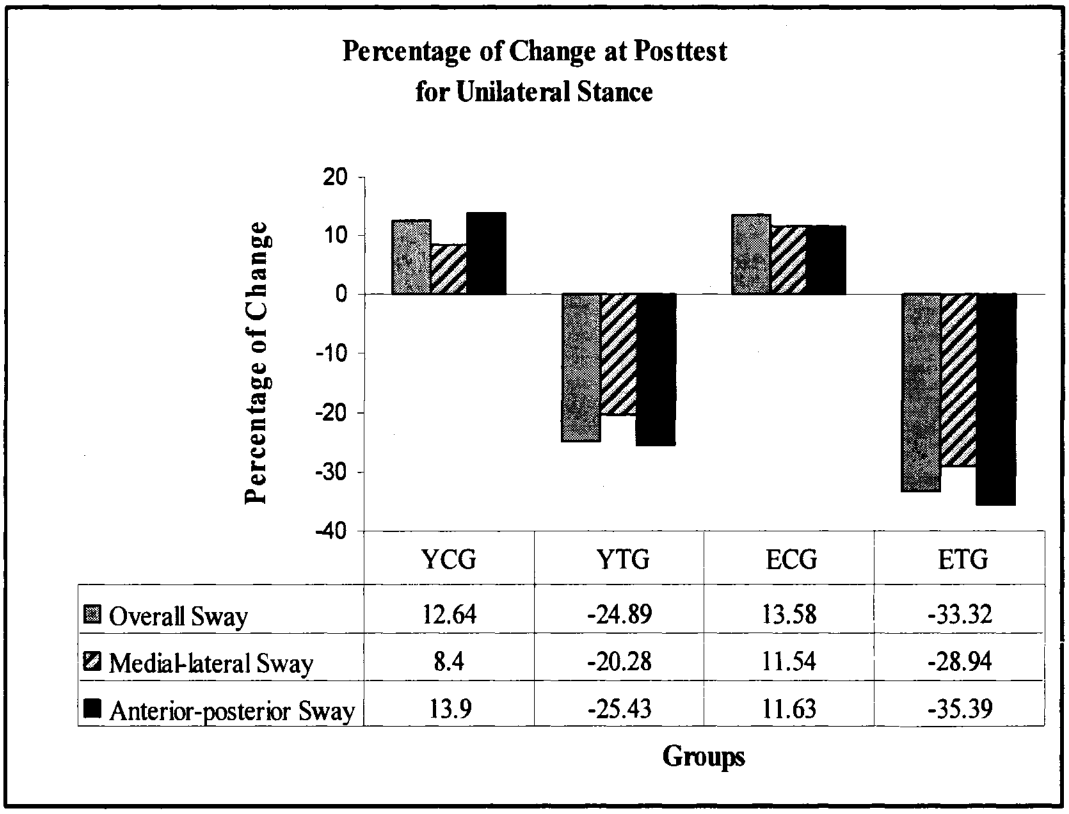
** Significant*

The F test determines the effect on the group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means

Negative values indicating improvement / sway reduced

Abbreviation= YCG: Young Control Group; YTG: Young Training Group;
ECG: Elderly Control Group; ETG: Elderly Training Group;
Min.: Minimum; Max.: Maximum; Med.: Median

Figure 6.4 depicts the comparison across the four study groups (YCG, YTG, ECG, and ETG) for overall sway, medial-lateral sway, and anterior-posterior sway measures in comparison with mean differences in percentage of change at posttest for unilateral stance.



	YCG	YTG	ECG	ETG
▒ Overall Sway	12.64	-24.89	13.58	-33.32
▨ Medial-lateral Sway	8.4	-20.28	11.54	-28.94
■ Anterior-posterior Sway	13.9	-25.43	11.63	-35.39

Figure 6.4: Percentage of change at posttest for overall sway, medial-lateral sway, and anterior-posterior sway for each group on the training for the unilateral stance. Lower or negative values represent a decrease in sway, thus improvements in postural sway control (i.e. YTG and ETG). Positive values indicate an increase in sway, therefore a decrement of postural sway control (i.e. YCG and ECG).

6.1.3.5 Training Effect for Dominant Leg

A. Comparison within Young Aged Groups and Elderly Aged Groups

Table 6.20 summarizes descriptive statistics for pretest and posttest values (in centimeters), SEMs and 95% confidence intervals for OS, MLS, and APS for the dominant leg between YCG and YTG, and between ECG and ETG, respectively.

At baseline, the MANOVA analysis indicated there were no significant differences between YCG and YTG for OS, MLS, and APS ($p = 0.996$; $p = 1.000$; $p = 0.988$, respectively), nor between ECG and ETG for OS, MLS, and APS ($p = 0.579$; $p = 0.296$; $p = 0.681$, respectively) recorded from the two different test conditions for dominant leg (i.e. right leg stance with the eyes-closed on stable platform or left leg stance with the eyes-closed on stable platform, and right leg stance with the eyes-open on platform moving linearly or left leg stance with the eyes-open on platform moving linearly).

In contrast to the pretest, the MANOVA analysis revealed significant differences at posttest between YCG and YTG, and between ECG and ETG for all three postural sway measures at $p \leq 0.000$. The results indicated that the training intervention was effective in reducing the amount of sway in all three postural sway measures for the dominant leg when compared to posttest values between the trained YTG and ETG, and the untrained YCG and ECG (refer to Table 6.20).

Table 6.20: Descriptive Statistics for Pretest and Posttest (in centimeters) for Dominant Leg Compared between Same Age Groups

Dominant Leg					
Group	**Measures**	**Pretest (cm)**		**Posttest (cm)**	
Young Control	OS	M±SD	1.12 ± 0.20	M±SD	1.27 ± 0.24
		SEM	0.06	SEM	0.07
		95% CI	0.99 – 1.24	95% CI	1.11 – 1.42
	MLS	M±SD	2.31 ± 0.31	M±SD	2.53 ± 0.36
		SEM	0.09	SEM	0.10
		95% CI	2.12 – 2.51	95% CI	2.30 – 2.75
	APS	M±SD	4.60 ± 1.06	M±SD	5.26 ± 1.32
		SEM	0.31	SEM	0.38
		95% CI	3.93 – 5.27	95% CI	4.42 – 6.10
Young Training	OS	M±SD	1.21 ± 0.21	M±SD	0.89 ± 0.10
		SEM	0.06	SEM	0.03
		95% CI	1.08 – 1.34	95% CI	0.82 – 0.95
		p-value	0.996	*p*-value	0.000 *
	MLS	M±SD	2.31 ± 0.33	M±SD	1.74 ± 0.14
		SEM	0.10	SEM	0.04
		95% CI	2.10 – 2.52	95% CI	1.65– 1.83
		p-value	1.000	*p*-value	0.000 *
	APS	M±SD	5.12 ± 1.10	M±SD	3.74 ± 0.46
		SEM	0.32	SEM	0.13
		95% CI	4.42 – 5.81	95% CI	3.45 – 4.03
		p-value	0.988	*p*-value	0.000 *
Elderly Control	OS	M±SD	1.91 ± 0.96	M±SD	2.21 ± 1.20
		SEM	0.28	SEM	0.35
		95% CI	1.30 – 2.51	95% CI	1.45 – 2.97
	MLS	M±SD	3.17 ± 0.87	M±SD	3.43 ± 0.96
		SEM	0.25	SEM	0.28
		95% CI	2.62 – 3.73	95% CI	2.82 – 4.04
	APS	M±SD	8.16 ± 3.97	M±SD	9.21 ± 4.62
		SEM	1.15	SEM	1.33
		95% CI	5.64 – 10.68	95% CI	6.27 – 12.15
Elderly Training	OS	M±SD	2.44 ± 1.76	M±SD	1.27 ± 0.23
		SEM	0.51	SEM	0.07
		95% CI	1.32 – 3.56	95% CI	1.12 – 1.41
		p-value	0.579	*p*-value	0.000 *
	MLS	M±SD	4.44 ± 0.34	M±SD	2.51 ± 0.46
		SEM	0.97	SEM	0.13
		95% CI	2.31 – 6.54	95% CI	2.22 – 2.80
		p-value	0.296	*p*-value	0.000 *
	APS	M±SD	9.95 ± 6.61	M±SD	5.30 ± 1.26
		SEM	1.91	SEM	0.36
		95% CI	5.75 – 14.15	95% CI	4.50 – 6.09
		p-value	0.681	*p*-value	0.000 *

* *Significant*

Abbreviation= OS: Overall Sway; MLS: Medial-lateral Sway; APS: Anterior-posterior Sway

B. Comparison across the Four Study Groups

The MANOVA indicated that there were significant differences across the four study groups at pretest for the dominant leg (Wilk's Lambda = 0.662, F (3, 44) = 2.099 at $p \leq 0.036$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at pretest (in centimeters) occurred across the four study groups (Table 6.21).

At pretest, all three OS, MLS, and APS means were significantly different between YTG and ETG (OS, $p = 0.024$; MLS, $p = 0.022$; APS, $p = 0.021$, respectively), and between YCG and ETG (OS, $p = 0.014$; MLS, $p = 0.023$; APS, $p = 0.009$, respectively), indicating that both YTG and YCG demonstrated reduced sway for all postural sway measures when compared with ETG for the dominant leg. There were no significant differences between ECG and ETG at pretest for OS, MLS, and APS ($p = 0.579$; $p = 0.296$; $p = 0.681$, respectively) for the dominant leg (refer to Table 6.21).

Table 6.21: Tukey's HSD Multiple Comparisons at Pretest (in centimeters) for Dominant Leg across the Four Study Groups

Dependent Variable	**Main Group (MG)**	**Comparison Group (CG)**	**Mean Difference (MG – CG)** [a]	**Sig.***
Overall Sway	Young Training	Young Control	0.09	1.000
		Elderly Control	-0.70	0.343
		Elderly Training	-1.23	0.024*
	Young Control	Elderly Control	-0.79	0.240
	Elderly Training	Young Control	1.32	0.014*
		Elderly Control	0.53	0.579
Medial-lateral Sway	Young Training	Young Control	-0.01	1.000
		Elderly Control	-0.87	0.620
		Elderly Training	-2.13	0.022*
	Young Control	Elderly Control	-0.86	0.624
	Elderly Training	Young Control	2.13	0.023*
		Elderly Control	1.27	0.296
Anterior-posterior Sway	Young Training	Young Control	0.52	0.988
		Elderly Control	-3.04	0.244
		Elderly Training	-4.83	0.021*
	Young Control	Elderly Control	-3.56	0.133
	Elderly Training	Young Control	5.35	0.009*
		Elderly Control	1.79	0.681

** Significant*

[a] *Negative values indicate lesser sway for the main group*

The MANOVA indicated that there were significant differences across the four study groups at posttest for the dominant leg (Wilk's Lambda = 0.334, F (3, 44) = 6.482 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at posttest (in percentage of change) occurred across the four study groups (Table 6.22).

At posttest, all three dependent variables showed the same pattern of pairwise differences between YTG and YCG; between YTG and ECG; between ETG and YCG, and between ETG and ECG for the dominant leg. The results demonstrated that both the trained young and elderly groups improved significantly in OS, MLS, and APS after completing the multisensory training intervention when compared with the untrained groups (YCG and ECG). The results indicate that the degree of improvement was significant enough to differentiate the trained (YTG and ETG) and the untrained groups (YCG and ECG) for the dominant leg.

None of the three dependent variable means were significantly different between YTG and ETG ($p = 0.801$, $p = 0.863$, and $p = 0.576$, respectively), and between YCG and ECG ($p = 0.999$, $p = 0.997$, and $p = 0.990$, respectively) on their posttest values in percentage of change for the dominant leg (Table 6.22).

Table 6.22: Tukey's HSD Multiple Comparisons at Posttest (in percentage of change) for Dominant Leg across the Four Study Groups

Dependent Variable	**Main Group (MG)**	**Comparison Group (CG)**	**Mean Difference (MG - CG)** [a]	**Sig.***
Overall Sway	Young Training	Young Control	-38.72	0.000*
		Elderly Control	-39.70	0.000*
		Elderly Training	6.83	0.801
	Young Control	Elderly Control	-0.97	0.999
	Elderly Training	Young Control	-45.56	0.000*
		Elderly Control	-46.53	0.000*
Medial-lateral Sway	Young Training	Young Control	-33.11	0.000*
		Elderly Control	-31.88	0.000*
		Elderly Training	4.88	0.863
	Young Control	Elderly Control	1.23	0.997
	Elderly Training	Young Control	-38.00	0.000*
		Elderly Control	-36.77	0.000*
Anterior-posterior Sway	Young Training	Young Control	-39.70	0.000*
		Elderly Control	-37.56	0.000*
		Elderly Training	9.10	0.576
	Young Control	Elderly Control	2.14	0.990
	Elderly Training	Young Control	-48.80	0.000*
		Elderly Control	-46.66	0.000*

** Significant*

[a] *Negative values indicate greater improvement for the main group*

The results demonstrated that there were no significant differences in postural sway control improvement or in the percentage of change at posttest between ETG and YTG for OS, MLS, and APS, although the ETG obtained a greater percentage of change for OS, MLS, and APS (31.84%, 28.22%, and 33.78%, respectively) for the dominant leg when compared with YTG (25.01%, 23.34%, and 24.68%, respectively) after the intervention. As for YCG and ECG, the posttest values for the dominant leg revealed no significant differences for OS, MLS, and APS between both untrained groups (refer to Table 6.22).

Table 6.23 presents the percentage of change at posttest across four study groups for the dominant leg. The observed effect sizes and power after the fact were calculated. The large observed effect sizes for OS, MLS, and APS (f = 0.596, f = 0.588, and f = 0.634, respectively), indicating the findings were clinically significant difference. This study obtained power after the fact of 100% for all three postural sway measures for the dominant leg.

Table 6.23: MANOVA Summary Table for Percentage of Change at Posttest for the Dominant Leg across the Four Study Groups

Group	Overall Sway		Medial-lateral Sway		Anterior-posterior Sway	
YCG	M±SD	13.72 ± 13.26	M±SD	9.97 ± 12.47	M±SD	15.02 ± 15.48
	Min.	1.15	Min.	0.85	Min.	0.39
	Max.	40.96	Max.	40.41	Max.	46.54
	Med.	7.71	Med.	3.13	Med.	6.94
	SEM	3.83	SEM	3.60	SEM	4.47
	95% CI	5.29 – 22.14	95% CI	1.85 – 17.69	95% CI	5.18 – 24.86
YTG	M±SD	-25.01 ± 12.91	M±SD	-23.34 ± 9.81	M±SD	-24.68 ± 13.70
	Min.	-16.80	Min.	-6.90	Min.	-1.56
	Max.	-33.21	Max.	-32.72	Max.	-47.04
	Med.	-27.10	Med.	-26.19	Med.	-27.50
	SEM	3.73	SEM	2.83	SEM	3.95
	95% CI	(-1.76) – (-41.89)	95% CI	(-6.31) – (-37.61)	95% CI	(-15.97)– (-33.38)
ECG	M±SD	14.69 ± 18.02	M±SD	8.55 ± 9.42	M±SD	12.88 ± 13.31
	Min.	63.05	Min.	25.38	Min.	0.26
	Max.	-6.07	Max.	-2.90	Max.	35.62
	Med.	9.96	Med.	8.54	Med.	8.37
	SEM	5.20	SEM	2.72	SEM	3.84
	95% CI	3.24 – 26.14	95% CI	2.56 – 14.53	95% CI	4.42 – 21.34
ETG	M±SD	-31.84 ± 26.30	M±SD	-28.22 ± 24.52	M±SD	-33.78 ± 24.41
	Min.	-7.62	Min.	-5.03	Min.	-6.47
	Max.	-74.89	Max.	-76.42	Max.	-71.18
	Med.	-20.81	Med.	-20.58	Med.	-23.23
	SEM	7.59	SEM	7.08	SEM	7.05
	95% CI	(-15.13) – (-48.55)	95% CI	(-12.65)– (-43.80)	95% CI	(-18.27)– (-49.28)
F Test p-value	F=21.670 p=0.000 *		F=20.961 p=0.000 *		F=25.433 p=0.000 *	
Effect Size	f = 0.596		f = 0.588		f = 0.634	
Power	1.000		1.000		1.000	

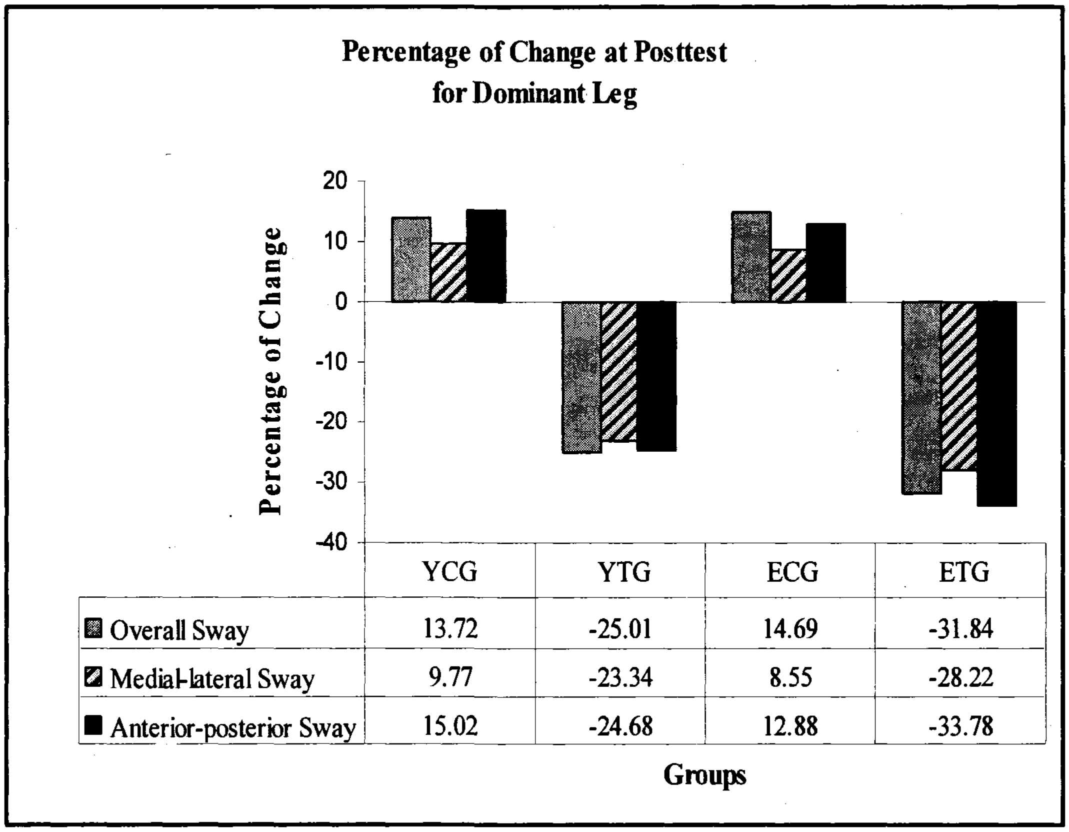
* *Significant*

The F test determines the effect on the group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means

Negative values indicating improvement / sway reduced

Abbreviation= YCG: Young Control Group; YTG: Young Training Group;
ECG: Elderly Control Group; ETG: Elderly Training Group;
Min.: Minimum; Max.: Maximum; Med.: Median

Figure 6.5 portrays the comparison across the four study groups (YCG, YTG, ECG, and ETG) for overall sway, medial-lateral sway, and anterior-posterior sway measures in comparison with mean differences in percentage of change at posttest for the dominant leg.



	YCG	YTG	ECG	ETG
▨ Overall Sway	13.72	-25.01	14.69	-31.84
▧ Medial-lateral Sway	9.77	-23.34	8.55	-28.22
■ Anterior-posterior Sway	15.02	-24.68	12.88	-33.78

Figure 6.5: Percentage of change at posttest for overall sway, medial-lateral sway, and anterior-posterior sway for each group on the training for the dominant leg. Lower or negative values represent a decrease in sway, thus improvements in postural sway control (i.e. YTG and ETG). Positive values indicate an increase in sway, therefore a decrement of postural sway control (i.e. YCG and ECG).

6.1.3.6 Training Effect for Non-dominant Leg

A. Comparison within Young Groups and Elderly Groups

Table 6.24 summarizes descriptive statistics for pretest and posttest values (in centimeters), SEMs and 95% confidence intervals for OS, MLS, and APS for the non-dominant leg between YCG and YTG, and between ECG and ETG, respectively.

At baseline, the MANOVA analysis indicated there were no significant differences between YCG and YTG for OS, MLS, and APS ($p = 0.959$; $p = 0.997$; $p = 0.935$, respectively), nor between ECG and ETG for OS, MLS, and APS measures ($p = 0.799$; $p = 0.340$; $p = 0.783$, respectively) recorded from the two different test conditions for the non-dominant leg (i.e. right leg stance with the eyes-closed on stable platform, right leg stance with the eyes-open on platform moving linearly, or left leg stance with the eyes-closed on stable platform, and left leg stance with the eyes-open on platform moving linearly).

In contrast to the pretest, the MANOVA analysis revealed significant differences at posttest between YCG and YTG, and between ECG and ETG for all three postural sway measures at $p \leq 0.000$. The results demonstrated that the training intervention was effective in reducing the amount of sway for all three postural sway measures for the non-dominant leg in comparison with the posttest values for the trained YTG and ETG, and the untrained YCG and ECG (refer to Table 6.24).

Table 6.24: Descriptive Statistics for Pretest and Posttest (in centimeters) for Non-dominant Leg Compared Compared between Same Age Groups

Non-dominant Leg					
Group	**Measures**	**Pretest (cm)**		**Posttest (cm)**	
Young Control	OS	M±SD	1.09 ± 0.15	M±SD	1.21 ± 0.13
		SEM	0.04	SEM	0.04
		95% CI	0.99 – 1.19	95% CI	1.13 – 1.29
	MLS	M±SD	2.23 ± 0.22	M±SD	2.39 ± 0.31
		SEM	0.06	SEM	0.09
		95% CI	2.09 – 2.37	95% CI	2.19 – 2.59
	APS	M±SD	4.34 ± 0.65	M±SD	4.99 ± 0.65
		SEM	0.19	SEM	0.19
		95% CI	3.93 – 4.76	95% CI	4.57 – 5.40
Young Training	OS	M±SD	1.27 ± 0.21	M±SD	0.96 ± 0.15
		SEM	0.06	SEM	0.04
		95% CI	1.14 – 1.40	95% CI	0.87– 1.06
		p-value	0.959	*p*-value	0.000 *
	MLS	M±SD	2.33 ± 0.14	M±SD	1.93 ± 0.12
		SEM	0.04	SEM	0.04
		95% CI	2.24 – 2.41	95% CI	1.86– 2.01
		p-value	0.997	*p*-value	0.000 *
	APS	M±SD	5.12 ± 0.63	M±SD	3.86 ± 0.71
		SEM	0.18	SEM	0.20
		95% CI	4.72 – 5.51	95% CI	3.41 – 4.31
		p-value	0.935	*p*-value	0.000 *
Elderly Control	OS	M±SD	1.93 ± 0.93	M±SD	2.15 ± 0.94
		SEM	0.27	SEM	0.27
		95% CI	1.34– 2.52	95% CI	1.56 – 2.75
	MLS	M±SD	3.05 ± 1.22	M±SD	3.48 ± 0.34
		SEM	0.35	SEM	0.39
		95% CI	2.28 – 3.83	95% CI	2.63 – 4.33
	APS	M±SD	8.04 ± 3.75	M±SD	8.90 ± 3.84
		SEM	1.08	SEM	1.11
		95% CI	5.66 – 10.43	95% CI	6.46 – 11.34
Elderly Training	OS	M±SD	2.25 ± 0.45	M±SD	1.24 ± 0.18
		SEM	0.42	SEM	0.05
		95% CI	1.34 – 3.17	95% CI	1.12 – 1.35
		p-value	0.799	*p*-value	0.000 *
	MLS	M±SD	3.89 ± 2.08	M±SD	2.43 ± 0.41
		SEM	0.60	SEM	0.12
		95% CI	2.57 – 5.21	95% CI	1.17 – 2.69
		p-value	0.340	*p*-value	0.000 *
	APS	M±SD	9.28 ± 5.13	M±SD	5.03 ± 0.83
		SEM	1.48	SEM	0.24
		95% CI	6.02 – 12.53	95% CI	4.50 – 5.56
		p-value	0.783	*p*-value	0.000 *

* *Significant*

Abbreviation= OS: Overall Sway; MLS: Medial-lateral Sway; APS: Anterior-posterior Sway

B. Comparison across the Four Study Groups

The MANOVA indicated that there were significant differences across the four study groups at pretest for the non-dominant leg (Wilk's Lambda = 0.539, F (3, 44) = 3.283 at $p \leq 0.001$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at pretest (in centimeters) occurred across the four study groups (Table 6.25).

At pretest, all three dependent variables showed the same pattern of pairwise differences for OS, MLS, and APS between YTG and ETG (p = 0.035; p = 0.050; p = 0.017, respectively), and between YCG and ETG (p = 0.007; p = 0.035; p = 0.003, respectively) significantly. The results demonstrated that both YCG and YTG demonstrated reduced sway for all postural sway measures when compared with the ETG at pretest, showing that both of the young aged groups had better postural sway control before the training intervention. There were no significant differences between ECG and ETG at pretest for OS, MLS, and APS (p = 0.619; p = 0.288; p = 0.664, respectively) for the non-dominant leg as can be seen in Table 6.25.

Table 6.25: Tukey's HSD Multiple Comparisons at Pretest (in centimeters) for Non-dominant Leg across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG)[a]	Sig.*
Overall Sway	Young Training	Young Control	0.28	0.934
		Elderly Control	-0.75	0.388
		Elderly Training	-1.31	0.035*
	Young Control	Elderly Control	-1.02	0.141
	Elderly Training	Young Control	1.59	0.007*
		Elderly Control	0.57	0.619
Medial-lateral Sway	Young Training	Young Control	1.14	0.998
		Elderly Control	-0.65	0.832
		Elderly Training	2.02	0.050*
	Young Control	Elderly Control	-0.78	0.737
	Elderly Training	Young Control	2.16	0.035*
		Elderly Control	1.37	0.288
Anterior-posterior Sway	Young Training	Young Control	1.16	0.911
		Elderly Control	-3.41	0.222
		Elderly Training	-5.41	0.017*
	Young Control	Elderly Control	-4.57	0.057
	Elderly Training	Young Control	6.57	0.003*
		Elderly Control	2.00	0.664

** Significant*

[a] *Negative values indicate lesser sway for the main group*

The MANOVA indicated that there were significant differences across the four study groups at posttest for the non-dominant leg (Wilk's Lambda = 0.237, F (3, 44) = 9.190 at $p \leq 0.000$). Tukey's HSD multiple comparisons were conducted to determine where significant differences at posttest (in percentage of change) occurred across the four study groups (Table 6.26).

At posttest, all three dependent variables showed the same pattern of pairwise differences between YTG and YCG; between YTG and ECG; between ETG and YCG, and between ETG and ECG for the non-dominant leg. The results demonstrated that both the trained young and elderly groups improved significantly in OS, MLS, and APS after completing the multisensory training intervention when compared with both the untrained young and elderly groups. The results indicate that the degree of improvement was significant enough to differentiate the trained (YTG and ETG) and untrained groups (YCG and ECG) for the non-dominant leg.

None of the three dependent variable means were significantly different between YTG and ETG ($p = 0.382$; $p = 0.099$; $p = 0.322$, respectively), and between YCG and ECG ($p = 0.982$; $p = 0.433$; $p = 0.948$, respectively) on their posttest values in percentage of change for the non-dominant leg (Table 6.26).

Table 6.26: Tukey's HSD Multiple Comparisons at Posttest (in percentage of change) for Non-dominant Leg across the Four Study Groups

Dependent Variable	Main Group (MG)	Comparison Group (CG)	Mean Difference (MG - CG) [a]	Sig.*
Overall Sway	Young Training	Young Control	-35.30	0.000*
		Elderly Control	-37.62	0.000*
		Elderly Training	10.01	0.382
	Young Control	Elderly Control	2.32	0.982
	Elderly Training	Young Control	-45.31	0.000*
		Elderly Control	-47.63	0.000*
Medial-lateral Sway	Young Training	Young Control	-23.96	0.000*
		Elderly Control	-31.97	0.000*
		Elderly Training	12.44	0.099
	Young Control	Elderly Control	-8.01	0.433
	Elderly Training	Young Control	-36.41	0.000*
		Elderly Control	-44.42	0.000*
Anterior-posterior Sway	Young Training	Young Control	-40.61	0.000*
		Elderly Control	-36.97	0.000*
		Elderly Training	11.61	0.322
	Young Control	Elderly Control	3.64	0.948
	Elderly Training	Young Control	-52.22	0.000*
		Elderly Control	-48.58	0.000*

* *Significant*

[a] *Negative values indicate greater improvement for the main group*

Despite the greater percentage of improvement obtained by ETG for OS, MLS, and APS (33.48%, 29.06%, and 36.05%, respectively) when compared with YTG (23.47%, 16.62%, and 24.45%, respectively) for the non-dominant leg, the results demonstrated that there were no significant differences in postural sway control improvement or in the percentage of change at posttest between ETG and YTG. As for YCG and ECG, the pattern of pairwise differences for the pretest and posttest values remained consistent, noting no significant differences for OS, MLS, and APS between both untrained groups in comparison with pretest and posttest values for the non-dominant leg (refer to Table 6.26).

Table 6.27 presents the percentage of change at posttest across four study groups for the non-dominant leg. The observed effect sizes and power after the fact were calculated. The large observed effect sizes for OS, MLS, and APS ($f = 0.676$, $f = 0.677$, and $f = 0.675$, respectively) indicate that the findings were clinically significant difference. This study obtained power after the fact of 100% for all three postural sway measures for the non-dominant leg.

Table 6.27: MANOVA Summary Table for Percentage of Change at Posttest for Non-dominant Leg across the Four Study Groups

Group	Overall Sway		Medial-lateral Sway		Anterior-posterior Sway	
YCG	M±SD	11.83 ± 10.97	M±SD	7.35 ± 11.41	M±SD	16.16 ± 17.15
	Min.	2.24	Min.	33.93	Min.	0.54
	Max.	35.15	Max.	-8.64	Max.	60.80
	Med.	6.48	Med.	4.18	Med.	8.95
	SEM	3.17	SEM	3.29	SEM	4.95
	95% CI	4.86 – 18.80	95% CI	0.10 – 14.60	95% CI	5.27 – 27.06
YTG	M±SD	-23.47 ± 9.71	M±SD	-16.62 ± 7.70	M±SD	-24.45 ± 10.32
	Min.	-5.58	Min.	-3.88	Min.	-1.56
	Max.	-39.57	Max.	-29.70	Max.	-42.00
	Med.	-21.40	Med.	-16.23	Med.	-25.36
	SEM	2.80	SEM	2.22	SEM	2.98
	95% CI	(-17.30) – (-29.64)	95% CI	(-11.73)–(-21.50	95% CI	(-17.89)– (-31.01)
ECG	M±SD	15.86 ± 12.46	M±SD	15.36 ± 11.24	M±SD	12.53 ± 14.29
	Min.	42.79	Min.	33.53	Min.	51.42
	Max.	-1.66	Max.	-0.57	Max.	-0.08
	Med.	9.68	Med.	13.27	Med.	8.99
	SEM	3.60	SEM	3.24	SEM	4.13
	95% CI	7.96 – 23.79	95% CI	8.22 – 22.49	95% CI	3.45 – 21.61
ETG	M±SD	-33.48 ± 22.59	M±SD	-29.06 ± 18.68	M±SD	-36.05 ± 21.89
	Min.	-4.05	Min.	-7.98	Min.	-2.15
	Max.	-75.96	Max.	-70.79	Max.	-71.78
	Med.	-33.90	Med.	-23.20	Med.	-34.41
	SEM	6.25	SEM	5.39	SEM	6.32
	95% CI	(-19.13) – (-47.84)	95% CI	(-17.19)–(-40.93)	95% CI	(-22.14)– (-49.96)
F Test *p-value*	*F=30.651* *p=0.000 **		*F=30.781* *p=0.000 **		*F=30.447* *p=0.000 **	
Effect Size	*f* = 0.676		*f* = 0.677		*f* = 0.675	
Power	1.000		1.000		1.000	

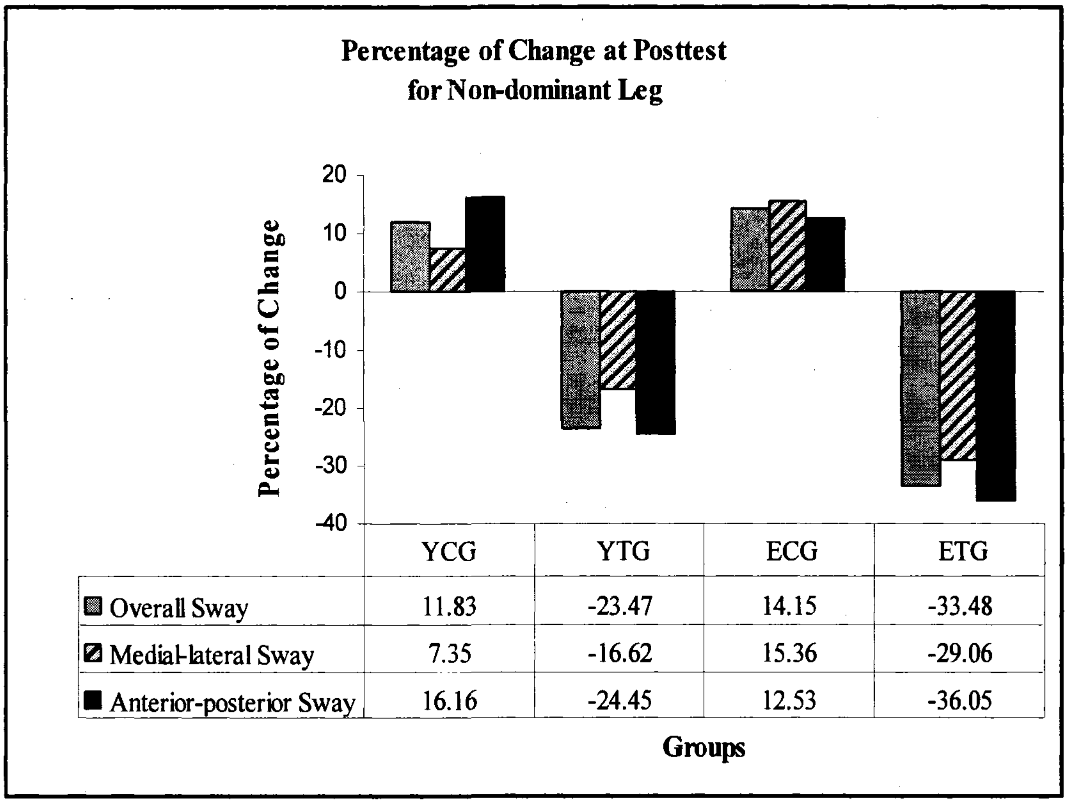
** Significant*

The F test determines the effect on the group. This test is based on the linearly independent pairwise comparisons among the estimated marginal means

Negative values indicating improvement / sway reduced

Abbreviation= YCG: Young Control Group; YTG: Young Training Group;
ECG: Elderly Control Group; ETG: Elderly Training Group;
Min.: Minimum; Max.: Maximum; Med.: Median

Figure 6.6 depicts the comparison across the four study groups (YCG, YTG, ECG, and ETG) for overall sway, medial-lateral sway, and anterior-posterior sway measures in comparison with mean differences in percentage of change at posttest for the non-dominant leg.



	YCG	YTG	ECG	ETG
▦ Overall Sway	11.83	-23.47	14.15	-33.48
▨ Medial-lateral Sway	7.35	-16.62	15.36	-29.06
■ Anterior-posterior Sway	16.16	-24.45	12.53	-36.05

Figure 6.6: Percentage of change at posttest for overall sway, medial-lateral sway, and anterior-posterior sway for each group on the training for the non-dominant leg. Lower or negative values represent a decrease in sway, thus improvements in postural sway control (i.e. YTG and ETG). Positive values indicate an increase in sway, therefore a decrement of postural sway control (i.e. YCG and ECG).

6.1.4 Summary Findings for Hypothesis 1

In summary, both the training groups (YTG and ETG) reduced the amount of sway on all three postural sway measures (OS, MLS, and APS) after the three-week multisensory training program, indicating that postural sway control improved significantly at posttest compared to the pretest at $p \leq 0.000$ for all six different training factors (i.e. static balance with the eyes-closed condition, dynamic balance with the eyes-open condition, bilateral stance, unilateral stance, dominant leg, and non-dominant leg) in contrast to both the control groups (untrained YCG and ECG).

The researcher is 95% confident that true improvements occurred for both YTG and ETG because the 95% confidence intervals of the pretest values for both YTG and ETG did not overlap with the 95% confidence intervals of the posttest values for all three postural sway measures for all training factors. However, the 95% confidence intervals of the pretest values for both YCG and ECG did overlap with 95% confidence intervals of the posttest values for all three postural sway measures for all training factors. Therefore, the observed differences between the training groups (i.e. YTG and ETG) and the control groups (i.e. YCG and ECG) were "real" or the likelihood that the differences were due to chance was very small.

The sway dispersions of ETG at pretest were significantly greater (i.e. poorer postural sway control performance) for all three postural sway measures for all six training factors when compared to the pretest scores of ECG, YCG, and YTG. It is noteworthy that the ETG did successfully improve their posttest values of all three postural sway measures to be almost identical to the pretest values of both the YTG and YCG after completing the training program. The results indicate that this three-week multisensory training program successfully trained the ETG (age range: 60 to 80 years) to have the same performance in postural sway control as the young (age range: 20 to 49 years) non-injured females.

Clinical significance refers to the magnitude of the effect. In the absence of pilot data for this kind of study, the population effect size was unknown. Indeed, the effect size employed in a power analysis was a theoretical value, and should be the smallest effect that would be important to detect change and to be meaningful. The effect size measures the magnitude of a treatment effect. [192] It is simply a way of quantifying the size of the difference between two groups, [193] the researcher estimated that an effect size performed prior to the research smaller than 0.35 would not be clinical important in this context. It is important to note that the present results not only revealed statistical significance ($p \leq 0.000$), they were clinically significant in improving postural sway measures due to the large observed effect sizes [172] (f ranged from 0.588 to 0.782) of the training. Furthermore, since the power is driven primarily by the effect size, the large observed effect sizes for all three postural sway measures on all six training factors resulted in 100% power after the fact.

The hypothesis 1 stated that there were significant differences across the trained non-injured young (YTG) and elderly (ETG) females on all three postural sway measures after completing the three-week multisensory training program using the CDBS when compared with the untrained non-injured young (YCG) and elderly (ETG) females when considering all six training factors was proven ($p \leq 0.000$).

6.1.5 Differences in Training Effects between Young and Elderly Training Groups

6.1.5.1 Comparison for Types of Balance with the Eyes Condition for Three Postural Sway Measures

The between-subjects factor demonstrated that there were no significant differences between ETG and YTG for OS, MLS, and APS ($F_{1,\,22} = 1.849$, $p=0.188$; $F_{1,\,22} = 1.641$, $p = 0.214$; and $F_{1,\,22} = 1.950$, $p = 0.177$, respectively) for static balance with the eyes-closed condition versus dynamic balance with the eyes-open condition. The within-subjects analysis indicates that the main effects of types of balance with the eyes condition for OS and APS were significant ($F_{1,\,22} = 14.467$, $p = 0.001$, and $F_{1,\,22} = 22.247$, $p = 0.000$, respectively), but the interaction effects were not ($F_{1,\,22} = 0.240$, $p = 0.877$, and $F_{1,\,22} = 0.059$, $p = 0.811$, respetively). For MLS, the main effect of the types of balance ($F_{1,\,22} = 0.083$, $p = 0.056$) and the interaction effect ($F_{1,\,22} = 1.146$, $p = 0.296$) were not significant as can be seen in Table 6.28.

Table 6.28: Summary Table for Two-way ANOVA with One Repeated Measure (Mixed Design) for Overall Sway, Medial-lateral Sway, and Anterior-posterior Sway with Groups (ETG and YTG) and Types of Balance with the Eyes Condition

Overall Sway
Types of Balance with the Eyes Condition : Static Eyes-closed vs. Dynamic Eyes-open

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	224.656	1	224.656	1.849	0.188	0.078	0.255
Error	2673.081	22	121.504				
Within Subjects Balance	7779.976	1	7779.976	14.467	0.001*	0.397	0.953
Group x Balance	13.122	1	13.122	0.024	0.877	0.001	0.053
Error (Balance)	11830.933	22	537.770				

Medial-lateral Sway
Types of Balance with the Eyes Condition : Static Eyes-closed vs. Dynamic Eyes-open

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	192.504	1	192.504	1.641	0.214	0.069	0.232
Error	2580.780	22	117.308				
Within Subjects Balance	1657.872	1	1657.872	4.083	0.056	0.157	0.489
Group x Balance	456.106	1	456.106	1.146	0.296	0.049	0.176
Error (Balance)	8932.346	22	8932.346				

Anterior-posterior Sway
Types of Balance with the Eyes Condition : Static Eyes-closed vs. Dynamic Eyes-open

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	203.634	1	203.634	1.950	0.177	0.081	0.267
Error	2297.768	22	104.444				
Within Subjects Balance	10652.971	1	10652.971	22.247	0.000*	0.503	0.994
Group x Balance	27.876	1	27.876	0.059	0.811	0.003	0.056
Error (Balance)	10445.532	22	474.797				

** Significant*

Sphericity Assumed (means homogeneity of variance): The variance of the differences between different conditions should be equivalent (in the population sampled) in order to produce a more accurate significance (p) value

Figure 6.7 portrays the effectiveness of the three-week multisensory training intervention for OS, MLS, and APS for both ETG and YTG. The ETG obtained greater improvement for all three postural sway measures for both static balance with the eyes-closed condition and dynamic balance with the eyes-open condition when compared to the YTG, but it was not significantly different statistically. The training factor for static balance with the eyes-closed condition indicated significantly greater improvement for OS and APS when compared with the dynamic balance with the eyes-open condition. However, for MLS, the differences in improvement between static balance with the eyes-closed condition and the dynamic balance with the eyes-open condition did not reach statistical significance.

6.1.5.2 Comparison for Types of Stance for Three Postural Sway Measures

The between-subjects factor demonstrated that there were no significant differences between ETG and YTG for OS, MLS, and APS ($F_{1,22} = 1.628$, $p = 0.215$; $F_{1,22} = 1.980$, $p = 0.173$; and $F_{1,22} = 1.953$, $p = 0.176$, respectively) for bilateral stance versus unilateral stance. The within-subjects analysis indicates that the main effects of types of stance and the interaction effects for OS ($F_{1,22} = 0.968$, $p = 0.336$, and $F_{1,22} = 0.231$, $p = 0.635$, respectively), MLS ($F_{1,22} = 1.131$, $p = 0.299$, and $F_{1,22} = 0.264$, $p = 0.612$, respectively), and APS ($F_{1,22} = 0.791$, $p = 0.383$, and $F_{1,22} = 0.661$, $p = 0.425$, respectively) were not significant as shown in the Table 6.29.

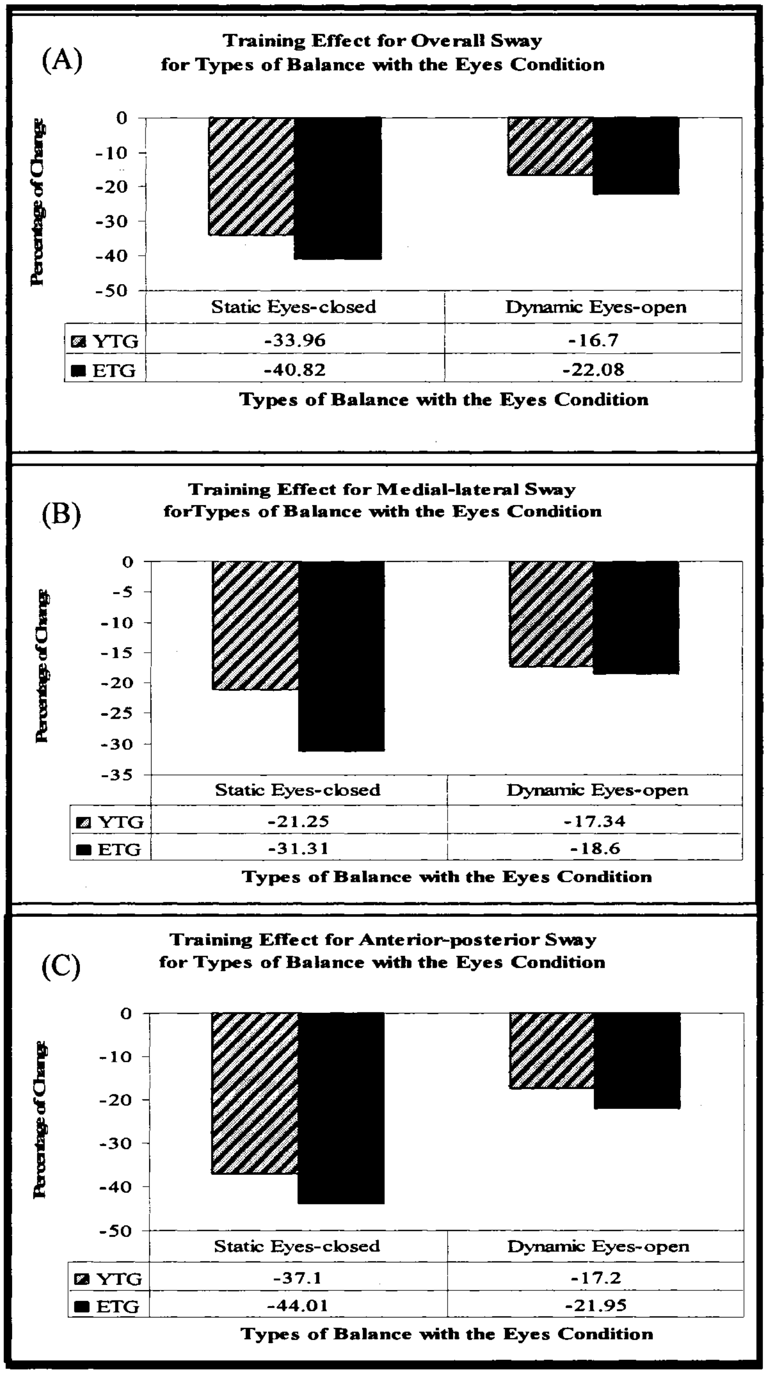


Figure 6.7: Greater percentage of change for overall sway (A), medial-lateral sway (B), anterior-posterior sway (C) for the elderly training group on training effect for types of balance with the eyes condition when compared to the young training group. However, the differences were not statistically significant. Negative values represent a decrease in sway. Lower negative values (e.g. -50) indicate greater improvements in postural sway control compared with higher negative values (e.g. -10).

Table 6.29: Summary Table for Two-way ANOVA with One Repeated Measure (Mixed Design) for Overall Sway, Medial-lateral Sway, and Anterior-posterior Sway with Groups (ETG and YTG) and Types of Stance

Overall Sway
Types of Stance : Bilateral Stance vs. Unilateral Stance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	221.947	1	221.947	1.628	0.215	0.069	0.231
Error	2998.510	22	136.296				
Within Subjects Stance	552.640	1	552.640	0.968	0.336	0.042	0.156
Group x Stance	132.108	1	132.108	0.231	0.635	0.010	0.075
Error (Stance)	12556.035	22	570.729				

Medial-lateral Sway
Types of Stance : Bilateral Stance vs. Unilateral Stance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	257.847	1	257.847	1.980	0.173	0.083	0.270
Error	2865.139	22	130.234				
Within Subjects Stance	454.075	1	454.075	1.131	0.299	0.049	0.174
Group x Stance	105.975	1	105.975	0.264	0.612	0.012	0.078
Error (Stance)	8829.629	22	401.347				

Anterior-posterior Sway
Types of Stance : Bilateral Stance vs. Unilateral Stance

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	436.713	1	436.713	1.953	0.176	0.082	0.267
Error	4920.391	22	223.654				
Within Subjects Stance	221.748	1	221.748	0.791	0.383	0.035	0.136
Group x Stance	185.037	1	185.037	0.661	0.425	0.029	0.122
Error (Stance)	6156.888	22	279.859				

** Significant*

Sphericity Assumed (means homogeneity of variance): The variance of the differences between different conditions should be equivalent (in the population sampled) in order to produce a more accurate significance (p) value

Figure 6.8 portrays the effectiveness of the three-week multisensory training intervention for OS, MLS, and APS for both ETG and YTG in comparison with mean differences in percentage of change for the two types of stance (i.e. bilateral stance and unilateral stance). The ETG obtained greater improvement for OS, MLS, and APS for the bilateral stance and the unilateral stance when compared to YTG, but the differences in improvements did not reach statistical significance. The training factor for bilateral stance indicated greater improvement for OS and APS when compared with unilateral stance, however, the differences did not show statistical significance. For MLS, the unilateral stance gained greater improvement when compared to the bilateral stance, but it did not show a statistically significant difference.

6.1.5.3 Comparison for Types of Leg Dominance for Three Postural Sway Measures

The between-subjects factor demonstrated that there were no significant differences between ETG and YTG for OS, MLS, and APS ($F_{1,22} = 1.363, p = 0.256$; $F_{1,22} = 1.812, p = 0.192$; and $F_{1,22} = 2.265, p = 0.147$, respectively) for dominant leg versus non-dominant leg. The within-subjects analysis indicates that the main effect of types of leg dominance and the interaction effect for OS were not significant ($F_{1,22} = 0.000, p = 0.986$, and $F_{1,22} = 0.283, p = 0.600$, respectively), as well as for MLS ($F_{1,22} = 1.871, p = 0.185$, and $F_{1,22} = 3.085, p = 0.093$, respectively), and for APS ($F_{1,22} = 0.108, p = 0.746$, and $F_{1,22} = 0.161, p = 0.692$, respectively) as shown in the Table 6.30.

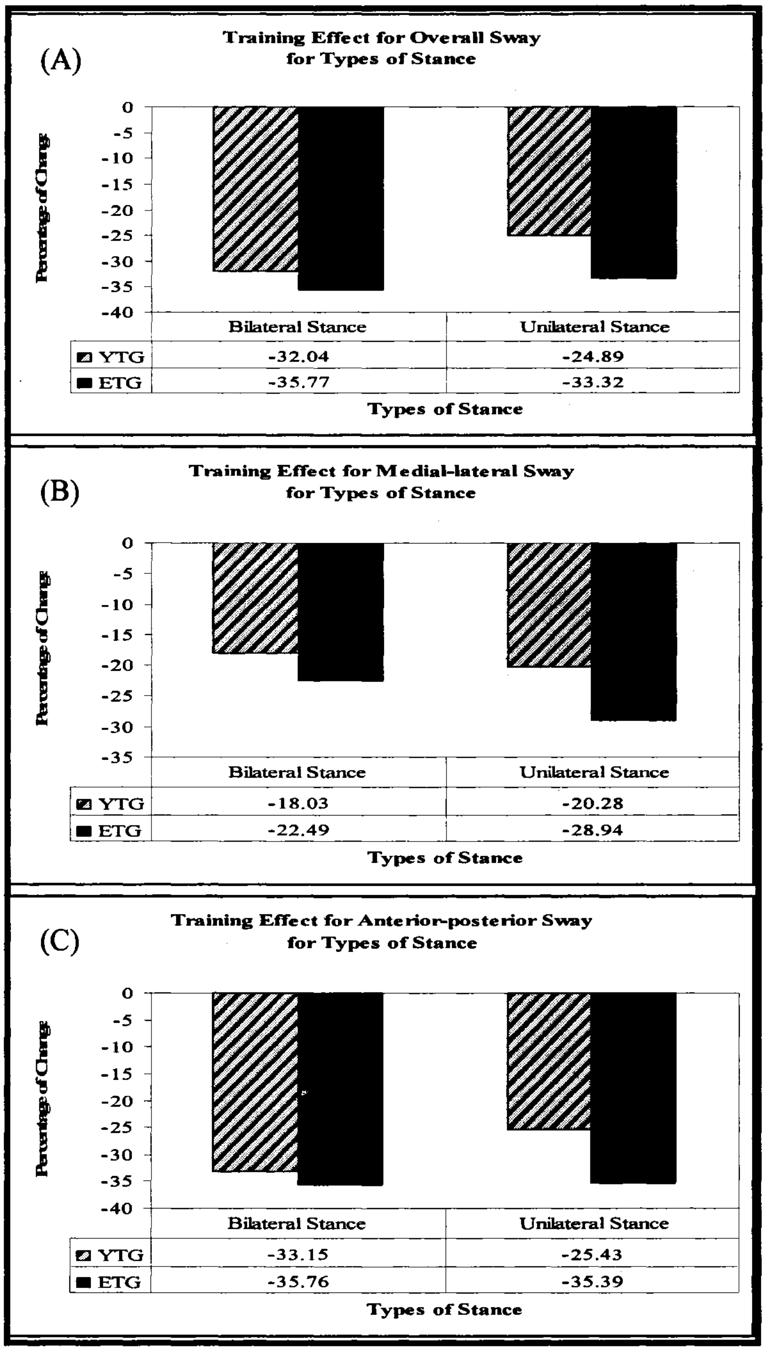


Figure 6.8: Greater percentage of change for overall sway (A), medial-lateral sway (B), anterior-posterior sway (C) for the elderly training group on training effect for types of stance when compared to the young training group. However, the differences were not statistically significant. Negative values represent a decrease in sway. Lower negative values (e.g. -40) indicate greater improvements in postural sway control compared with higher negative values (e.g. -10).

Table 6.30: Summary Table for Two-way ANOVA with One Repeated Measure (Mixed Design) for Overall Sway, Medial-lateral Sway, and Anterior-posterior Sway with Groups (ETG and YTG) and Types of Leg Dominance

Overall Sway
Types of Leg Dominance : Dominant Leg vs. Non-dominant Leg

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	425.546	1	425.546	1.363	0.256	0.058	0.201
Error	6870.370	22	312.290				
Within Subjects Leg Dominance	0.072	1	0.072	0.000	0.986	0.000	0.050
Group x Leg Dominance	60.506	1	60.506	0.283	0.600	0.013	0.080
Error (Leg Dominance)	4711.239	22	214.147				

Medial-lateral Sway
Types of Leg Dominance : Dominant Leg vs. Non-dominant Leg

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	450.370	1	450.370	1.812	0.192	0.076	0.251
Error	5468.658	22	248.575				
Within Subjects Leg Dominance	207.865	1	207.865	1.871	0.185	0.078	0.258
Group x Leg Dominance	342.849	1	342.849	3.086	0.093	0.123	0.390
Error (Leg Dominance)	2444.144	22	111.097				

Anterior-posterior Sway
Types of Leg Dominance : Dominant Leg vs. Non-dominant Leg

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Effect Size	Power
Between Subjects Group	643.105	1	643.105	2.265	0.147	0.093	0.302
Error	6246.021	22	283.910				
Within Subjects Leg Dominance	25.124	1	25.124	0.108	0.746	0.005	0.061
Group x Leg Dominance	37.674	1	37.674	0.161	0.692	0.007	0.067
Error (Leg Dominance)	5134.882	22	233.404				

** Significant*

Sphericity Assumed (means homogeneity of variance): The variance of the differences between different conditions should be equivalent (in the population sampled) in order to produce a more accurate significance (p) value

Figure 6.9 portrays the effectiveness of the three-week multisensory training intervention for OS, MLS, and APS for both ETG and YTG in comparison with mean differences in percentage of change for the two types of leg dominance (i.e. dominant leg and non-dominant leg). The ETG obtained greater improvement for OS, MLS, and APS for dominant leg and non-dominant leg when compared to YTG, but the difference did not reach statistical significance. Likewise, the training factor for non-dominant leg indicated greater improvement for OS and APS when compared with the dominant leg, however, it was not statistically significant. In contrast, for MLS, the dominant leg indicated greater improvement when compared with the non-dominant leg, but the differences did not reach statistical significance.

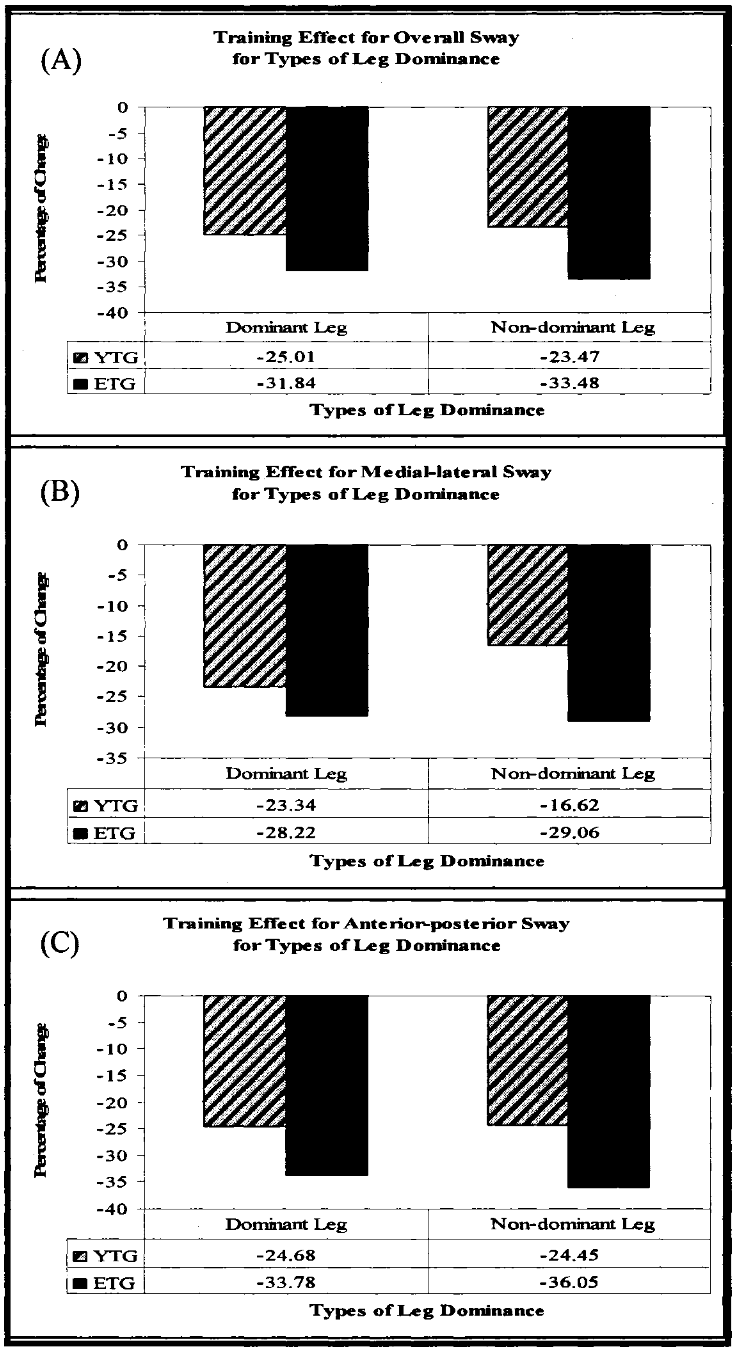


Figure 6.9: Greater percentage of change for overall sway (A), medial-lateral sway (B), anterior-posterior sway (C) for the elderly training group on training effect for types of leg dominance when compared to the young training group. However, the differences were not statistically significant. Negative values represent a decrease in sway. Lower negative values (e.g. -30) indicate greater improvements in postural sway control compared with higher negative values (e.g. -5).

6.1.6 Summary Findings for Hypothesis 2

In summary, the elderly training group (ETG) obtained greater improvement by gaining a greater percentage of change on all three postural sway measures of OS, MLS, and APS in comparison to the young training group (YTG) on all three training factors (two levels each) of: a) types of balance with the eyes condition, b) types of stance, and c) types of leg dominance, after the three-week multisensory training intervention. However, the differences in improvement for all three postural sway measures on all training factors between ETG and YTG were not statistically significant nor clinically significant (i.e. effect sizes < 0.35).

It is interesting to note that the three-week multisensory training intervention revealed a trend of reducing all three postural sway measures for all training factors for both ETG and YTG. However, when comparing the degree of improvement across the types of balance with the eyes condition, types of stance, and types of leg dominance, the percentage of change did not show significant differences between bilateral stance and unilateral stance, and between dominant leg and non-dominant leg. In contrast, the types of balance with the eyes condition demonstrated that the static balance with the eyes-closed condition obtained significantly greater improvements for OS and APS when compared with the dynamic balance with the eyes-open condition for both training groups (i.e. ETG and YTG).

The hypothesis 2 expected a significantly greater percentage of improvement on the trained elderly females (ETG) when compared with the trained young females (YTG) for all three postural sway measures on all six training factors. This was not supported.

6.1.7 Training Effect on the Berg Balance Test (BBT)

As shown in Table 6.31, the descriptive statistics for the pretest and posttest values of the total BBT scores between ETG and ECG were reported with means (M) and standard deviations (SDs), standard error of measurements (SEMs), and 95% confidence intervals (CI). At pretest, the BBT mean scores for ECG and ETG were 53 and 52.67, respectively. After completing the three-week multisensory training program, at posttest, the BBT mean score for ETG was 55.25. However, for the ECG who received no training, the BBT mean score at posttest remained the same as at pretest (i.e. 53).

Table 6.31 : Descriptive Statistics for Pretest and Posttest and *t*-statistic for the Berg Balance Test Scores before and after the Three-week Multisensory Training Program between the Elderly Control Group and the Elderly Training Group.

The Berg Balance Test Scores						
Time	**ECG (N=12)**		**ETG (N=12)**		***t***	***p***
Before (Pretest)	M±SD	53.00 ± 1.54	M±SD	52.67 ± 2.77	0.364	0.719
	Min.	50.00	Min.	48.00		
	Max.	55.00	Max.	56.00		
	Med.	53.00	Med.	53.00		
	SEM	0.44	SEM	0.80		
	95% CI	52.02 – 53.98	95% CI	50.90 – 54.43		
After (Posttest)	M±SD	53.00 ± 1.54	M±SD	55.25 ± 1.14	- 4.075	0.001*
	Min.	50.00	Min.	53.00		
	Max.	55.00	Max.	56.00		
	Med.	53.00	Med.	56.00		
	SEM	0.44	SEM	0.33		
	95% CI	52.02 – 53.98	95% CI	54.53 – 55.97		

* *Significant*

Observed t (22) ≥ ± 2.074 to reject Ho

Abbreviation= ECG: Elderly Control Group; ETG: Elderly training Group
Min.: Minimum; Max.: Maximum; Med.: Median

An independent *t*-test was utilized to analyze this pretest-posttest design study where there were only two groups (ETG and ECG) and two measurements (pretest and posttest) for each subject. A two-tailed test was used with $\alpha = 0.05$. Two separate *t*-tests were conducted on the pretest and posttest data. The results demonstrated that the differences in the BBT scores between ECG and ETG at pretest were not statistically significant [$t\ (22) = 0.364$, $p \leq 0.719$]. However, after completing the three-week multisensory training intervention, the ETG revealed a significantly greater change (i.e. improvement) when compared to the ECG in the BBT scores (55.25 and 53, respectively), indicating that the training conditions had led to an increase in total BBT scores [$t\ (22) = -4.075, p \leq 0.001$].

The researcher can conclude with 95% confident that a true improvement occurred in ETG because the 95% confidence interval of the BBT scores at pretest for ETG did not overlap with the 95% confidence interval at posttest. However, the 95% confidence interval of the BBT scores at pretest for the ECG did overlap with the 95% confidence interval at posttest. Therefore, the observed difference between the elderly trained group (ETG) and the elderly untrained group (ECG) was "real" or the likelihood that the difference was due to chance was very small.

It is interesting to note that the effect size observed in this study was large (i.e. $d = 1.74$), indicating the improvement was clinically significant with power after the fact of 99.99%. Although it was beyond the scope of this study to determine the test-retest reliability of the BBT scale, test-retest reliability of the BBT scale was conducted on the pretest and posttest values (three weeks apart) of the ECG to ensure the reproducibility of measurements over time. The results indicate that the BBT scale obtained high test-retest reliability of ICC = 1.00 (i.e. ECG scored 53 for both pretest and posttest sessions).

Figure 6.10 depicts the effectiveness of the three-week multisensory training program shown on the Berg Balance Test (BBT) for both ETG and ECG when comparing the pretest and posttest values. Both ECG and ETG were similar at pretest, but the ETG demonstrated significant improvement on the BBT scores at posttest after training when compared with the ECG who received no training.

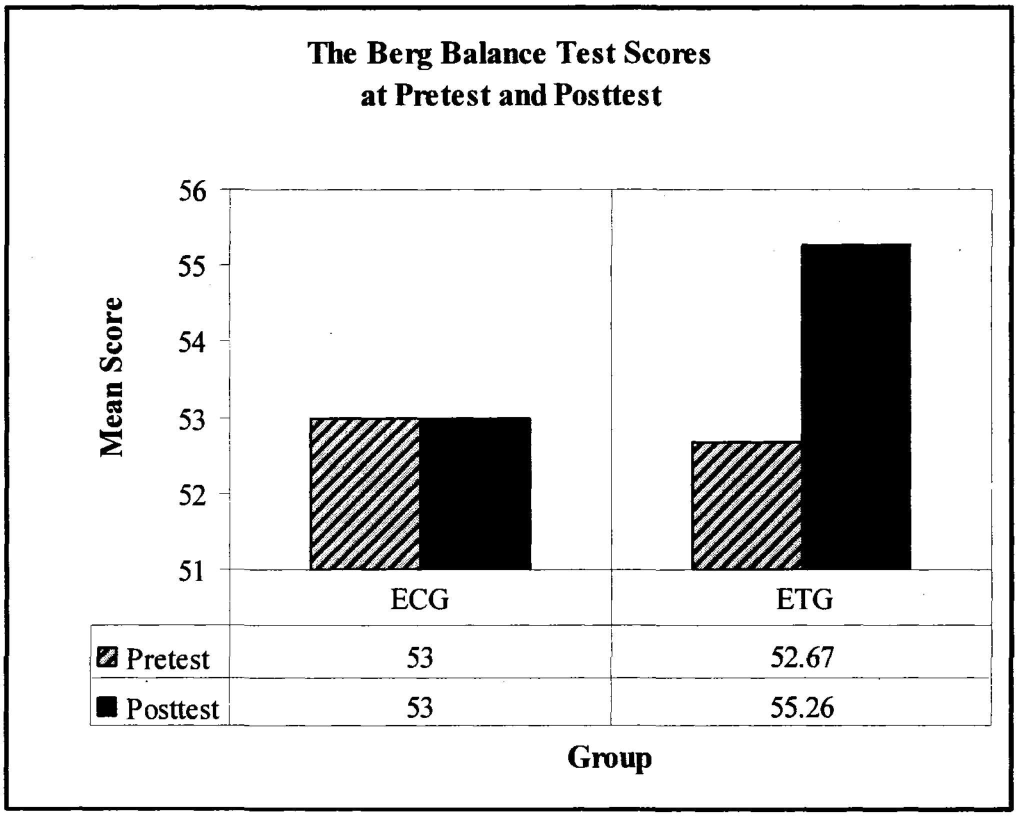


Figure 6.10: The Berg Balance Test scores for pretest and posttest between the elderly training group (ETG) and the elderly control group (ECG).

6.1.8 Summary Findings for Hypothesis 3

In summary, the findings of this study demonstrate that the trained ETG improved in their total BBT scores at posttest after the three-week multisensory training intervention when compared with the untrained ECG. The improvement of the ETG on the BBT scores after training showed significant differences statistically ($p \leq 0.001$) when compared with the ECG who received no training on the CDBS. The improvement on the BBT scores showed clinically significant differences as well (i.e. large effect size d = 1.704). The BBT scale showed a high test-retest reliability of ICC = 1.00. In addition, this study revealed a high power after the fact of 99.99%.

Therefore, the researcher can conclude with 95% confident that the improvement of ETG was true, and the possibility of the results being due to chance was slim. Thus, the hypothesis 3 was proven by the positive results of the present study with a $p \leq 0.001$.

6.2 DISCUSSIONS

6.2.1 Differences in Training Effects across the Four Study Groups

This study was designed to explore whether a three-week multisensory training program would affect the ability to minimize postural sway control in non-injured young and elderly females. This randomized control trial study used the pretest-posttest control group design. Since volunteers were randomly assigned to the training groups (YTG and ETG) and the control groups (YCG and ECG), it was expected that both YCG and YTG, and both ECG and ETG would reflect similar pretest results in their own aged group. Overall, the YTG was not different from the YCG with respect to age, weight, height, BMI, active level, and pretest values. Likewise, there were no significant differences between ETG and ECG from their personal characteristics and pretest values. In addition, both the elderly groups demonstrated similar pretest results on the BBT scores, indicating that they were equivalent prior to the three-week multisensory training intervention.

This is the first intervention trial to demonstrate improvements in postural sway control in non-injured young and elderly females with exercise training. On average, the young trained females improved (range from 16.62% to 37.10%) for all three postural sway measures on all six training factors. The highest improvement of this young training group reached as high as 62% improvement and the median of improvement ranged from 15% to 18% on postural sway measures. In comparison, the elderly training group also improved (range from 18.60% to 44.01%) for all three postural sway measures on all six training factors. The maximum improvement of the elderly group was 82.61% and the median of improvement ranged from 17% to 42% on postural sway measures. Although the greater improvements (on average 1.26% to 12.44%) demonstrated by the ETG did not reach statistical significance compared with the YTG, it is noteworthy that the ETG successfully improved their posttest values of postural sway measures so that the values were almost identical to pretest values of both YTG and YCG. This three-week multisensory training program successfully trained the ETG (age range: 60 to 80 years) having the same performance in all three postural sway measures as the young (age range: 20 to 49 years) non-injured females. In contrast, the pretest and posttest values for both the young and elderly control groups did not show significant differences. Therefore, the first hypothesis that there would be significant differences in postural sway measures after training intervention when considering all six training factors across young (YTG) and elderly (ETG) trained groups and young (YCG) and elderly (ECG) untrained groups was accepted.

The results of this study revealed a significant training effect in the reduction of all three postural sway measures as a result of the three-week multisensory training intervention. The training program was conducted to reduce the sensory information by altering more than one of the sensory systems. The postural sway control not only depends on somatosensory information but also on vestibular and visual cues. Therefore, measurements in this study included the eyes-closed and the eyes-open conditions, where the eyes-closed condition was included to rule out any visual cues that might aid postural control. Furthermore, some researchers suggest that when a person stands on a moving platform, the somatosensory feedback that they are receiving is changed in a way to make it less sensitive. [159,194] The visual information remains unperturbed but there is a mismatch between the amount of visual flow and the corresponding somatosensory feedback. Thus, for a given amount of visual flow, the CNS is not receiving the usual or expected somatosensory feedback making the integration of the two sources of feedback more attentionally demanding. [194]

In the present investigation, for the eyes-closed condition, the visual inputs were fully eliminated by blindfolding. The somatosensory inputs were partially altered by using a unilateral stance and a moving platform (i.e. moving up and down). The vestibular inputs were modified using a moving platform with different movements.

Sensory Systems	**Training Protocols used for Elimination or Alteration of Sensory Systems**
Visual Input	Fully eliminated by eyes-closed and blindfolding.
Somatosensory Input	Partially altered by unilateral stance and moving platform.
Vestibular Input	Modified by moving platform with different movements.

This suggests that when the sensory information from visual inputs was eliminated (i.e. the eyes-closed condition) and / or the somatosensory inputs from the ankles and feet were manipulated (i.e. the unilateral stance and a moving platform), both YTG and ETG were able to improve all postural sway measures (i.e. OS, MLS, and APS) significantly following the training regimen. The positive training effects suggested that the vestibular and somatosensory systems were able to fully compensate for the loss of visual inputs (i.e. for the eyes-closed condition) in the maintenance of balance and postural sway control. On the other hand, with the eyes-open condition, the visual inputs remained available but both vestibular and somatosensory inputs were minimized by setting the platform to various moving patterns and / or to a unilateral stance for the dynamic balance. The improved training effects showed that sensory information from the visual inputs could successfully compensate for the altered somatosensory and vestibular inputs.

The YTG and ETG showed significant improvements as compared to the control groups (YCG and ECG) for all postural sway measures (i.e. OS, MLS, and APS) for all six training factors. These findings suggest that the three-week multisensory training program could be used to improve the postural responses for altered visual inputs (i.e. the eyes-closed condition), modified vestibular inputs (i.e. the moving platform), and manipulated somatosensory inputs (i.e. the unilateral stance and moving platform). The positive training effects suggest that multisensory training program could be generalized to an overall improvement in postural sway control. These improvements could be the accumulated effects of changes in several neural mechanisms underlying balance function. The first possible mechanism for improvement is increased sensitivity at the receptor level in the visual, somatosensory, or vestibular sensory systems. [159] This was possible for the vestibular and the somatosensory receptors due to the unusual stimulation caused by the variety of platform movements during training. However, this mechanism cannot serve to explain the improvement in postural sway control under training conditions with the eyes-closed. Therefore, other mechanisms may be involved.

The second possible mechanism for improved postural sway control is enhanced inter-sensory interactions and sensorimotor integration in the central nervous system. In the postural system model, balance skill training mainly affects the sensorimotor feedback pathway. [2] Since postural sway control significantly improved for the training conditions that required sensory interactions, processing improvement within the central integration mechanism is the underlying mechanism that is likely to have been responsible for balance improvement following training. [2,159,195] The improvements were likely to be the result of the increased use of somatosensory, visual and vestibular information when performing the various training protocols under sensory deprivation conditions. Sensory feedback originating from the visual, vestibular, and somatosensory systems provides variable contributions to the maintenance of balance appropriate for the environmental context. The sensitivity of sensory feedback and compensation might have improved sensorimotor integration of postural sway control in the central nervous system, serving to activate and coordinate motor processes (e.g. action of the proper muscles synergies). [45,159,195] In addition, several researchers also noted that balance improved more after rehabilitation with visual deprivation than with free vision in stroke subjects. [195,196] These results suggest that enhanced multisensory interaction resulting from sensory training could improve the sensorimotor integration of postural control. This is in agreement for the current findings. The third possible mechanism for these improvements is that the trained subjects were able to compare, select, and combine reliable sensory information for postural control more efficiently following the multisensory training. [45,159,195,196]

An additional body system that contributes to balance control is the musculoskeletal system (i.e. muscle strength). Many studies reported that muscle strength decreases significantly with age. [156-158] Several authors have stated that postural sway is primarily controlled by ankle dorsiflexion strength. [134,156,157] They found that ankle dorsiflexion strength was most severely impaired in elderly with a history of falls. [134,156,157] Therefore, the fourth possible mechanism for improvements is increased endurance and strength of the leg muscles involved during training. Looking at the remarkable improvements gained by the elderly training group, showing their postural sway measures were reduced to the same performance level of young female adults, suggests that the three-week multisensory training program may have improved the muscle strength, especially of the ankle dorsiflexors in the elderly training females. However, ankle dorsiflexion strength was not measured in this study, this effect can only be postulated at this time, and is an area that requires further study. Likewise, the training of postural sway control may be effective in increasing the onset latency for the tibialis anterior muscles of the elderly training group. The underlying mechanisms, however, remain to be determined.

At the beginning of the training period (the first three sessions), the majority of subjects demonstrated signs of fatigue during the sessions, and they required longer and more frequent resting periods, especially the elderly group. By the fourth training session, the majority of subjects indicated less fatigue and was able to fulfill all training protocols with ease. All of the young and elderly trained females performed all of the evaluation protocols easily during the posttest evaluation. They expressed that after being trained four minutes standing erect on each training protocol for every session over the three weeks, the 10-second evaluation protocols became a minimal challenge when compared to the pretest evaluation. This might be due the enhanced endurance and strength of leg muscles involved, that allowed them to accomplish the task efficiently. However, previous training programs based upon endurance physical exercises have not consistently demonstrated improvement in the postural sway control of their subjects.[197,198] Furthermore, Barrett [199] suggested that limb function relies more on somatosensory input than strength during activity. Therefore, in the current study, the possibility of improvement for postural sway control was due to improved endurance or to repetitions of muscle contractions (strength) requires further investigation.

6.2.2 Training Effects between the Young and the Elderly Training Groups

According to the literature, postural sway increases with aging. Older adults have more difficulty balancing when sensory inputs contributing to balance and postural control are reduced, so that they have less redundancy of sensory information. Thus, when both visual and somatosensory inputs are made incongruent with postural sway, the older adults show significant increases in sway compared with young adults, and many older adults lose balance completely. [2,111,151,152,157] Deterioration of postural control ability is believed to be a key factor in falls and other mobility problems in the elderly. Previous studies have noted the important connection between postural stability and the ability to avoid falls. [150,151,157] They showed that postural sway during quiet stance is larger in elderly adults when compared to young adults, and larger in elderly adults with a history of falls compared to elderly adults without a fall history.

Because of the physiological changes that are known to occur in aging (e.g., deterioration of visual, vestibular, and proprioceptive functions; reduction in muscle strength; decrease in nerve conduction velocity; and deterioration in balancing synergies), one would expect to find age-related differences in postural sway control. [20,45,53,150,157,200,201] In general agreement with these findings, the present experimental results did, in fact, demonstrate highly significant differences between young and elderly normal adult females, indicating that more sway in the elderly at pretest. This agrees with previous findings that older subjects sway significantly more than young subjects do, when there is an increased reliance on the visual and vestibular inputs, with the other sensory inputs reduced and / or distorted. [161,202] Such an increase in sway is thought to be attributable to the different degrees of deterioration that can occur with aging in the somatosensory, visual, and vestibular systems responsible for postural sway control and functional balance ability. [20,52,143]

Interestingly, this relationship was observed or supported by the results of the present study. The findings that postural sway increases with age (ETG had greater sway at pretest when compared to both YCG and YTG in current study) was consistent with previous research findings on standing body sway using other systems and measurement techniques, even when the subject inclusion criteria was adhered to strictly. [5,20,43,52,141,161,203]

In a study on normal adults, Brandt et al. [131] noted that one has greater initial risk of falling, the greater the percent reduction in sway amplitudes with training. The elderly group had greater initial risk of falling due to natural aging process, thus it was expected that the elderly group would have more room to improve when compared with the young group. For current study, it was hypothesized that the ETG would gain greater improvement for their postural way control through a balance training program when compared with the YTG. This second hypothesis was rejected. Although the differences in the improvement between YTG and ETG were not statistically significant nor clinically significant (i.e. effect sizes $f < 0.35$), it is worthwhile mentioning the improvements of ETG were in the range of 1.26% to 12.44% greater than YTG. The potential explanation for the lack of a significant difference between YTG and ETG could have been due to the large standard deviation obtained by the ETG. The large standard deviation indicated that there was greater variability among the elderly trained subjects. This finding is consistence with the results of Biaszczyk and colleagues, [204] and Woollacott et al. [157] who reported that elderly individuals demonstrated greater variability in sway when compared to younger individuals.

It is interesting to note that the ETG began this study with poorest performance level at pretest on all three postural sway measures on all six training factors among all study groups. However, after completing the training program, at posttest, they improved to the same performance level as at pretest for both the YTG and the YCG. The similarity of posttest scores for postural sway measures of the ETG with pretest scores for both the YCG and the YTG, indicates that the three-week multisensory training program produced a greater training effect for the elderly training females. The three-week multisensory training program successfully enhanced the elderly training females' capability to reduce postural sway to the same extent as young females, in both the control and training groups. It is important to state that the current study is the first study that successfully trained non-injured elderly females (60 to 80 years of age) to have the same performance level as non-injured young females (20 to 49 years of age) on postural sway measures.

In the current study, the training program focused in improving the acuity and integration ability of the sensory systems, improving the awareness of the mechanoreceptors, effectiveness of the motor system, and vigilance especially for older adults. The results determined that the non-injured young and elderly females could significantly improve their postural sway control under complex sensory training conditions. According to the systems model, these results indicate that postural control is a property that involves the interactions of a number of sensory systems. The results show that as long as two sensory inputs are available, both young and elderly females can easily shift from the use of one sensory input to another. All the subjects in the present study were trained under complex sensory training conditions where they were trained over nine sequences incorporated alteration of visual inputs (i.e. the eyes-closed conditions, and watching a bull's-eye for visual feedback), alteration of somatosensory inputs, and modification of vestibular inputs in the training program (i.e. the unilateral stance, and, on a platform moving up and moving down). The findings showed that both YTG and ETG improved on all postural sway measures (i.e. OS, MLS, and APS) for all six training factors. Additionally, this result suggests that the integrative ability of higher brain centers was enhanced. Other studies have demonstrated that higher brain centers retain plasticity at the molecular level and that practice can induce the modulation of neuronal activity in the cerebellum. [159] Research on the nervous system mechanisms underlying balance and postural control has shown that in young adults, postural responses to external threats to balance are directionally specific and organized into discrete synergies that include muscles of the lower leg, thigh, and trunk. The sequence of muscle activation typically radiates upward from the base of support, starting with the ankle musculature. Thus, when balance is lost in the forward direction, the muscles activated would be the stretched gastrocnemius, followed by the hamstrings and the paraspinal muscles of the trunk. This sequence serves to efficiently compensate for the body sway. In addition, Woollacott et al. [157] found that older adults showed a significant slowing in the onset time for activation of these postural responses, and occasional reversals in the activation sequence. For the current study, it is possible that the elderly females were able to optimize the intersensory interaction within the higher brain centers, where, in turn, increased sensory convergence occurred following a three-week period of multisensory training. Thus, the elderly females were able to compare their sensory inputs and to select reliable sensory information for postural control under changing sensory conditions. The cerebellum is a likely location as the control center for this improvement, since it receives both ascending inputs from the spinal cord and descending inputs from the cerebrum. [205]

The investigator noted that the improvements are unlikely to be due to a repeated testing effects or learning effects, in view of the fact that there was no evidence of improvement in postural sway measures (i.e. OS, MLS, and APS) with repeated trials during posttest in both YCG and ECG. Furthermore, to minimize repeated testing effects or learning effects, all subjects practiced each evaluation condition once prior to pretest and posttest sessions. In addition, the training protocols were not similar to those used in the evaluation protocols. The possibility that the positive improvements for both the training groups and the negative decrements for both the control groups were due to unreliable measurement device was not accepted. This is because in a concurrent study (i.e. Study 1), the researcher assessed the test-retest reliability of the CDBS as a measurement tool for postural sway measures and found the CDBS has good test-retest reliability with ICCs > 0.80.

It has been documented that the ability to maintain balance or a postural task involves additional attention requirements. [194,206,207] In fact, the attention demands are subsequently increased in relation to the complexity of the task at hand. More specifically, it was found that dynamic balance or even the ability to maintain an upright standing position under various perturbations is substantially more attention demanding when compared to a normal sitting condition. [207] Also, the additional attention resources are required by the elderly population in order to maintain balance or upright posture. [208] In view of this fact, a possible explanation of the postural sway control decrements obtained by both the control groups at posttest was most likely due to their attention, concentration, motivation, and self-initiation to show maximal performance during the posttest. The majority of the subjects in the control groups showed less motivation and less attention during posttest after knowing their postural sway control ability from the pretest scores. In contrast, majority of the young and elderly subjects in training groups showed good cooperation and initiative during the training sessions, allowing for efficient balance training, with minimal opposite extremity surface touchdown, grabbing the handrail, and opened eyes in the eyes-closed condition. These subjects were highly motivated, treating the training difficulties as self-challenging and self-achievement. These positive attitudes appear to have driven them to show their best performance across training sessions, as well as in the post evaluation session.

6.2.3 Differences between Training Factors

6.2.3.1 Types of Balance: Static with the Eyes-closed versus Dynamic with the Eyes-open

The static balance with the eyes-closed condition showed significantly greater improvement when compared to the dynamic balance with the eyes-open condition for both OS and APS. Same trend was found for MLS, but the differneces in improvement were not statistically significant. However, it was close to significant at $p = 0.056$ (see Table 6.28). These findings showed that the training condition with visual cue deprivation seemed more effective than the condition with available visual cues. After training, the improvements were greater in static balance with the eyes-closed condition than dynamic balance with the eyes-open condition for both young and elderly trained groups. The current study results agree with the findings of Bonan et al. [209] These findings suggested that both YTG and ETG improved their integration of somatosensory and vestibular inputs and that the balance training program enabled them to use the pertinent inputs (i.e. visual, vestibular, and somatosensory inputs) and to become less reliant on visual input. Although visual influence is predominant in aging, [157] the findings of greater improvements gained with the eyes-closed condition in this study probably indicating that the multisensory training program successfully induces the elderly trained subjects to increase their use of somatosensory and vestibular information to make up for the absence of a visual compensatory strategy. These positive results suggest that physical therapy programs focusing on balance retraining should consider including exercises to be performed under condition of visual deprivation (i.e. eyes-closed condition).

The differential effects of multisensory training on postural sway with the eyes-open and the eyes-closed condition clearly showed that the process of sensorimotor rearrangement with subsequent postural stability is related to the degree of the initial instability. Several spontaneous studies and perturbation experiments have shown that with the eyes-closed resulted in increased sway in most normal subjects. [90,104,141,210] Also, researchers of postural control generally agree that vision plays a strong stabilizing influence on postural control and that sway measurements are greater with the eyes-closed than with the eyes-open. [141,210,211]

In addition, the findings of this study are in agreement with Bernier and Perrin, [138] suggesting that the training groups improved with the eyes-closed on a stable platform and for the eyes-open on a tilting platform. Nashner and Peters [212] reported that when somatosensory input is intact, removing visual input should only increase sway minimally. If somatosensory input is improved through training, the eyes-closed condition should reveal some improvement. Therefore, the greater improvement in static balance with the eyes-closed condition could mean that both the trained groups improved their processing of somatosensory information during the training regimen.

Contrary to these findings, three studies [160,162,163] suggested that standing on one leg with the eyes-open had greater sensitivity to the effects of physical training than the eyes-closed condition. These authors explained that the exercise group performed most of the training sessions with the eyes-open, enhancing the integration of the visual, vestibular, and somatosensory systems, but not with the eyes-closed. There are a number of methodological differences that may account for the discrepancies in the findings with previous studies. These discrepancies including the duration of the trials, the methods for deriving scores, the types of subjects selected, and varying balance training program. For instance, in the study conducted by Kammerlind et al., [160] they trained elderly adults with vertigo and unsteadiness. The authors noted that standing on one leg with the eyes-closed was too difficult for elderly adults with vertigo and unsteadiness. Furthermore, the subjects performed most of the training sessions with the eyes-open, impeding the equal training intensity for the eyes-closed condition. A study conducted by Ledin et al. [161] confirmed that healthy elderly adults improved in one leg stance with the eyes-closed, unlike the elderly adults with pathology. Similar to a study by Ledin et al., [161] the present study trained healthy and non-injured elderly females, and there was an agreement in both findings. Unlike the study conducted by Kammerlind et al., [160] the subjects in the present study were trained for an equal duration and intensity of the eyes-closed and the eyes-open conditions.

6.2.3.2 Types of Stance: Bilateral Stance versus Unilateral Stance

There was a greater improvement with bilateral stance when compared to unilateral stance for OS and APS. For MLS, the unilateral stance yielded a greater improvement when compared to the bilateral stance. No significant difference was noted between the bilateral stance and the unilateral stance when the percentage of change for OS, MLS, and APS for both ETG and YTG were compared. This can be seen in Figure 6.8 with similar trends being displayed between the two types of stance.

The bilateral stance measures reflect the integrity of the proprioceptors, muscle stretch receptors, vestibular system, visual system, and motor control of postural muscles. The possible reason for the improvement observed when bilateral stance was used in this study suggests that the three-week multisensory training program was able to successfully enhance the integrity of sensorimotor integration. Two out of three training protocols in this study (i.e. a. bilateral Romberg stance on a platform moving down with the eyes-closed, and b. bilateral Romberg stance on a platform moving up with the eyes-open watching a bull's-eye for visual feedback) may have altered all three somatosensory inputs (i.e. Romberg stance, and platform moving down), vestibular inputs (i.e. platform moving down), and visual inputs (i.e. the eyes-closed, and the eyes-open watching a bull's-eye for visual feedback). The third training protocol (i.e. bilateral tandem stance on a stable platform with the eyes-closed) altered two sensory systems by manipulating somatosensory inputs with tandem stance and totally eliminated the visual inputs by having the eyes-closed and blindfolded, keeping the vestibular inputs at normal (Table 6.32). These training protocols were quite intensive, forcing all three sensory systems and the motor system to integrate efficiently, thus enhanced the sensitivity of sensorimotor integration.

Table 6.32: Sensory Systems Alteration involved in Bilateral Stance Training Protocols

Training Protocols	**Sensory Systems**		
	Visual	**Vestibular**	**Somatosensory**
1. Bilateral Romberg stance on platform moving down with the eyes-closed	Eliminated	Altered	Altered
2. Bilateral Romberg stance on a platform moving up with the eyes-open watching a bull's-eye for visual feedback	Altered	Altered	Altered
3. Bilateral tandem stance on stable platform with the eyes-closed	Eliminated	**Normal**	Altered

This study findings are contradictory with prior studies [164,197] which demonstrated no change in bilateral stance following balance training programs. They stated that bilateral stance postures were not challenging to healthy older persons and would not be expected to improve.

The findings of improved unilateral stance (up to 30.41%) for both ETG and YTG agree with the findings of Brandt et al., [131] who measured postural sway activity (balancing on one foot) in healthy young subjects. They found up to 50% improvement with five days of training. Their findings stated that the better initial stability from the trained gymnasts achieved weaker training effects when compared with the untrained students. Their findings were in agreement with the current study, noting that the ETG achieved better training effects when compared to the YTG. For the ETG, the initial absolute postural sway was greater at pretest, whereas at the end of the training period, at posttest, the ETG matched the postural sway measures of the YTG at pretest. Rozzi et al. [184] also studied balance training for persons with functionally unstable ankles and they found that both the unstable ankle individuals and the unimpaired individuals, who participated in a single-leg balance training program, demonstrated an overall improvement in balance scores.

In comparison with the training protocols for unilateral stance in the present study, two of the training protocols involved alteration of three sensory systems: (a) right leg on platform moving down (i.e. somatosensory inputs, and vestibular inputs altered) with the eyes-open watching a bull's eye for visual feedback (i.e. conflict visual inputs), and (b) left leg on platform moving down with the eyes-open watching a bull's eye for visual feedback). Another four training protocols manipulated two of three sensory systems: (a) right leg on a stable platform (i.e. somatosensory inputs altered) with the eyes-open watching a bull's-eye for visual feedback (i.e. conflict visual inputs), (b) left leg on a stable platform (i.e. somatosensory inputs altered) with the eyes-open watching a bull's-eye for visual feedback (i.e. conflict visual inputs), (c) right leg on a stable platform (i.e. somatosensory inputs altered) with the eyes-closed (i.e. visual inputs eliminated), and (d) left leg on a stable platform (i.e. somatosensory inputs altered) with the eyes-closed (i.e. visual inputs eliminated) (Table 6.33).

The most intensive training protocols of unilateral stance were both right and left leg standing on a stable platform with the eyes-closed and blindfolded. Even though the above-mentioned protocols eliminated visual inputs, the vestibular inputs remained unmodified and the somatosensory inputs were partially altered by standing on one leg. According to the feedback of the subjects, these protocols were the most challenging procedures. They reflected that they never experienced any situation that required them to stand on one foot with the eyes-closed. It may also have been challenging because of the weaknesses of the active contraction of several muscles groups, particularly the ipsilateral hip adductor and gluteus medius muscles for aging group. Furthermore, the eyes-closed and blindfolded conditions may have caused discomfort, lack of confidence, and fear of falling in addition to standing on one leg. This was particularly obvious in the elderly training group. Through the investigator's observation during the training sessions, the elderly females tended to place their hands above or close to the handrail to enable them to grab it immediately if they were out of balance, although they worn a safety harness. However, despite these complications, both the young and elderly training groups obtained significant improvement compared to both the control groups for unilateral stance.

Table 6.33: Sensory Systems Alteration involved in Unilateral Stance Training Protocols

Training Protocols	**Sensory Systems**		
	Visual	**Vestibular**	**Somatosensory**
1. Right leg on platform moving down with the eyes-open watching a bull's eyes for visual feedback	Altered	Altered	Altered
2. Left leg on platform moving down with the eyes-open watching a bull's eyes for visual feedback	Altered	Altered	Altered
3. Right leg on stable platform with the eyes-open watching a bull's-eye for visual feedback	Altered	**Normal**	Altered
4. Left leg on stable platform with the eyes-open watching a bull's-eye for visual feedback	Altered	**Normal**	Altered
5. Right leg on stable platform with the eyes-closed	Eliminated	**Normal**	Altered
6. Left leg on stable platform with the eyes-closed	Eliminated	**Normal**	Altered

6.2.3.3 Types of Leg Dominance: Dominant Leg versus Non-dominant Leg

There has been no documented evidence of sway characteristics during static or dynamic movement on the force platform in terms of foot preference. It has been previously reported that there was no difference in body sway between the dominant and non-dominant leg during one-legged stance. [141,142,213,214] This was in agreement with the findings of the current study. Both YTG and ETG improved significantly on the dominant leg and non-dominant leg. The results found that the differences in improvement of both the dominant leg and non-dominant leg were not statistically significant. This finding is different to the findings of Soderman and colleagues, [215] who suggested the young intervention group (mean age 20.4 ± 4.6 years) had significantly improved standing on the non-dominant leg with extended knee, but not the dominant leg.

Surprisingly, both the YTG and ETG in the present study showed different trends when considering the training effect on leg dominance. The YTG improved to a greater degree for the dominant leg than non-dominant leg for all three postural sway measures. The ETG indicated greater improvement for the non-dominant leg when compared to the dominant leg for OS, MLS, and APS measures. However, it is doubtful that this had any meaning due to the lack of significance when comparing the improvement between ETG and YTG for the dominant leg and the non-dominant leg for all three postural sway measures.

There was a lack of significance in the interaction effect, which means that the two variables, group and type of leg dominance, did not interact. The effect of leg dominance was not significantly different between the ETG and the YTG for all postural sway measures. In addition, the results demonstrated that although both ETG and YTG improved in percentage of change to a greater degree on the non-dominant leg than the dominant leg, the difference in improvement between the non-dominant leg and the dominant leg was small enough to be interesting but not significantly different.

6.2.4 Training Effect on the Berg Balance Test (BBT)

The Berg Balance Test (BBT) is used as an indicator to predict risk of falling among elderly adults aged 60 years and above. In fact, it has been noted that of all the functional tests, the BBT scale was, one of the most effective predictors for falls within community-dwelling adults. [216] In addition, the BBT scale shows high inter-rater and intra-rater reliability (ICC=0.98). [185,187,189] This was supported by the current study, reporting that the BBT scale revealed high test-retest reliability with ICC = 1.00.

The items in the BBT scale address the subject's ability to maintain positions of increasing difficulty by diminishing the base of support from sitting, to comfortable stance, to standing with feet together, and finally the two most challenging items such as tandem standing, and single leg stance. Other items assess how well the subject is able to change positions from sitting to standing, transfer from chair to chair, turn, pick up an object from the floor, and sit down. More difficult items, require the subject to bring the center of mass closer to the edges of the base of support by actively shifting weight side to side, as each foot is placed alternately on a stool, and forward; when the subject reaches her out-stretched arm forward. [187] According to the BBT indicator, the individual who scores below 45 has a higher risk of falling. [186,187]

However, the Chattecx Dynamic Balance System (CDBS) used the force platform method to measure the center of pressure to quantify postural sway. It is based on the simultaneous measurement of vertical ground reaction force at points in the corners of a rigid platform on which subject is placed in an upright stance. Upright stance is maintained by keeping the body's center of gravity (COG) vertically above the base of support, which comprises the area of the feet and the ground between them. Contractions of the muscles of the lower extremities, trunk, and neck keep the body stable during this process, causing oscillating movement about a vertical axis. [65]

Previous studies have shown positive effects with balance training in healthy elderly adults. [161,162,217] Similar to the results of present investigation, the improved postural sway control measured through the CDBS is consistent with the improved BBT scores shown by the ETG after completing the three-week multisensory training program. It can be explained partly by the fact that both the CDBS and the BBT scale address the ability to hold a posture and maintain a position, as well as to change positions while keeping postural stability and balance.

With respect of the BBT scores, it was found that the ETG had significantly higher scores than the ECG after the three-week multisensory training intervention. The training group increased their total BBT scores from 52.56 at pretest to 55 at posttest, whereas the pretest and posttest of total BBT scores for the control group remained the same. The median of the BBT scores for the training group was 55 out of 56 as maximum scores. The average total BBT scores for the ETG were 55 (Table 6.31).

This improvement in the BBT scores appears to reflect improved functional balance ability along with enhanced postural sway control by sway regression because the CDBS's postural sway measures demonstrated the similar training effects illustrated by the BBT scale. The results of the present study suggest that the three-week multisensory training program was an effective means of improving functional balance ability and postural sway control, thus preventing the risk of falling and fall-associated injuries among elderly females. Condron et al., [111] suggested that measures of balance and postural sway on the CDBS, in particularly dynamic platform conditions using anterior-posterior tilting movement, were the most effective in accurate classification of fall risks in a sample with minimal to mild falls risk. In addition, the CDBS may be a key measure in early identification of fall risk for elderly adults. The CDBS can be used as a measurement device to predict risk of falling because balance ability has been shown to be an important predictor of falls within the elderly population. [187]

A previous study indicated that increased postural sway increased the risk of falls of community-dwelling elderly. [164] The positive results of the present study suggest that the three-week multisensory training program was able to successful reduced postural sway. Thus, it may be suitable to adapt as a fall prevention strategy program for elderly who present with a substantial risk of falling. Such a program would ensure significant lower incidences of falls. In turn, this would lead to substantially lower health related costs to falls and fall related injuries.

The elderly females from the current study were free from any injuries or disorder of the central nervous system, reflected that they were healthy and non-injured elderly females. However, in this study, the elderly females with a greater number of problematic items in the BBT scale at their pretest, tended toward diminished performance during the CDBS evaluations at baseline as well. Moreover, it may be concluded that multiple problems in the sensitivity of sensorimotor integration are a contributing factor to poor postural control and functional balance ability among elderly adults. It is noteworthy to mention that the subjects in present study who had difficulty in the BBT items such as Romberg stance, tandem stance, and standing with the eyes-closed, gained greater improvement at posttest on the BBT scale after completing the three-week multisensory training intervention.

None of the subjects included in the present study had received any specific training aimed at reducing postural sway or improving functional balance ability before the study started. This may explain the generally high motivation and good attendance in the training groups. Moreover, most of the subjects in the training groups provided their best efforts while moving within their comfort range while training. The most noticeable item that improved in the BBT scale for the majority of the trained elderly after the multisensory training was "turning a full circle". For this task, the vestibular inputs were altered. In light of this improvement, this research found that the multisensory training program might substantially improve the maintenance of equilibrium while in motion. In the other words, the vestibular adaptation was improved. In addition, the improvement can be explained partly by the fact that through the multisensory training intervention, the subjects were able to change positions without losing their balance. Another likely explanation is that the trained elderly may have gained greater confident on their own postural sway control and functional balance ability after the training program, thus enable them to perform the "turning a full circle" task confidently in a shorter time (a timed item).

Items such as sit to stand, standing to sitting, and stool stepping were examples of less challenging items in the BBT scale for this study population and were unlikely to have direct bearing on postural control for the non-injured elderly females seen in this study. All of the subjects scored full marks (4 points) for these items at pretest. Therefore, it was not possible to see any improvement for these items at posttest. The most difficult items for the subjects to perform successfully were standing on one leg, and standing with one foot in front of the other (i.e. tandem stance) at pretest. Their performances on both items improved at posttest. Although these two items ostensibly involve static maintenance of a position, they also incorporate a dynamic component.

The BBT scale does not test for performance under conditions of altered sensory context or attentional distracters. Furthermore, the lack of an item that requires a postural response to an external stimulus or uneven support surface is a limitation of the BBT scale. It likely limits the utility of the scale when assessing very active persons with minimal deficits. The three-week multisensory training program designed for this study was conducted using the CDBS. The training program consisted of nine training protocols that were designed under conditions of altered sensory systems. When comparing the strength of the CDBS as an evalution device capable of measuring postural responses to external stimulus or moving the support surface or under conditions of altered sensory systems with the limitations of the BBT scale as aforementioned, it may not be possible to show the positive training effects gained by non-injured elderly females after training through the BBT scale.

The results of this study suggest that the multisensory training protocols used in the current study are an effective means of improving both the postural sway control

(OS, MLS, and APS measures) and functional balance ability (the BBT scores) for elderly females. These improvements in postural sway control and functional balance ability along with enhanced BBT scores demonstrated the similar (but not completely) positive treatment effects illustrated by the postural sway measures using the CDBS. Therefore, the third hypothesis, which stated that there would be a significant difference in the BBT scores for the trained elderly females after the three-week multisensory training program when compared with the untrained elderly females, was supported.

6.2.5 Comparisons to other Training Programs

It is not generally possible to make direct comparisons between different studies because of the widely varying experimental conditions, measurement techniques and devices, difference populations of interest, the differing protocols followed, and methods of calculating scores of sway. Furthermore, the majority of studies on the effect of balance training on postural sway involved subjects with functional ankle instability and/or did not include a control group in the study design. [132,138,184] However, the methodology used in this study was similar to the methods previously used by Hu, [159] and to a large extent comparable to a previous study by Hoffman and Payne. [218] The results of this study support the findings of Hu et al., [159] who found that balance training designed to improve intersensory interaction could effectively improve balance performance in healthy older adults. Subjects (age range: 65 to 90 years) were randomly assigned to a training (N=12) or a control group (N=12). Training subjects received a 10-hour balance training program which selectively manipulated sensory inputs from the visual, vestibular, and somatosensory systems. Hoffman and Payne, [218] who reported a significant decrease in single limb stance center of pressure excursion with the eyes-open after a 10-week balance training program using the Biomechanical Ankle Platform System on 30 healthy young subjects. The training took place three days per week for a period of ten minutes each day. The results revealed a significant improvement in the experimental group, but not the control group. In studies conducted by France et al. [219] and Balogun et al., [220] healthy non-impaired individuals demonstrated improvements in single-leg balance ability following a balance training program, as compared with the untrained control group.

Previous studies [132,138,184] suggested that balance training is an effective means of improving joint propriception and single-leg standing ability in subjects with unstable and non-impaired ankles. The findings stated that not only did the trained subjects report a decrease in postural sway, but also an improved pattern of balance control. This was evident in the injured limb as well as in the uninjured, untrained limb.

Past research has shown that training programs designed to specifically enhance the function of a single system, such as the vestibular system or muscle strength, are generally more effective in the improvement of balance than training programs with a more global approach. There were several studies [10,160,161,221] that supported the evidence that training programs with identified aims toward specific physiological systems related to postural control have consistently reported significant training effects. For instance, Brandt et al. [131] reported that a training program based upon the manipulation of sensory inputs significantly improved postural stability among younger adults (17 to 33 years of age). Similarly, the proprioceptive training program conducted by Islam et al.[222] was based on the manipulation of sensory inputs from visual, somatosensory, and vestibular systems. The result indicated that the program was effective in improving both static and dynamic balance (i.e. 82% and 43%, respectively) in older adults (mean age 76 ± 4 years) and the improvements showed clinical significance. Holm et al. [223] reported 16% improvement in dynamic balance on healthy female handball players (mean age 23 ± 2.5 years) after completing a neuromuscular training program for balance, proprioception, and muscle strength. These studies findings are in agreement with the results of present study, suggesting that a training program designed to specifically improve sensory functions was effective in the improvement of postural sway control and balance control among young (20 to 49 years of age) and elderly (60 to 80 years of age) females. The improvements were not only statistically significant, they were clinically significant as well.

A study by Cox et al. [66] found that there was no improvement following a training period in normal subjects. In their study, no significant improvement was shown in the sway index of uninjured individuals who trained five minutes per day for six weeks on either a firm surface or a compliant foam rubber surface. Subjects were tested using the Chattecx Dynamic Balance System (CDBS) for 10-second trials. Cox et al. [66] attributed the lack of improvement in postural sway to the amount of time of the training and to the fact that subjects were uninjured, normal subjects. They reported that perhaps five minutes of training was too demanding and that a shorter period of training could possibly produce a better quality of training. Cox and colleagues [66] felt that it was also possible that the uninjured subjects simply had no room for improvement. Their results are in agreement with Verhagen et al., [79] who found no difference in changes of center of pressure excursion between any of the study groups over the 5.5-week balance board training period. These findings are similar to Chong et al., [224] who, studying healthy young subjects, found no effects of a 4-week balance training program on center of pressure excursion. These contradictory findings to current results may be due to the differing balance training program. In addition, the intensity, duration, and frequency of the training regimen are known to be crucial elements to be considered carefully when designing a training program. It does not matter how long the entire training program last (e.g. 10 weeks), what matters the most appears to be the time allocated to each specific physiological system related to postural control -- in this case, the sensory systems that needed sufficient time to respond to the training intensity. For the present study, the actual training time of these systems was 216 minutes over the three weeks of the training period. Each combination of systems was trained four minutes during each training session and over-training was applied to reinforce the training effect, hence allowing a process of retention.

A training effect occurred through a progression of motor skill learning stages. Skill acquisition is the first stage. In this stage, errors are frequent, and performance is inefficient and inconsistent. Within the nervous system, only temporary changes are occurring. In the skill refinement stage, the goal is to improve the performance, reducing the number and size of the errors, and increasing the consistency and efficiency of the movements. Skill retention is the final stage. The ability to perform the movements and achieve the functional goal has been accomplished, and the new objective is to retain the skill (across time) and transfer the skill to different settings. Retention and transfer are the hallmarks of true learning, where some relatively permanent changes have occurred within the nervous system after sufficient time of skill practicing and training intensity.[8]

A learning effect may occur through repeated testing or practice. People may learn something from the test taking experience itself that enables them to get a better score when taking the test a second time, even though there has been no treatment intervention and no improvement in the characteristics being measured.[123] The effect of learning how to do the test could easily influence the results. If there are repeated tests using the same instrument within the study, subjects are likely to achieve some learning. They may perform better on later tests simply because they have learned the material on the test rather than because of an experimental intervention.[225] The same effect is present in most testing protocols unless the subjects are allowed to practice the test a few times before the real testing takes place.

Three basic design strategies can be used to minimize a learning effect due to testing. The first is to use randomly selected experimental and control groups so that the learning effects of testing in the control group can be removed by comparison with the effects of testing and treatment in the experimental group. The second strategy is to eliminate multiple testing by a posttest-only design. However, in the absence of a pretest to establish that the control and experimental groups are the same at the start of the experiment, posttest-only studies must have effective random assignment of subjects to groups. The third design strategy is to conduct familiarization sessions through practice with the testing equipment so that the effects of learning are accounted for before the independent variable is manipulated. To determine the extent of familiarization needed, the researcher should conduct a pilot study to determine how much time or how many sessions are needed before performance is stable. One drawback of multiple testing is the possibility that the familiarization process will itself constitute a "treatment".[97]

To encounter the learning effects, it is recommended that one must design the training program specifically and carefully plan the testing protocols in order to avoid similarity and lack of specificity in the training and testing protocols. The possibility of a significant improvement due to learning effect could occur in any training program and researchers are always advised to address the threat of the learning effect as a potential confounding variable in their study.

In the current study, learning effects were counteracted by using a randomized controlled trial design in which subjects were randomly assigned to training and control groups in order to diminish the learning effects of testing in the control groups by comparison with the effects of testing and intervention in the training groups. Furthermore, a practice session to familiarize the subjects with the testing device was included so that the learning effects were taken into account prior to the manipulation of the independent variables. In addition, the testing repetitions were controlled using two trials for each condition to counteract the possibility of the familiarization process constituting a "treatment". The researcher was aware of the threat of learning effects confounding study results. The six evaluation protocols were entirely different from the nine training protocols, in order to avoid similarity of the training and testing protocols.

The improvements on three postural sway measures on six training factors gained by both the young (YTG) and elderly (ETG) training groups (23% and 31%, respectively) suggested true improvements occurred through training effects. The improvements were unlikely due to learning effects through repeated testing. This is because there were no significant improvements in posttest scores when compared to pretest scores for both the young (YCG) and elderly (ECG) control groups who received no training. Strange et al. [226] suggested that a diminution of 12% was needed if the balance ability was to be improved. Even if the researcher agreed to a diminution of 12% for learning effects, the YTG still showed a true improvement of 11% and the ETG improved 19% because their improvements were as high as 23% and 31%, respectively. This further confirmed that the improvements for all three postural sway measures for all six training factors were the result of improved postural sway control and functional balance ability through training effects rather than learning effects.

Although it is not within the scope of this study to determine the age impact on postural sway control, it is interesting to note that the findings of this study demonstrated that age has impact on postural sway control in healthy non-injured adults where the non-injured young females (age range: 20 to 49 years, mean age 32.17 ± 7.70 years) showed a trend toward reduced sway for the three postural sway measures when compared to the non-injured elderly females (age range: 60 to 80 years, mean age 64.12 ± 4.58 years). This is in agreement with several studies in the literature that reported postural sway increased with age due to the normal aging process. [141,143,144,149,150,152] The various authors stated that there was a tendency for elderly adults (above 60 years of age) to have larger sway index than younger adults (below 60 years of age). In addition, Shepard et al. [10,43] reported that aging had an impact on virtually all aspects of the individual sensory and motor components of the balance system. Experimental and clinical evidences suggest a decline in the ability to integrate the three sensory inputs (sensory systems) for maintenance of posture and balance control (motor components) due to aging.[52] This is in accordance with the current results that found the non-injured elderly females showed a trend toward greater sway when compared to the non-injured young females at baseline where the evaluation protocols were designed to measure the ability to integrate visual, somatosensory and vestibular inputs by altering one or more sensory systems.

Although the population of interest in this study was female adults, the findings of the impact of aging on postural sway control might be implied to male adults population because several authors reported that there was no significant difference in postural sway measures based on gender effects on a force platform.[141,143-145,151,152] However, this remains as speculation and needs further investigation since the subjects used in this study were female adults.

6.2.6 Strengths of Study 2

The major strengths of the study are the use of a randomized controlled trial, and an experimental design, utilizing control groups for pretest and posttest design. In the present investigation, the wide range of evaluation protocols that consisted of different types of balance, stance, eyes conditions, and leg dominance were assessed. Furthermore, the wide range of postural sway measures that consisted of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) were measured.

Different aged groups were compared in this study, which enhanced the accuracy and information content of the effectiveness of the three-week multisensory training program. Moreover, the subjects involved in this study were healthy and non-injured young and elderly females. Generally, it is believed that the selection of active, high-level functioning females with good baseline functional balance ability and postural sway control would limit the improvement possible from an exercise intervention, because they were perceived to have no room for improvement due to their initial postural sway stability and functional balance ability especially for the young aged group. Interestingly, the findings of the present study found that even healthy, active, and high level functioning non-injured young individuals could improve, as can elderly adults after completing a multisensory training intervention.

It is noteworthy to mention that this three-week multisensory training program also caused a remarkable improvement of postural sway control and functional balance ability of elderly training adults so that their sway measurements were at the level of young adults.

The investigator suggests that, if the multisensory training program is carefully designed to train specific systems (e.g. sensorimotor integration as in this study), even non-injured young individuals can improve remarkably although previous research found that there was little for improvement for non-injured young individuals due to their high level of postural sway control and functional balance ability.

In the present study, the results were reported with effect sizes and confidence intervals (95%) in conjunction with power analysis. Effect sizes were determined for all variables using the ratio of the difference between pretest and posttest mean scores to the pooled standard deviation. [172] The effect size observed in the sample is "best guess" about the magnitude of the difference in the population. The major goal of analyzing the effect sizes was to establish guidelines for determining clinically relevant change for postural sway measures and the effectiveness of the multisensory training intervention. The confidence interval provides information about how confident the researcher is in this estimate. The confidence interval reflects the likely upper and lower boundary of the effect in the population. By presenting the effect size and confidence interval, however, the focus of the report shifts from the issue of whether or not the effect is clinically important.

Large effect sizes (ranged from $f = 0.588$ to $f = 0.782$) reported from this study suggest that the improvements received from the multisesory training intervention not only showed statistical significance, but also proved to be clinically significant.[159,160,164,184] For all the findings, powers after the fact were at 100%; implying that the researcher was 95% confident that the improvements reported by both young and elderly training groups were true improvements. The sample size used was large enough to obtain high power after the fact (1.000). Most of the studies described previously did not report the power after the fact and effect size, and were using small sample sizes that make the external validity of those results questionable. It is interesting to note that the current study suggests that the BBT scale revealed high test-retest reliability (ICC = 1.00) to be used for evaluationg functional balance ability.

6.2.7 Weaknesses of Study 2

An area of weakness in this study is the fact that the researcher played the role of trainer, as well as rater for this study. In addition, the researcher was not blind to the subject's pretest and posttest evaluations. Although the researcher can assure there were no biases because the results were calibrated by the CDBS, it is suggested by others that the use of two difference personnel for this purpose could avoid the complication and eliminate this possible bias.

A longer follow-up period would have been desirable to identify the retention of the training effects, whether the newly acquired functional balance ability and postural control skill are stored and preserved for weeks after the termination of training.

Since most research on older adults relies on self-reports of "apparent health", borderline peripheral or CNS pathology, as well musculoskeletal borderline pathology contributing to motor control deterioration may have been overlooked. Despite strict adherence to the guidelines established for subject selection, some subjects, especially the elderly groups, may have had undiagnosed or unrecognized pathological conditions that may have affected their postural control abilities. This suggests a need to perform neurological examinations on all elderly adults involved in studies on aging, in order to validate the generalizability for the results to a "normal" population.

Caution is advised when applying the results of this study to other populations because of the differences in subject selection and measuring techniques. Due to the fact that non-injured subjects were utilized in this study, the results cannot be directly applied to the injured individuals.

The psychological factors of subjects may be a confounder. The subjects' motivation and ability to follow the instructions may have influenced the results. In addition, variations in mental status (arousal level) may vary from pretest to posttest. Several possible explanations why both the control groups showed increased amount of sway for the posttest included: (a) less motivation, (b) less attention, and (c) poor concentration. The control groups tended to show less effort in completing the tasks, after knowing their profile at pretest. In contrast, some "high achievers"were too intense during posttest, indirectly causing performance anxiety. Previous studies have demonstrated increased spontaneous sway in anxious individuals [227] and the results may have been influenced by fear [203,228] or by the level of attention given to the test. [229]

Another shortcoming of the present study is that concentration may be compromised due to extraneous factors such as visual or audible disturbances that may be present in a shared laboratory. Controlling for these disturbances may improve the reliability of measurement. Although every effort was made to control the test environment, the test setting was not completely isolated for this investigation. The investigator recommends that assessment of balance and postural sway occur in a completely isolated setting, while minimizing external influences.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 SUMMARY AND CONCLUSIONS OF STUDY 1

This study demonstrated that the Chattecx Dynamic Balance System (CDBS) revealed good test-retest reliability (ICCs > 0.80), produced a small measurement error (SEM 0.00 cm to 0.03 cm), and yielded a small confidence interval (95% CI) when it is utilized as a measurement device for quantifying postural sway measures. Thus, the first hypothesis stated that the CDBS has good test-retest reliability as measurement device for quantifying postural sway measures was supported.

The CDBS did not, however, portray good discriminant validity in distinguishing the effect of hours spent at sporting activities per week on postural sway control between vigorously active (Group 1: five hours or more) and moderately active (Group 2: less than five hours) non-injured young females when testing static and dynamic balance. Therefore, the second hypothesis, which stated that the CDBS could discriminate between Group 1 and Group 2, was not supported. A possible explanation was due to the lack of a more refined weighing system to discriminate between levels of sporting activity.

7.2 SUMMARY AND CONCLUSIONS OF STUDY 2

This randomized controlled trial study used the pretest-posttest control group design. This is a pioneer study showing positive findings of a multisensory training program using the Chattecx Dynamic Balance System in non-injured young and elderly females. Both young and elderly training groups were trained using static and dynamic balance protocols: with the eyes-closed and the eyes-open conditions; bilateral and unilateral stance; and the dominant and non-dominant legs to determine the training effects of three primary postural sway measures. As hypothesized, both the young training group (YTG) and the elderly training group (ETG) were able to improve postural sway control of overall sway (OS), medial-lateral sway (MLS), and anterior-posterior sway (APS) by the three-week multisensory training intervention while sensory information from the visual, vestibular, and somatosensory systems were selectively manipulated. The positive training effects on postural sway control were identified and compared between YTG and ETG for all six different training factors of: (a) static balance with the eyes-closed condition, (b) dynamic balance with the eyes-open condition, (c) bilateral stance, (d) unilateral stance, (e) dominant leg, and (f) non-dominant leg, respectively. The effectiveness of training factors was compared accordingly to types of balance, types of stance, and types of leg dominance.

In conclusion, the first hypothesis was accepted, suggesting that both YTG and ETG revealed significant decreases of sway dispersion for all three postural sway measures after completing the multisensory training intervention using the CDBS when compared to both YCG and ECG for all six training factors. Initially, the postural sway measures for both YCG and YTG, and both ECG and ETG were similar at baseline. At posttest, these measures remained unchanged for both YCG and ECG. However, both YTG and ETG improved remarkably for these measures at posttest. Surprisingly, the ETG demonstrated overall improvements that reached the same performance level of young female adults after completing the multisensory training program, even when the ETG was significantly different (sway more) at their baseline in comparison with both YCG and YTG.

It is noteworthy that the CDBS was able to discriminate postural sway measures between young females (N=24) and elderly females (N=24) at pretest values. Both the young control and training groups (age range: 20 to 49 years, mean age 32.17 ± 7.70 years) showed a trend toward reduced sway when compared to both elderly control and training groups (age range: 60 to 80 years, mean age 64.21 ± 4.58 years), and the differences were statistically significant at $p \leq 0.000$. This is in agreement with the literature which stated that individuals older than 60 years in age showed greater sway when compared to the individuals younger than 60 years in age. [141,146,149] Furthermore, when comparing the posttest values between young training and young control groups, the results found that the differences at posttest scores between the young training group and the young control group were significant at $p \leq 0.000$. The same findings were seen when comparing posttest values between elderly training and elderly control groups ($p \leq 0.001$).

With all these comparisons made in Study 2, the CDBS was able to distinguish all three postural sway measures for the different age groups (i.e. young and elderly) and for both trained (i.e. YTG and ETG) and untrained groups (YCG and ECG). The findings of

Study 2 further confirmed that the CDBS is valid measurement tool for quantifying postural sway measures and showed good discriminant validity.

After completing the three-week multisensory training program, the ETG showed greater improvement than the YTG for all three postural sway measures for all six training factors. However, the differences in improvement between the ETG and the YTG did not show statistically significance.

Notably, there were no significant differences among each type of training factor for all three postural sway measures except for OS and APS for static balance with the eyes-closed condition when compared to dynamic balance with the eyes-open condition for both YTG and ETG.

At pretest, both the ECG and the ETG showed no significant difference in their Berg Balance Test scores (BBT). However, after completing the training intervention using the CDBS, the BBT scores of the ETG improved significantly. The positive training effects gained after training using the CDBS were carried over to greater BBT scores. A possible explanation is that the same changes (improved postural sway control) on the CDBS after the three-week multisensory training program could be shown on clinical measures (i.e. the BBT). Hence, the third hypothesis was supported, suggesting that the ETG gained greater BBT scores when compared to the untrained ECG after completing the multisensory training program.

7.3 OVERALL CONCLUSIONS

Measurements of postural sway have numerous potential applications in rehabilitation, such as determining the effect of injury, surgery, and treatment. It is important to establish the reliability of postural sway measurements for different testing conditions. To date, few standardized measurement tools exclusively measure postural sway. The Chattecx Dynamic Balance System (CDBS) (Chattanoogo Group, Inc, Hixson, TN) (Figure 1.3) has been utilized as one of the devices capable of quantifying postural sway measurements. However, this system revealed a wide range of reliability values from previous studies. Since the researcher intended to use the CBDS to measure the effectiveness of a three-week multisensory training program (Study 2), it was wise to test the reliability of the CBDS before the researcher could use it confidently to quantify postural sway measures for the second study.

The first investigation addressed reliability and validity of measurement and added to the limited pool of normative data for postural sway. The information coming from this study could increase clinicians understanding of the importance of selecting a valid and reliable measurement tool in clinical setting for quantifying postural sway measures and functional balance ability. The study findings suggest that the CDBS yielded good test-retest reliability (ICCs > 0.80) to be utilized over time for quantifying postural sway although it failed to show discriminant validity to distinguish between vigorously active and moderately active non-injured young females identified by hours spent doing sporting activities per week.

After the test-retest reliability was established (ICCs > 0.80) in Study 1, the CDBS was utilized to determine the effectiveness of a three-week multisensory training program on postural sway control in Study 2. The second investigation proved that both the trained non-injured young and elderly females could successfully reduce the amount of sway for all three postural sway measures after completing the training regimen. This means the CDBS can identify changes in all three postural sway measures after a training regimen. The discriminant validity of the CDBS was conducted in Study 2 to reestablish whether the CDBS show discriminant validity. In the case of distinguishing postural sway measures following the training regimen, the CDBS showed discriminant validity in differentiating the improved postural sway measures of both training groups with the unchanged postural sway measures of both control groups.

It is interesting to note that in order to further support that the CDBS showed good test-retest reliability for quantifiying postural sway measures in Study 1, the test-retest reliability were analysized in Study 2 using pretest and posttest scores for both the YCG and the ECG although it was not within the scope of Study 2. The results demonstrated that the CDBS revealed higher test-retest reliability of ICC = 0.99 in Study 2 than reported in Study 1 (ICCs > 0.80).

It is suggested that when designing postural sway control training programs, specific sensory systems have to be targeted. These results imply adaptation of the CNS in response to peripheral training. Subjects likely gained familiarity with specific tasks and thus were able to alter existing motor control programs or develop new ones to meet the demands of new balancing tasks. The results are supported by previous studies [196,230] which showed that in the absence of sensory training on postural sway, very limited changes for both static and dynamic balance tasks for stroke subjects were seen. Furthermore, the positive findings of the present study seem to provide some insight into the relationship between the sensory systems and motor control and the underlying causes of postural sway.

Another important aspect in this type of intervention study is to know how well the subjects have complied with the intervention program. It might be difficult to motivate the subjects to perform the training as prescribed and to maintain their motivation at a high level throughout the entire study period. It is important to minimize fatigue-related changes by allowing seated rests between training protocols and by limiting the length of the training duration and testing session.

As noted earlier, there were no significant differences in improvement across all six training factors in both age groups. However, both the YTG and the ETG did indicate greater improvement for static balance with the eyes-closed condition, and bilateral stance. In view of these, the researcher suggests that in order to expect training improvement, a multisensory training program should focus on both the aforementioned training factors especially for elderly adults. The dynamic balance and unilateral stance conditions might be too demanding especially for elderly population with pathology. For training, there is no preference in terms of leg dominance to obtain the desired training effect.

Important Considerations for a Multisensory Postural Sway Control Training Program for the Elderly
* Target the three specific sensory systems. * Be sure to include static balance with the eyes-closed condition because it is the most effective training factor. * Leg preference is not an issue. * Minimize fatigue-related changes. * Provide seated rest between training protocols. * Provide motivation and support.

The tendency to lose balance at pretest for the elderly females could indicate a failure of central integrative mechanisms to adapt to sensory conflict. The ETG were able to balance when repeated trials were given. This could indicate a difficulty in adjusting sensory weightings and control strategy to unfamiliar and difficult conditions at pretest. The training protocols were designed to provoke a sensory mismatch to expose the subjects to increasingly unstable body positions in order to facilitate rearrangement and recruitment of control capacities. Hence, the subjects enhanced compensation by facilitating central recalibration through various training protocols. [131]

The dynamic training and evaluation protocols more effectively mimic everyday activities than traditional evaluation of postural characteristics (e.g. Romberg test). [231,232] Much information exists that gives values for postural sway under different sensory conditions for normative populations. For this type of multisensory training program using visual feedback for postural rehabilitation in a dynamic setting, the training effects of both non-injured young and elderly females over a course of repeated training needed to be established for a population without postural disorders. Although this study is limited in sample size, and cannot be considered a normative study; training effectiveness and improved postural performance for both the ETG and the YTG have been established, and should be considered before interpreting information from injured patient populations.

7.4 CLINICAL RELEVANCE

7.4.1 Study 1

It is critical to establish the test-rest reliability and validity of a device used in the clinical setting, to ensure that it provides useful and meaningful information for the intended purposes on a specific population as validity addresses what the research is able to do with the test results. Additionally, research is needed to document validity each time the same instrument used because like reliability, the validity is not an all-or-none thing, but rather a characteristic that an instrument has to a varying degree. [118]

Little is known about the validity and reliability of the CDBS in evaluating postural sway. Therefore, the results of the first study provided valuable information on the validity and reliability of the CDBS in evaluating postural sway measures on non-injured females who ranged from 20 to 49 years of age. The findings support the use of the CDBS as a clinical measurement tool to assess postural sway within a similar laboratory or clinical setting, as the Study 1 revealed good clinical test-retest reliability values (ICCs > 0.80). Most importantly, the information provided by this study helped to increase the clinicians' confidence when using the CDBS to evaluate the same construct of postural sway. Furthermore, data obtained from this study are essential in increasing the understanding of postural sway evaluation.

Various methods are available to assess the ability of postural sway control and functional balance ability using field and laboratory measures. No one measurement device can evaluate all aspects of postural sway and balance control. The assessment approach selected by a clinician depends on the purpose of the assessment and on the type of balance deficits to be evaluated.

The Berg Balance Test (BBT) [233-235] is the most popular functional balance assessment tool in physical therapy which was originally designed to predict falls in the ambulatory elderly. Elements of the test are supposed to be representative of daily activities that require balance. However, the BBT scale does not test for performance under conditions of altered sensory context or attention distracters and does not include gait. The lack of items that require a postural response to an external stimulus or uneven support surface is a limitation of this test. It will likely limit the utility of the test when evaluating very active persons with minimal deficits. However, the test does appear to give a range of scores for persons with identified balance impairment and in the frail and elderly.

Advances in computer and force platform technology allow objective and quantitative measures of balance control in term of postural sway.[78] Force platforms measure the center of pressure (COP) exerted by the individual standing on the platform. The COP excursion provides an indirect measurement of postural sway.[10] The force platform technology was further refined by the development of computerized dynamic posturography. The Chattecx Dynamic Balance System (CDBS) is one of the computerized dynamic posturography machines utilizes the force platform technology. The CDBS measures and records a patient's "absolute" center of gravity (COG) utilizing a pair of patented footplates. The plates each have four transducers, which allow the user to locate the mean center of balance (COB).[126] The sway index representing the degree of scatter of the data about the COB is unique to the CDBS. The software allows for documentation of session as well as comparative analysis over time.

When compared the usefulness of the BBT scale to the CDBS in measuring postural sway measures and functional balance ability, the CDBS shows advantages that were not found in the BBT scale. More importantly, the BBT scale did not contain items to address postural response to an external stimulus or uneven support surface, nor any test for performance under conditions of altered sensory context, where these criteria were critical in measuring postural sway control based on a systems approach. Furthermore, the BBT scale did not provide quantitative information about the function of the sensorimotor systems involved with postural sway control. It addressed the ability to hold, maintain, and change positions with minimal alterations in visual inputs (i.e. standing with the eyes-closed) and somotosensory inputs (i.e. standing with feet together, standing with one foot in front, and standing on one foot). However, the CDBS allowed varieties of postural responses to external stimuli or an uneven support surface and it is capable to measure the performance under various conditions of altered sensory context. In addition, the BBT scale did not provide comprehensive feedback, objective scoring, or graphic recording.

It is noteworthy that the CDBS and the BBT scale indicated significant correlation ($r = 0.46$) at $\alpha_2 = 0.05$ for postural sway measures and functional balance ability assessment.

7.4.2 Study 2

The second study probed linkages between sensorimotor interaction training and decrease postural sway in healthy adults. The positive results of this study could have a direct bearing upon the design and clinical usefulness of postural sway control and balance retraining programs. The results are useful in providing additional information about postural control abilities in healthy young and elderly females. Clearly, the findings of the present study provide insight into balance and postural sway control and may help improve the rehabilitation and prevention programs using a similar training setting. The findings are timely because of the more widespread use of computerized laboratory measures for postural sway control testing and training. Additionally, research is needed to document the effectiveness that training has on balance and postural sway control and how this is related to recurrent injury and performance.

Although the data provided by this study could not be considered as normative data due to the sample size, the pretest values for baseline evaluation and the posttest values for after training intervention of the non-injured young and elderly females could be a valuable preliminary data used to characterize balance disordered patients and to compare training effects after rehabilitation process of patients with balance disordered.

The improvement demonstrated by the ETG (average 31%) and the YTG (average 23%) in postural sway control has implications for balance retraining in clinical populations, focusing on enhancing the sensitivity of sensorimotor integration. Such a program effectively trained static and dynamic postural sway control. Rehabilitation and preventive programs can be designed to challenge, enhance, and improve the sensitivity of sensorimotor integration. It has been suggested by Horak [41] that a systems approach could be used for the evaluation of balance functions and the design of treatment programs for patients with balance deficits. To design customized treatment programs for individuals, a systems approach includes the evaluation of such differing physiological aspects as sensory functions, motor coordination, higher level adaptive mechanisms, and musculoskeletal constraints to postural control.[41]

Prerequisites for a Postural Sway Control Training for Non-injured Elderly Adults using a Systems Approach

* Normal sensory functions (visual, vestibular, and somatosensory).
* Normal motor coordination.
* Normal higher level adaptive mechanisms.
* Normal musculoskeletal systems.
* No history of neurological pathologies.

Thus, evidence presented in prior research as well as the findings from the present study suggest that the systems approach would be more effective than general exercise training programs in effecting improvement of functional balance ability and postural sway control especially among an elderly population.

The effectiveness of current multisensory training intervention could be beneficial to athletic trainers, coaches, and individuals as a preventive training program for postural sway control and functional balance ability. In the long term, it is conceivable that the practice of multisensory training as a daily exercise, especially for elderly adults, could result in long term health maintenance, thus result in a significant conservation of financial and other health care resources.

As for other types of training regiments, the training volume, intensity, and duration are the most important factors to be considered. It is important to note that the training volume, intensity, and duration of this three-week multisensory training intervention were proved to be sufficient to improve postural sway control significantly on the selected population of interest.

7.5 DIRECTIONS FOR FUTURE RESEARCH

While the first study provides initial data regarding the test-retest reliability of the CDBS and groups performances on the six evaluation protocols of postural sway measures, future research is needed to further understand the CDBS clinical utility. Although the test-retest reliability of all three postural sway measures which consisted of OS, APS, and MLS produced by the CDBS were good and comparable to that of other evaluation devices, further studies are needed to determine whether the reliability of these postural sway measures might differ among injured populations and athlete populations.

Additional strategies for improving the CDBS reliability such as increasing the number of test repetitions or occasions should also be investigated to determine if the measure stabilizes. If multiple trials are performed, appropriate rest periods should be included to prevent fatigue. In addition, the possibility of learning effects due to multiple testing should not be overlooked because the learning effect could be a confounding variable and a threat to internal validity of the study.

The researcher noticed during the testing procedures that subjects had individual techniques to maintain concentration in order to maintain balance. For instance, some subjects would count down for 10 seconds (test duration) to themselves to remain focused on the task. Future research should examine different concentration techniques for maintaining or improving functional balance ability and postural sway control.

The positive impact on postural sway control yielded by both trained non-injured young and elderly females after following the three-week multisensory training program can be attributed to a training effect. This training effect should be accounted for when performance is evaluated in injured patient populations utilizing the CDBS therapeutically.

Further investigation is needed to determine if this multisensory training program may delay premature balance dysfunction and may reduce risk of falling for elderly adults. In addition, future studies should focus on whether the measures of the CDBS predict falls in older adults. Research is needed as well to examine the relationship of the CDBS and the BBT scale to predict risk of falling in elderly adults. Additional studies need to be performed to confirm these results and to determine whether the improvement is maintain over time.

Additionally, future studies are necessary to train and to compare the improvements seen in this study to other populations such as injured young and elderly individuals, including male populations. Application of this multisensory training program to rehabilitation and preventive postural sway control and balance retraining program for geriatric patients also needs further investigations.

Additional research is needed to determine the training effect on muscle strength especially of ankle dorsiflexion on elderly populations. Hence, additional research is needed to answer this question and to examine whether muscle strength contributed to balance and postural sway control.

More research is needed in this area to determine the contribution that multisensory training program makes to overall functional balance ability and enhanced postural sway control. Nonetheless, in view of the limitations of the study, it is clear that further research is needed to verify the present results and to assess their generalizability.

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Appendix 1.A
Self-report Questionnaire for Study 1

Personal Demographic and Anthropometric Data

Name:____

Date of Birth: ____________________(dd/mm/yy) Age: ( ) yrs

Height: ( ) cm / ( ) feet ( ) inches BMI: ( )

Weight :( ) lbs/ ( ) kg

Now we would like to know about your sporting activities during the past 7 days.
For at least the last three months, please noted that which of the following sports activities you have performed regularly each week? Also, please recall your sporting activities during the past 7 days and quantify the time spent of each activity as precisely as possible.

List of examples of sports activities ^{74} and actual playing time:

You may choose more than one activity: _/
(See next page)

Sporting Activities	M	T	W	T	F	S	S	Hours Spent
1. ( ) jogging								( ) hrs ( ) mins
2. ( ) brisk walking								( ) hrs ( ) mins
3. ( ) cycling								( ) hrs ( ) mins
4. ( ) skating								( ) hrs ( ) mins
5. ( ) swimming								( ) hrs ( ) mins
6. ( ) tennis								( ) hrs ( ) mins
7. ( ) ping pong								( ) hrs ( ) mins
8. ( ) badminton								( ) hrs ( ) mins
9. ( ) basketball								( ) hrs ( ) mins
10.( ) volleyball								( ) hrs ( ) mins
11.( ) soccer								( ) hrs ( ) mins
12.( ) hockey								( ) hrs ( ) mins
13.( ) baseball								( ) hrs ( ) mins
14.( ) cross country skiing								( ) hrs ( ) mins
15.( ) snow boarding								( ) hrs ( ) mins
16.( ) golf								( ) hrs ( ) mins
17.( ) aerobic dance								( ) hrs ( ) mins
18.( ) work out in gymnasium								( ) hrs ( ) mins
19.( ) yoga								( ) hrs ( ) mins
20.( ) tai chi								( ) hrs ( ) mins
21.( ) running								( ) hrs ( ) mins
Other :								
____________________								( ) hrs ( ) mins
____________________								( ) hrs ( ) mins
____________________								( ) hrs ( ) mins
____________________								( ) hrs ( ) mins
____________________								( ) hrs ( ) mins

*Compared with your sporting activities over the past 3 months, was last week's sporting activities more, less, or the same?

a. _____ more (please specify _____hours _____minutes
b. _____ less (please specify _____ hours _____minutes
c. _____ the same

Total hours spent on sporting activities per week: ( ) hours ( ) minutes

THANK YOU

Appendix 1.B
Information Letter to Subjects (Study 1)

Title Study 1: Assessment of Test-retest Reliability and Discriminant Validity on Postural Sway Measures using the Chattecx Dynamic Balance System of Non-injured Females.

Principle Investigator: Dr. David Magee – Ph.D, Professor
Faculty of Rehabilitation Medicine.
Phone number: 780-492-5765 / 4824

Co-Investigator: Ai Choo Lee -- Doctoral Candidate
Ph.D Program in Rehabilitation Science.
Phone number: 780-492-4824

Background: Testing postural balance ability can play an important part in the rehabilitation of injury. Postural balance ability of healthy individuals is important as reference to compare with injured individuals.

Purpose: The purpose of this study is to find out whether the Chattecx Dynamic Balance System (CDBS) is a reliable device for the postural sway measurement. Meanwhile, the validity of the CDBS will be estimated. This is to distinguish between individuals who are regularly practicing sporting activities five hours or more per week, and less than five hours per week.

Procedures: Before beginning, you will be asked to complete personal demographic data. You will be answered a self-report questionnaire. This will take about 20 minutes. If you meet all the inclusion criteria, you will be chose to participate in this study. If you agree to participate, you will read, understand, and sign the informed consent form.

Firstly, I will adjust the length of the Heel Plate. Your heel/heels will be bisected by the center line on the computer screen. Then you will put on the safety harness. You will then cross both your arms. Your hands will touch the opposite shoulder. You will try to maintain your body upright.

There will be six tests in an assessment. You will have to stand as still as possible while being tested. You can practice for each test. You will be tested with the eyes-open and the eyes-closed. You will be tested with one-legged and two-legged stance. All tests will be either on a stable or a moving platform. You will have to repeat the six tests twice. The tests will be in a difference order. Each test only takes 10 seconds. You will have a one minute rest period between each test. You will be asked to sit down during the rest period.

Please do not open your eyes (the eyes-closed condition). Please do not grab hold of the handrails. Please do not lean on the safety harness. Please do not bended hips into more than 30^0, please do not bended your knees more than 30^0 to regain balance. If you do so, you will have to redo the test.

The testing process will take about 25 minutes each session. You will be tested twice in a week. Both the testing days will be set according to your time.

All testing and training sessions will be held in CH1-81, Sport Therapy Research Laboratory, Corbett Hall, Faculty of Rehabilitation Medicine, University of Alberta.

The information collected for the study may be used for secondary analysis at a later time. If used for this purpose, these data will be handed in for separate ethical review.

Benefits / Risks: This study will provide information for validity and reliability of the CDBS for postural sway measurement. The results of this research will help clinicians use the CDBS confidently. The process of testing protocols will not harm you physically or psychologically. However, a harness will be use as safety precaution to prevent you from falling.

Confidentiality: All information will be held confidential, unless when professional codes of ethics require reporting. All data will be kept private. No one will have access to the information and study data. Except the investigators, and when codes of ethics requires. The information you provide will be kept for at least five years after the study is done. The information will be kept in a secure area (i.e. locked filing cabinet). Your name or any other identifying information will not be shown with the information you gave. Your name will also never be used in any presentations or publications of the study results. The information gathered for this study may be looked at again in the future to help us answer other study questions. If so, the ethics board will first review the study to ensure the information is used ethically.

Freedom to withdraw: You can choose not to take part or to withdraw from the study at any time. You can also choose to withdraw your information from the study database at any time.

Contact Information: You will be given a copy of this consent form. If you have any questions about the study, please call Ai Choo Lee at 780-492-4824 or Dr. David Magee at 780-492-5765 / 4824.

If you have any concerns about any aspect to this study, you may contact Dr. Paul Hagler, Associate Dean of Graduate Studies and Research in the Faculty of Rehabilitation Medicine, University of Alberta at 780-492-9674. Dr. Hagler is independent from the study investigator.

Please initial if you have read and understood the information stated above.

Name of Participant: ________________________Date:__________(Please print)

Initial of Participant: ________________________Date:__________

Initial of Investigator: ________________________Date:__________

Appendix 1.C
Information Letter to Subjects (Study 2)

Title Study 2: The Effect of a Three-week Multisensory Training Program for Postural Sway Control.

Principle Investigator: Dr. David Magee – Ph.D, Professor
Faculty of Rehabilitation Medicine
Phone number: 780-492-5765

Co-Investigator: Ai Choo Lee -- Doctoral Candidate
Ph.D program in Rehabilitation Science
Faculty of Rehabilitation Medicine
Phone number: 780-492-4824

Background: Postural balance training plays an important part in any rehabilitation program. The effectiveness of postural balance training provides information about healthy young and elderly individuals as a reference to train and to rehabilitate injured individuals.

Purpose: The Chattecx Dynamic Balance System (CDBS) is used as a postural balance training tool. The purpose of this study is to train the healthy young and elderly female adults on postural sway control using the CDBS for three week to determine if training will cause an improvement in postural sway control. This study is undertaken to create a baseline data for postural sway control training program for future research that could use subjects with previous injury or injured athlete populations. This study also will serve to establish a more normative baseline data for effective postural sway control training program that will enable clinicians to make comparisons between rehabilitation programs.

Procedures: Before beginning, you will complete a questionnaire. This will take about 20 minutes. If you agree to take part in the study, you will be asked to read, and sign the informed consent form. If you have any questions about consent information, please ask. You are being asked to come for two test sessions within three weeks. Each session will take about 40 minutes. Both testing days will be set according to a time that is convenient for you.

If you are randomly assigned to experimental group, you will be trained twice weekly for three weeks. Each training session will last for an hour. You will be trained either with a stable or a moving platform; one-legged or two-legged; eyes-open or eyes-closed. You will wear a blindfold for the eyes-closed condition. You will be trained for one minute for each condition two times. Across training conditions, there will be 30 seconds rest and a five-minute break between training sets. You are asking to train in bare feet. The nine training conditions as follows:

1. Left leg on stable platform with the eyes-open watching bull's-eye for visual feedback
2. Bilateral Romberg stance on platform moving down with the eyes-closed

3. Right leg on stable platform with the eyes-open watching bull's-eye for visual feedback
4. Left leg on platform moving down with the eyes-open watching bull's-eye for visual feedback
5. Bilateral tandem stance on stable platform with the eyes-closed
6. Right leg on platform moving down with the eyes-open watching bull's-eye for visual feedback
7. Left leg on stable platform with the eyes-closed
8. Bilateral Romberg stance on platform moving up with the eyes-open watching bull's-eye for visual feedback
9. Right leg on stable platform with the eyes-closed

All testing sessions will be held in CH1-81, Sport Therapy Research Laboratory, Corbett Hall, Faculty of Rehabilitation Medicine, University of Alberta.

Benefits / Risks: There is a possibility of improved balance and postural control for two of the young and elderly training groups. This study will provide information on the effectiveness of postural sway control training program using the CDBS. The results of this research will help clinicians use the CDBS as training device for rehabilitating postural balance ability for young and elderly adults. The process of testing protocols will not harm you physically or psychologically. However, a harness will be use as safety precaution to prevent you from the possibility of falling.

Confidentiality: All information will be held confidential. All data will be kept private. No one will have access to the study data, except the investigators. The information you provide will be kept for at least five years after the study is completed. The information will be kept in a secure area (i.e. locked filing cabinet). Your name or any other identifying information will not be shown with the information you give. Your name will never be used in any presentations or publications of the study results. The information gathered for this study may be looked at again in the future to help us answer other study questions. If so, the ethics board will first review the study to ensure the information is used ethically.

Freedom to withdraw: You can choose not to take part or to withdraw from the study at any time. You can also choose to withdraw your information from the study database at any time.

Contact Information: You will be given a copy of this consent form. If you have any questions about the study, please call Ai Choo Lee at 780-492-4824 or Dr. David Magee at 780-492-5765.

If you have any concerns about any aspect of this study, you may contact Dr. Paul Hagler, Associate Dean of Graduate Studies and Research in the Faculty of Rehabilitation Medicine, University of Alberta at 780-492-9674. Dr. Hagler is independent from the study investigator.

Appendix 1.D
Consent Form (Study 1 and 2)

Part 1: Researcher Information

Name of Principal Investigator and Academic Advisor: Dr. David Magee
Affiliation: University of Alberta, Faculty of Rehabilitation Medicine
Contact Information: 780-492-5765 / 4824

Name of Co-Investigator: Ai Choo Lee
Doctoral Candidate for Ph.D. Program in Rehabilitation Science
Affiliation: University of Alberta, Faculty of Rehabilitation Medicine
Contact Information: 780-492-4824
Email: ail@ualberta.ca

Part 2: Consent of Subject

	Yes	**No**
Do you understand that you have been asked to be in a research study?		
Have you read and received a copy of the attached information sheet?		
Do you understand the benefits and risks involved in taking part in this research study?		
Have you had an opportunity to ask questions and discuss the study?		
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your care.		
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records/information?		

Part 3: Signatures

This study was explained to me by: ______________________________
Date:

I agree to take part in this study.

Signature of Research Participant: ______________________________
Printed Name:

Witness (if available): ____
Printed Name:

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

Researcher: ____

Printed Name:

* *A copy of this consent form must be given to the subject.*

Appendix 3.A
Sample Size Calculation

Study 1: Discriminant Validity

A study power of 0.80 ($\beta = 0.20$) was desired.

The effect size *d* of an experiment is one of the factors that influence the statistical power of an experiment. Due to no prior research looking at sample means and variances, the effect size was fixed according to a set of conventions proposed by Jacob Cohen.[172] The researcher decided to set a large effect size *d* of 0.70. The significance level was set at $\alpha_2 = 0.05$ for a two-tailed test. An additional 20% was included to allow for attrition, and to enlarge the normative data pool. Based on Table 3.1, the number of subjects required for the two independent samples t-test was 33. With the 20% (N = 7) for attrition and to enlarge the normative data pool, the total sample size required in this study were 40 subjects.

Table 3.1: Sample size needed for the t- test to achieve power of 0.80 with an effect size (*d*) of 0.70 at the $\alpha_2 = 0.05$ significance level for a two-tailed test. (Modified from Table 2.4.1 in Cohen, J., p.55, 1988.)[172]

	***d* at α_2 = 0.05**								
Power	0.10	0.20	0.30	0.40	0.50	0.60	**0.70**	0.80	0.90
0.70	1235	310	138	78	50	35	26	20	13
0.80	1571	393	175	99	64	45	**33**	26	17
0.90	2102	526	234	132	85	59	44	34	22

Sample Size Calculation

Study 1: Test-retest Reliability

A study power of 0.80 ($\beta = 0.20$) was desired.

The effect size *r* of an experiment is one of the factors that influence the statistical power of an experiment. Due to no prior research looking at sample means and variances, the effect size was fixed according to a set of conventions proposed by Jacob Cohen. [172] The researcher decided to set a large effect size *r* of 0.50. The significance level was set at $\alpha_2 = 0.05$ for a two-tailed test. An additional 20% was included to allow for attrition, and to enlarge the normative data pool. Based on Table 3.2, the number of subjects required for the correlation coefficient (*r*) was 28. With the 20% attrition (N = 6), the total sample size required in this study was 34 subjects.

Due to the reliability and validity study being conducted concurrently, the researcher decided to refer to the sample size required by the validity study (i.e. 40 subjects).

Table 3.2: Sample size needed for the correlation coefficient (*r*) to achieve power of 0.80 with an effect size (*r*) of 0.50 at the $\alpha_2 = 0.05$ significance level for a two-tailed test. (Modified from Table 3.3.1 in Cohen, J., p.92, 1988). [172]

	***r* at α_2=0.05**								
Power	0.10	0.20	0.30	0.40	**0.50**	0.60	0.70	0.80	0.90
0.70	616	153	67	37	23	15	10	7	5
0.80	783	194	85	46	**28**	18	12	9	6
0.90	1047	259	113	62	37	24	16	11	7

Appendix 3.B
Screening Questionnaire: Study 1

***All personal information given by subjects is for the purpose of a screening process to identify qualified subjects for this study. The information is guaranteed confidential and will not be release and printed to any resource.*

Name:_______________________________
Date of Birth: (dd/mm/yy) Age: ( ) yrs

Health Information (please check your answer)

i. Inclusion Criteria:

1. Normal ankle with no known injury	Yes ( ) No ( )
2. Normal visual function.	Yes ( ) No ( )
3. Normal vestibular (balance) function.	Yes ( ) No ( )
4. Normal function of all joints.	Yes ( ) No ( )
5. Vigorously active in sporting activities five hours or more per week participating in competition or as an active pastime for pleasure or exercise. [74]	Yes ( ) No ( )
6. Moderately active in sporting activities less than five hours per week participating in competition or as an active pastime for pleasure or exercise. [74]	Yes ( ) No ( )

ii. Exclusion Criteria

1. Injuries (sprain or fracture) to either ankle.	Yes ( ) No ( )
2. Past history of surgery to either lower extremity.	Yes ( ) No ( )
3. Ankle pain while at rest.	Yes ( ) No ( )
4. Lower extremity (thigh/knee/hip) injury within six months of study.	Yes ( ) No ( )
5. History of neurological conditions affecting balance.	Yes ( ) No ( )
6. Abnormal posture (to move or hold one or more parts of the body in a particular way).	Yes ( ) No ( )
7. Abnormal body mechanics (e.g. feet shape).	Yes ( ) No ( )
8. Physically impaired (e.g. amputation).	Yes ( ) No ( )
9. Medication that would affect or alter the ability to balance. (see next page)	Yes ( ) No ( )

THANK YOU

Examples of medications that could affect normal balance

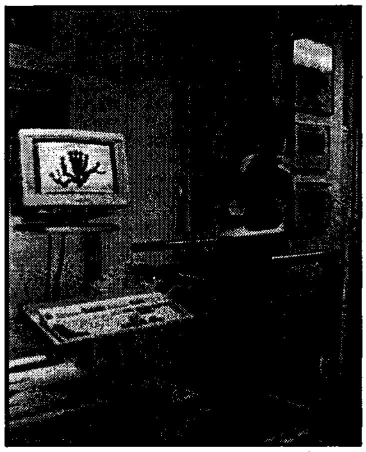
Pain Relief: Tramadol Ultram Fioricet Codeine Celebrex OxyContin Esgic Plus Imitrex	**Antihistamines:** Diphenhydramine (Benadryl) Atarax (Hydroxyzine) Gravol Cetrizine (Reactin) Claritine Meclizine	**Heart and Cardiovascular:** Aldactone Betapace Calan Digitek Fluvastatin Lopid Hytrin
Depression: Prozac, Fluoxetine Effexor Paxil Buspar Wellbutrin	**Anti-Inflammatory:** Bextra Indocin Naproxen Ponstan Celebrex	**Muscles Relaxants :** Cyclobenzaprine Soma Skelaxin Zanaflex Carisoprodol
Hyprotics: Alcohol Ativan Valium Librium	**Anti-Biotic:** Avelox Biaxin Cipro XR Daraprim	**Cough and Cold Remedies:** Sinutab Neocitran Contac Co-actiFed
Headache and Migraine Esgic Depakote Relpax	**ADHD Medications:** Ritalin Dexedrine	**Allergy:** Allegra-D Zyrtec
Cigarates: Nicotine	**Stop smoking:** Zyban	**Diet Pills:** Phentermine
	Insomnia: Ambien	

**In view of the fact that the study population are healthy female adults, these example medications are listed according to the possible needs of the study population after consulting a pharmacist at the University Health Centre, University of Alberta.*

Appendix 3.C: Recruitment Poster for Study 1

Would you like to be involved in a study to measure postural sway?

Volunteers Needed for Research on Postural Sway (Balance) in Healthy Females



Are you in the age range of 20 to 49 years old?

If so, we invite you to take part in our research study.
We are assessing reliability and validity of
the Chattecx Dynamic Balance System for postural sway measures.

The evaluation protocol will take place at the Sport Therapy Laboratory
(RM 1-81), Faculty of Rehabilitation Medicine, Corbett Hall,
University of Alberta.

The evaluation process will take about 45 minutes for 2 sessions
within a week period.

It will be an interesting experience for you.

Please email to Ai Choo Lee at ail@ualberta.ca and leave a message
at 492-4824 for more information or to enroll.

Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824

Appendix 3.D
Standardization of Evaluation Protocols for Study 1 and 2

Thank you for agreeing to be evaluated as part of this research project. All evaluations will be performed in bare feet. Each evaluation takes about 10 seconds. You will have to repeat this evaluation twice for the six tests done in a difference sequence.

Prior to Testing:

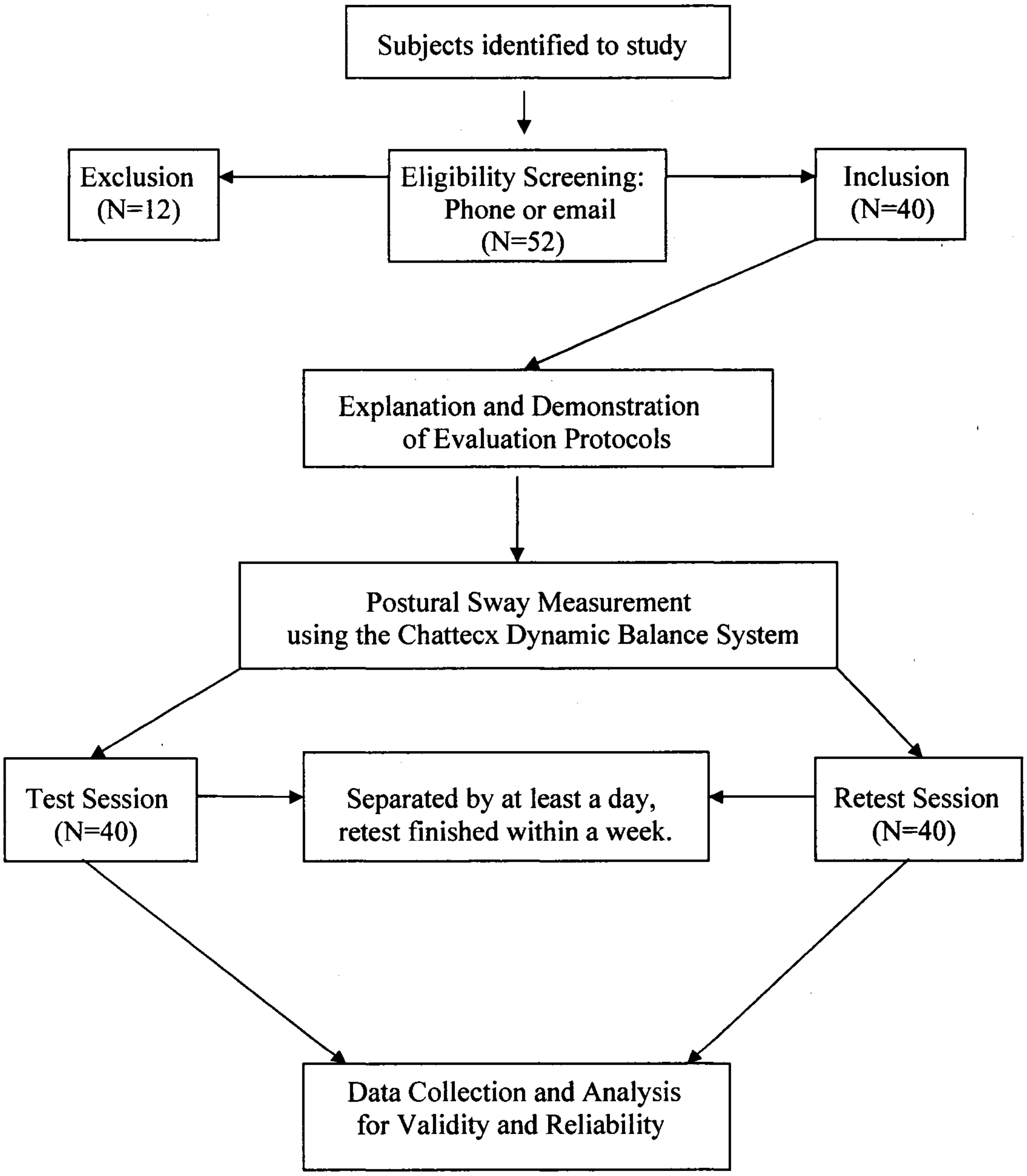
1. I will measure your height and weight using the beam scale.
2. To determine the length of your feet, you will step on the footplates of the CDBS. Your toes will rest just above the center line of the toe plate. I will adjust the length of the heel plates so your heels are bisected by the center line on the computer screen.
3. You will put on the safety harness in such a way that will not impede your body sway.
4. You will then cross both arms and hands to touch the opposite shoulders.
5. For the one foot protocols in which you stand on one leg, you will have to stand with the test leg straight, while the untested leg will have the knee flexed to 90^0 and the hip flexed to 20^0.
6. Please maintain your posture erect and upright for all tests.
7. Please stand as still as possible while being tested. Small corrections in the ankle, knee, hip, arms, and trunk may occur and are considered normal.
8. You will have an opportunity to practice each test before actual testing begins. I will tell you about each test condition before each practice trial.

During Testing:

1. You will not be told the order of the test conditions except whether the test involves two-leg standing or one leg standing, and eyes open and closed. You will not be told how the platform will move until I say “go”.
2. There are six test conditions that will be randomly assigned:
   a. Two feet on stable platform (eyes-closed)
   b. Two feet on platform moving up and down (eyes-open)
   c. Right foot on stable platform (eyes-closed)
   d. Left foot on stable platform (eyes-closed)
   e. Left foot on platform moving forward and backward (eyes-open)
   f. Right foot on platform moving forward and backward (eyes-open)
3. For each test condition, when you say you are balanced and ready, I will tell you when to start by saying “go”.
4. I will inform you as soon as the test is completed by saying “stop”. You will have a one minute rest period between each test. You will be allowed to sit down during the rest period if you wish.

Appendix 3.E
Project Administration for Study 1

Study Design: Methodological Research



Appendix 3.F
Randomized Order of Evaluation Sequences
(Study 1 and 2)

Name	Bilateral				Unilateral							
	Trial 1		Trial 2		Trial 1				Trial 2			
1.	1	2	2	1	1	2	3	4	2	4	3	1
2.	2	1	1	2	2	3	4	1	3	1	4	2
3.	1	2	2	1	3	4	2	1	4	1	2	3
4.	2	1	1	2	1	2	3	4	2	4	3	1
5.	1	2	2	1	2	3	4	1	3	1	4	2
6.	2	1	1	2	3	4	1	2	4	2	1	3
7.	1	2	2	1	2	1	3	4	1	4	3	2
8.	2	1	1	2	1	3	4	2	3	2	4	1
9.	1	2	2	1	3	4	1	2	4	2	1	3
10.	2	1	1	2	4	1	2	3	1	3	2	4
11.	1	2	2	1	1	2	4	3	2	3	4	1
12.	2	1	1	2	3	4	1	2	4	2	1	3
13.	1	2	2	1	4	1	2	3	1	3	2	4
14.	2	1	1	2	1	2	3	4	2	4	3	1
15.	1	2	2	1	2	3	4	1	3	1	4	2
16.	2	1	1	2	3	4	1	2	4	2	1	3
17.	1	2	2	1	2	1	3	4	1	4	3	2
18.	2	1	1	2	1	3	4	2	3	2	4	1
19.	1	2	2	1	3	4	1	2	4	2	1	3
20.	2	1	1	2	4	1	2	3	1	3	2	4
21.	1	2	2	1	2	1	3	4	1	4	3	2
22.	2	1	1	2	1	3	4	2	3	2	4	1
23.	1	2	2	1	3	4	1	2	4	2	1	3
24.	2	1	1	2	4	1	2	3	1	3	2	4
25.	1	2	2	1	1	2	4	3	2	3	4	1
26.	2	1	1	2	3	4	1	2	4	2	1	3
27.	1	2	2	1	4	1	2	3	1	3	2	4
28.	2	1	1	2	1	2	3	4	2	4	3	1

Appendix 3.G
Data Collection Form for Study 1 and 2

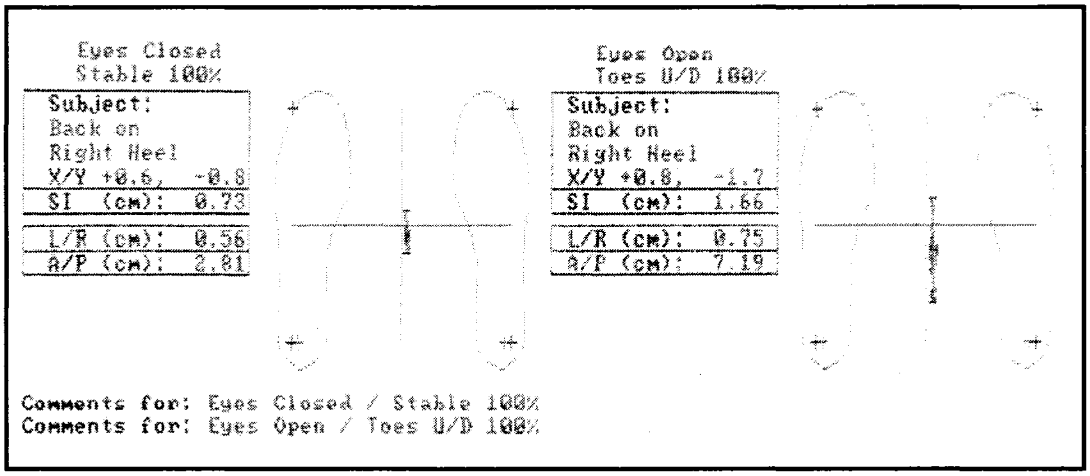
Name:

Study 1=> Group: G1 ( ) G2 ( )
Study 2=> Group: YCG ( ) YTG ( ) ECG ( ) ETG ( )

Pretest	Date:		**Posttest**	Date:	
Test 1: Bilateral Eyes-closed Stable					
Evaluation 1	Evaluation 2	Average	Evaluation 1	Evaluation 2	Average
OS			OS		
ML			ML		
AP			AP		
Test 2: Bilateral Eyes-open Toes Up-down					
Evaluation 1	Evaluation 2	Average	Evaluation 1	Evaluation 2	Average
OS			OS		
ML			ML		
AP			AP		
Test 3: Right Leg Eyes-open Linear					
Evaluation 1	Evaluation 2	Average	Evaluation 1	Evaluation 2	Average
OS			OS		
ML			ML		
AP			AP		
Test 4: Right Eyes-closed Stable					
Evaluation 1	Evaluation 2	Average	Evaluation 1	Evaluation 2	Average
OS			OS		
ML			ML		
AP			AP		
Test 5: Left Leg Eyes-open Linear					
Evaluation 1	Evaluation 2	Average	Evaluation 1	Evaluation 2	Average
OS			OS		
ML			ML		
AP			AP		
Test 6: Left Eyes-closed Stable					
Evaluation 1	Evaluation 2	Average	Evaluation 1	Evaluation 2	Average
OS			OS		
ML			ML		
AP			AP		

* *OS: Overall Sway Index*
ML: Medial-lateral Sway Index
AP: Anterior-posterior Sway Index

Appendix 3.H
Examples of Postural Sway Test Results
(Study 1 and 2)

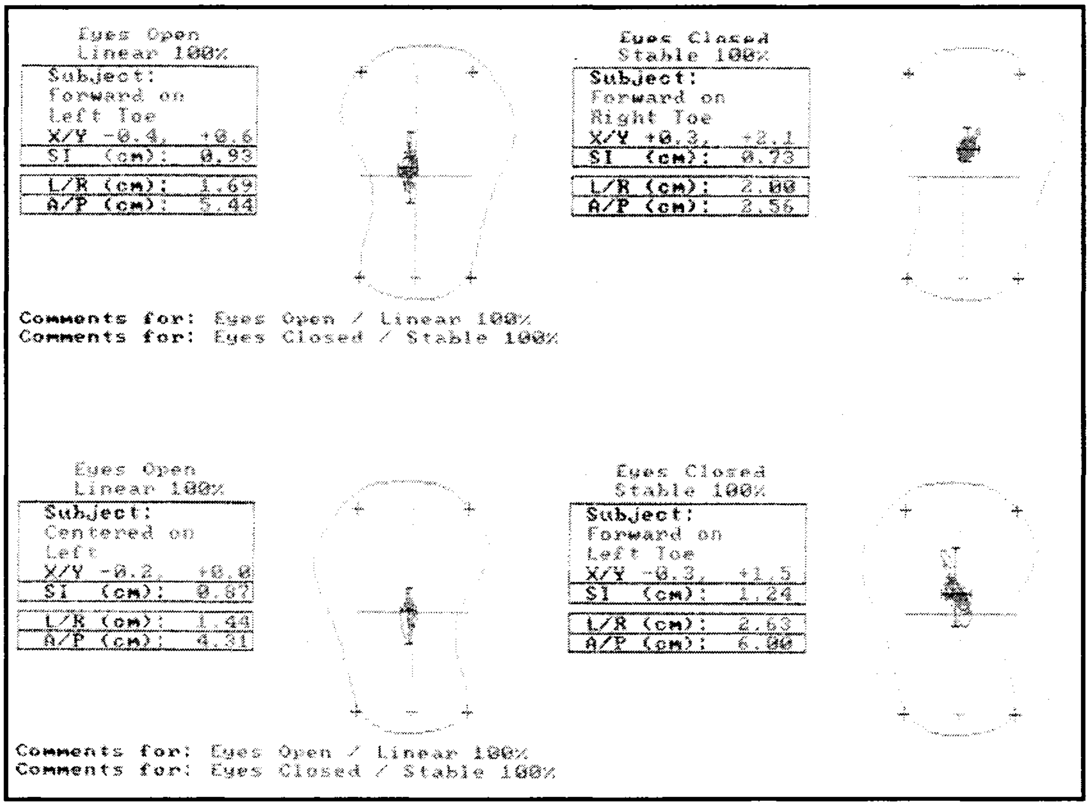


```
Eyes Closed
Stable 100%
Subject:
Back on
Right Heel
X/Y +0.6,  -0.8
SI  (cm):  0.73
L/R (cm):  0.56
A/P (cm):  2.81

Eyes Open
Toes U/D 100%
Subject:
Back on
Right Heel
X/Y +0.8,  -1.7
SI  (cm):  1.66
L/R (cm):  0.75
A/P (cm):  7.19

Comments for: Eyes Closed / Stable 100%
Comments for: Eyes Open / Toes U/D 100%
```

Figure 3.10: Two Evaluation Protocols for Bilateral Parallel Stance



```
Eyes Open
Linear 100%
Subject:
forward on
Left Toe
X/Y -0.4,  +0.6
SI  (cm):  0.93
L/R (cm):  1.69
A/P (cm):  5.44

Eyes Closed
Stable 100%
Subject:
Forward on
Right Toe
X/Y +0.3,  +2.1
SI  (cm):  0.73
L/R (cm):  2.00
A/P (cm):  2.56

Comments for: Eyes Open / Linear 100%
Comments for: Eyes Closed / Stable 100%

Eyes Open
Linear 100%
Subject:
Centered on
Left
X/Y -0.2,  +0.0
SI  (cm):  0.87
L/R (cm):  1.44
A/P (cm):  4.31

Eyes Closed
Stable 100%
Subject:
Forward on
Left Toe
X/Y -0.3,  +1.5
SI  (cm):  1.24
L/R (cm):  2.63
A/P (cm):  6.00

Comments for: Eyes Open / Linear 100%
Comments for: Eyes Closed / Stable 100%
```

Figure 3.11: Results of Four Evaluation Protocols for Unilateral Stance

Appendix 3.I

Statistical Analysis for Study 1

The power of this study was estimated at 0.80 ($\beta = 0.20$) with a large effect size of $r = 0.60$.[172] Two measurements were taken for the test and retest measures, and with mean rating, the intraclass correlation coefficients ICC (*3*, *k*) were utilized to analyze the test-retest reliability. Furthermore, SEM and CI (95%) were reported in this study.

Reliability Statistics

Standard Error of Measurement (SEM) $= s_x \sqrt{1 - r_{xx}}$

where s_x is the standard deviation of the set of observed test scores,

and r_{xx} is the reliability coefficient for that measurement.

To obtain the boundaries of a confidence interval using the formula:

Confidence Intervals (CI) $= \overline{X} \pm (z)\ s_{\overline{x}}$

where $\overline{X}$ = sample mean

$s_{\overline{x}}$ = estimator of standard error of the mean, is based on the standard deviation and size of the sample ($s / \sqrt{n}$)

* for 95% confidence intervals, **z = 1.96**

Intraclass Correlation Coefficients [118]

$$\mathrm{ICC}(1,1) = \frac{\mathrm{BMS} - \mathrm{WMS}}{\mathrm{BMS} + (k\text{-}1)\,\mathrm{WMS}}$$

$$\mathrm{ICC}(1,k) = \frac{\mathrm{BMS} - \mathrm{WMS}}{\mathrm{BMS}}$$

$$\mathrm{ICC}(2,1) = \frac{\mathrm{BMS} - \mathrm{EMS}}{\mathrm{BMS} + (k\text{-}1)\,\mathrm{EMS} + [\mathrm{k}\,(\mathrm{RMS} - \mathrm{EMS})/\mathrm{n}]}$$

$$\mathrm{ICC}(2,k) = \frac{\mathrm{BMS} - \mathrm{EMS}}{\mathrm{BMS} + [(\mathrm{R} - \mathrm{EMS})/\mathrm{n}]}$$

$$\mathrm{ICC}(3,1) = \frac{\mathrm{BMS} - \mathrm{EMS}}{\mathrm{BMS} + (k - 1)\,\mathrm{EMS}}$$

$$\mathrm{ICC}(3,k) = \frac{\mathrm{BMS} - \mathrm{EMS}}{\mathrm{BMS}}$$

*where:

BMS = the between-subjects mean square

EMS = the error mean square

RMS = the between raters mean square

k = the number of raters (Model 1 and 2)

the number of measurements (Model 3)

n = the number of subjects tested

Appendix 3.J

The Boundaries of a *t*-ratio for the Significance of a *t* Statistic for Study 1

A *t*-ratio with the significant level of $\alpha_2 = 0.05$ was used to determine the statistical significance of a *t*-test.

To calculate the critical value of *t* and to identify the boundaries to be significant:

Steps:

a. Find the degrees of freedom, df
   => df = N - 2
   = 40 - 2 = 38
b. Find the *t* critical value for df of 38.
c. Refer to 0.05 level of significance for a two-tailed t-test (α_2) with df of 38. Because there was no df of 38, the nearest value of df = 40 would used.
d. Therefore, the t critical value was ± 2.021.
   * If $t_{obs} \geq t_{crit}$, reject H_O.
   * If $t_{obs} \leq t_{crit}$, do not reject H_O.

OR

*Results were considered to be statistically significant when the $p \leq 0.05$.

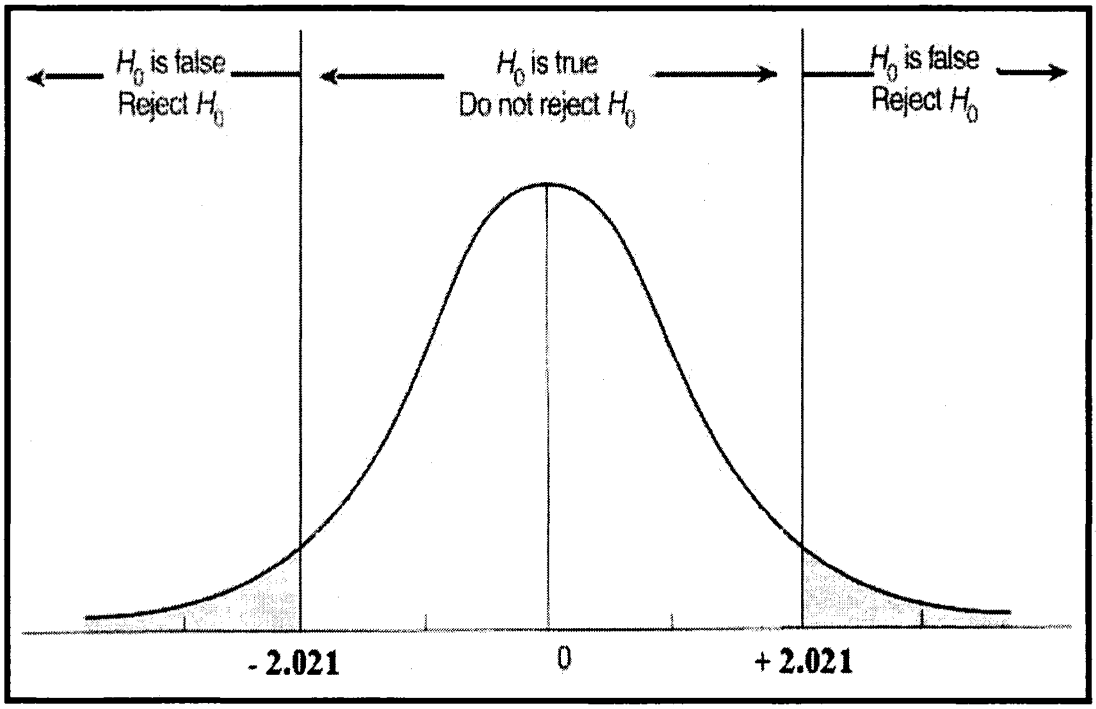


Figure 3.12: The boundaries showing critical values of a *t*-test: t_{crit} (38) = ± **2.021** for a two-tailed at $\alpha_2 = 0.05$ for Study 1.

Appendix 4.A
Sample Size Calculation for Study 2

The sample size calculation was based on AVONA procedure (repeated measures).

A study power of 0.80 ($\beta = 0.20$) was desired.

Medium effect size $f = 0.35$ was preferred.

Formula: $n_c = [(n-1)(u+1) / \text{total number of cells}] + 1$

Find out total number of cells.

Group	Pretest	Posttest
YTG		
YCG		
ETG		
ECG		
	4 cells	+ 4 cells = 8 cells in total

Find $u = (\text{row} - 1) \times (\text{column} - 1)$
$u = (4 - 1) \times (2 - 1) = 3 \times 1 = 3$

Refer to Table 8.4.4 (Cohen, 1988, pg 384) [172] for $u = 3$, power 0.80, $f = 0.35$, therefore $n = 23$.

Apply the information into formula.

Find out number of subject in each cell (n_c) for each study group.

$$
\begin{aligned}
n_c &= [(23 - 1)(3 + 1) / 8] + 1 \\
&= [(22)(4) / 8] + 1 \\
&= [(88) / 8] + 1 \\
&= 11 + 1 = 12
\end{aligned}
$$

This study needed 12 subjects for each group in each cell. There were four study groups. Because a two-way ANOVA with repeated measures procedure was used (same subjects being measured repeatedly for different factors i.e. pretest and posttest), a total of 48 subjects were required in this study for all three dependent variables.

Appendix 4.B
Self-report Screening Questionnaire for Study 2

***All personal information given by subjects is for the purpose of a screening process to identify qualified subjects for this study. The information is guaranteed confidential and will not be release and printed to any resource.*

Name:	Phone: Email:

<u>Health Information (please check your answer)</u>

i. Inclusion Criteria

1. Do you fall within the study age range (20 to 49 years)?	Yes ( ) No ( )
2. Do you fall within the study age range (60 to 80 years)?	Yes ( ) No ( )
3. Do you have normal ankle with no known injury? a. Problem for dorsiflexion b. Problem for plantar flexion c. Problem for inversion d. Problem for eversion e. Problem for rotation	Yes ( ) No ( ) (yes / no) (yes / no) (yes / no) (yes / no) (yes / no)
4. Do you have normal visual function? a. Cataracts b. Partially blind c. Totally blind	Yes ( ) No ( ) (yes / no) (yes / no) (yes / no)
5. Do you have normal vestibular (balance) function? a. Total hearing loss b. Inner ear injuries c. Sense of spinning – vertigo	Yes ( ) No ( ) (yes / no) (yes / no) (yes / no)
6. Do you have normal musculoskeletal function of all joints in lower extremity? a. Ankle pain b. Knee pain c. Hip pain	Yes ( ) No ( ) (yes / no) (yes / no) (yes / no)

ii. Exclusion Criteria

1. Have you had injuries to either ankle or foot within 6 months of the study?	Yes ( ) No ( )
2. Have you had a history of surgery to either lower extremity (hip, knee, ankle) during past five years? If so, what, where, and when?	Yes ( ) No ( )
3. Have you had a history of knee or hip replacement?	Yes ( ) No ( )
4. Do you have ankle pain while at rest?	Yes ( ) No ( )
5. Have you had lower extremity (thigh/knee/hip) injury within 6 months of the study?	Yes ( ) No ( )
6. Do you have a history of neurological conditions affecting balance? (e.g. Parkinson's disease, Multiple Sclerosis, dizziness, nausea, motion sickness)	Yes ( ) No ( )
7. Do you have a history of hypertension?	Yes ( ) No ( )
8. Do you have cardio respiratory problems?	Yes ( ) No ( )
9. Do you have abnormal posture? (e.g. bony deformity, soft tissue tightness, inability to assume a normal upright posture)	Yes ( ) No ( )
10. Do you have abnormal body mechanics? (e.g. cannot assume foot flat position)	Yes ( ) No ( )
11. Have you fallen within 6 months of the study? If yes, please explain.	Yes ( ) No ( )
12. Do you need an assistive device for ambulation?	Yes ( ) No ( )
13. Are you physically impaired? (e.g. amputation)	Yes ( ) No ( )
14. Are you taking any prescription or over-the-counters medications? If so, are any of these medications on the example medication list? (See next page)	Yes ( ) No ( )

**Please list the medications currently consume by you if it is not on the example medication list.

Examples of medications that could affect normal balance

Pain Relief: Tramadol Ultram Fioricet Codeine Celebrex OxyContin Esgic Plus Imitrex	**Antihistamines:** Diphenhydramine (Benadryl) Atarax (Hydroxyzine) Gravol Cetrizine (Reactin) Claritine Meclizine	**Heart and Cardiovascular:** Aldactone Betapace Calan Digitek Fluvastatin Lopid Hytrin
Depression: Prozac, Fluoxetine Effexor Paxil Buspar Wellbutrin	**Anti-Inflammatory:** Bextra Indocin Naproxen Ponstan Celebrex	**Muscles Relaxants :** Cyclobenzaprine Soma Skelaxin Zanaflex Carisoprodol
Hyprotics: Alcohol Ativan Valium Librium	**Anti-Biotic:** Avelox Biaxin Cipro XR Daraprim	**Cough and Cold Remedies:** Sinutab Neocitran Contac Co-actiFed
Headache and Migraine Esgic Depakote Relpax	**ADHD Medications:** Ritalin Dexedrine	**Allergy:** Allegra-D Zyrtec
Cigarates: Nicotine	**Stop smoking:** Zyban	**Diet Pills:** Phentermine
	Insomnia: Ambien	

**In view of the fact that the study population are healthy female adults, these example medications are listed according to the possible needs of the study population after consulting a pharmacist at the University Health Centre, University of Alberta.*

Appendix 4.C
Self-report Questionnaire for Study 2

Personal Demographic and Anthropometric Data

Name:______________________________ Age: ( ) yrs

Height: ( ) cm / ( ) feet ( ) inches BMI: ( )

Weight :( ) lbs / ( ) kg

Please identify your dominant leg: **leg used to kick a ball.** Left ( ) Right ( )

Active Level

Now we would like to know about your weekly sporting activities.

Please list down sporting activities you have practiced regularly each week and actual playing time.

Day	Type	Time
Monday		
Tuesday		
Wednesday		
Thursday		
Friday		
Saturday		
Sunday		

Total hours spent on sporting activities per week: ( ) hours ( ) minutes

THANK YOU

Appendix 4.D
Recruitment Poster for Study 2

Would you like to measure and train on postural sway control?

Volunteers Needed for Research on Postural Sway (Balance) in Healthy Females

Are you in the age range of 20 to 49 years OR 60 to 80 years?

If so, we invite you to take part in our research study.
We have designed a multisensory training program using
the Chattecx Dynamic Balance System to train for postural sway control.

The training will take place at the Sport Therapy Laboratory
(RM 1-81), Faculty of Rehabilitation Medicine, Corbett Hall,
University of Alberta.

Subjects will be randomly assigned to one of four groups.
All groups will be pre and post tested 3 weeks apart.

For training groups, the training program will take about an hour twice weekly for 3 weeks, in addition to two 1-hour pre and posttest periods.

You will be partially compensated for your time.
It will be an interesting experience for you.

Please email to Ai Choo Lee at ail@ualberta.ca or leave a message at 492-4824 for more information or to enroll.

Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824	Ai Choo Lee ail@ualberta.ca 780-492-4824

Appendix 4.E

Standardization of Training Protocols for Study 2

Thank you for agreeing to be trained as part of this research project. There are nine training conditions. All training conditions will be performed in bare feet. Each condition will be trained for one minute with two repetitions in two sets (1 minute x 2 repetitions x 2 sets). There is a 30-second rest between variations and five-minute break between sets.

Prior to Training:

1. To determine the length of your feet, you will step on the footplates of the CDBS. Your toes will rest just above the center line of the toe plate. I will adjust the length of the heel plates so your heels are bisected by the center line on the computer screen.

2. You will put on the safety harness in such a way that will not impede your body sway.

3. You will then cross both arms and hands to touch the opposite shoulders.

4. For the two feet tandem protocol, you will have to stand with one foot in front of the other as if standing on a straight line. You will be trained with each foot alternately being in the lead position.

5. For the one foot protocol in which you stand on one leg, you will have to stand with the test leg straight, while the other leg will have the knee flexed to 90^0 and the hip flexed to 20^0.

6. Please maintain your posture erect and upright during training.

During Training:

7. You will be told the training condition each time whether it involves two leg standing or one leg standing, and eyes open or closed. You will be told how the platform moves (stable, up, and down).

8. There are nine training conditions that will be trained in different sequences as follows:
   a. Left leg on stable platform with the eyes-open watching a bull's-eye for visual feedback

   b. Bilateral Romberg stance on platform moving down with the eyes-closed

   c. Right leg on stable platform with the eyes-open watching a bull's-eye for visual feedback

   d. Left leg on platform moving down with the eyes-open watching a bull's-eye for visual feedback

   e. Bilateral tandem stance on stable platform with the eyes-closed

   f. Right leg on platform moving down with the eyes-open watching a bull's-eye for visual feedback

   g. Left leg on stable platform with the eyes-closed

   h. Bilateral Romberg stance on platform moving up with the eyes-open watching a bull's-eye for visual feedback

   i. Right leg on stable platform with the eyes-closed

9. Please stand as still as possible while training.

10. If you lose your balance during training, you should make the necessary adjustments and return to the training position as quickly as possible. Small corrections in the ankle, knee, hip, arms, and trunk may occur and are considered normal.

11. I will inform you as soon as each training condition is completed by saying "over". You will have a 30-second rest period between each training condition. You will be instructed to sit down during the five-minute break period.

Appendix 4.F
Training Sequences for Study 2
(9 conditions, 2 repetitions each condition, repeat for two set)

C1 1 min
30 sec rest
C1 1 min
30 sec rest
C2 1 min
30 sec rest
C2 1 min
30 sec rest
C3 1 min
30 sec rest
C3 1 min
================================ ➔ 1 min break
C4 1 min
30 sec rest
C4 1 min
30 sec rest
C5 1 min
30 sec rest
C5 1 min
30 sec rest
C6 1 min
30 sec rest
C6 1 min
================================ ➔ 1 min break
C7 1 min
30 sec rest
C7 1 min
30 sec rest
C8 1 min
30 sec rest
C8 1 min
30 sec rest
C9 1 min
30 sec rest
C9 1 min
================================ ➔ First set of training end

5-MINUTE BREAK

Appendix 4.G

The Berg Balance Test [185]

BALANCE SCALE*

Name ____________________ Date ______________

Location ____________________ Rater ______________

ITEM	DESCRIPTION	SCORE (0-4)
1.	Sitting to standing	_____
2.	Standing unsupported	_____
3.	Sitting unsupported	_____
4.	Standing to sitting	_____
5.	Transfers	_____
6.	Standing with eyes closed	_____
7.	Standing with feet together	_____
8.	Reaching forward with outstretched arm	_____
9.	Retrieving object from floor	_____
10.	Turning to look behind	_____
11.	Turning 360 degrees	_____
12.	Placing alternate foot on stool	_____
13.	Standing with one foot in front	_____
14.	Standing on one foot	_____
	TOTAL	_____

*references on page 4

GENERAL INSTRUCTIONS

Please demonstrate each task and/or give instructions as written. When scoring, please record the lowest response category that applies for each item.

In most items, the subject is asked to maintain a given position for specific time. Progressively more points are deducted if the time or distance requirements are not met, if the subject's performance warrants supervision, or if the subject touches an external support or receives assistance from the examiner. Subjects should understand that they must maintain their balance while attempting the tasks. The choices of which leg to stand on or how far to reach are left to the subject. Poor judgment will adversely influence the performance and the scoring.

Equipment required for testing are a stopwatch or watch with a second hand, and a ruler or other indicator of 2, 5 and 10 inches (5, 12.5 and 25 cm). Chairs used during testing should be of reasonable height. Either a step or a stool (of average step height) may be used for item #12.

1. **SITTING TO STANDING**
INSTRUCTIONS: Please stand up. Try not to use your hands for support.

( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or to stabilize
( ) 0 needs moderate or maximal assist to stand

2. **STANDING UNSUPPORTED**
INSTRUCTIONS: Please stand for two minutes without holding.

( ) 4 able to stand safely 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unassisted

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

3. **SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL**
INSTRUCTIONS: Please sit with arms folded for 2 minutes.

( ) 4 able to sit safely and securely 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

4. **STANDING TO SITTING**
INSTRUCTIONS: Please sit down.

( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assistance to sit

5. TRANSFERS

INSTRUCTIONS: Arrange chairs(s) for a pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.

( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cueing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

6. STANDING UNSUPPORTED WITH EYES CLOSED

INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.

( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays steady
( ) 0 needs help to keep from falling

7. STANDING UNSUPPORTED WITH FEET TOGETHER

INSTRUCTIONS: Place your feet together and stand without holding.

( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand for 1 minute with supervision
( ) 2 able to place feet together independently and to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds

8. REACHING FORWARD WITH OUTSTRETCHED ARM WHILE STANDING

INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the finger reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

( ) 4 can reach forward confidently >25 cm (10 inches)
( ) 3 can reach forward >12.5 cm safely (5 inches)
( ) 2 can reach forward >5 cm safely (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/ requires external support

9. PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION

INSTRUCTIONS: Pick up the shoe/slipper which is placed in front of your feet.

( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5cm (1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

10. TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING

INSTRUCTIONS: Turn to look **directly** behind you over toward left shoulder. Repeat to the right.

Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.

( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

11. TURN 360 DEGREES

INSTRUCTIONS: Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only in 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cueing
( ) 0 needs assistance while turning

12. PLACING ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED

INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.

( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps >20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete >2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

13. **STANDING UNSUPPORTED ONE FOOT IN FRONT**

INSTRUCTIONS: (DEMONSTRATE TO SUBJECT)

Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width)

( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead of other independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds
( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

14. **STANDING ON ONE LEG**

INSTRUCTIONS: Stand on one leg as long as you can without holding.

( ) 4 able to lift leg independently and hold >10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold = or >3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently
( ) 0 unable to try or needs assist to prevent fall

( ) **TOTAL SCORE (Maximum = 56)**

***References**

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Berg K, Maki B, Williams JI, Holliday P, Wood-Dauphinee S: A comparison of clinical and laboratory measures of postural balance in an elderly population. Arch Phys Med Rehabil 73: 1073-1083, 1992

Berg K, Wood-Dauphinee S, Williams JI, Maki, B: Measuring balance in the elderly: validation of an instrument. Can. J. Pub. Health July/August supplement 2:S7-11, 1992

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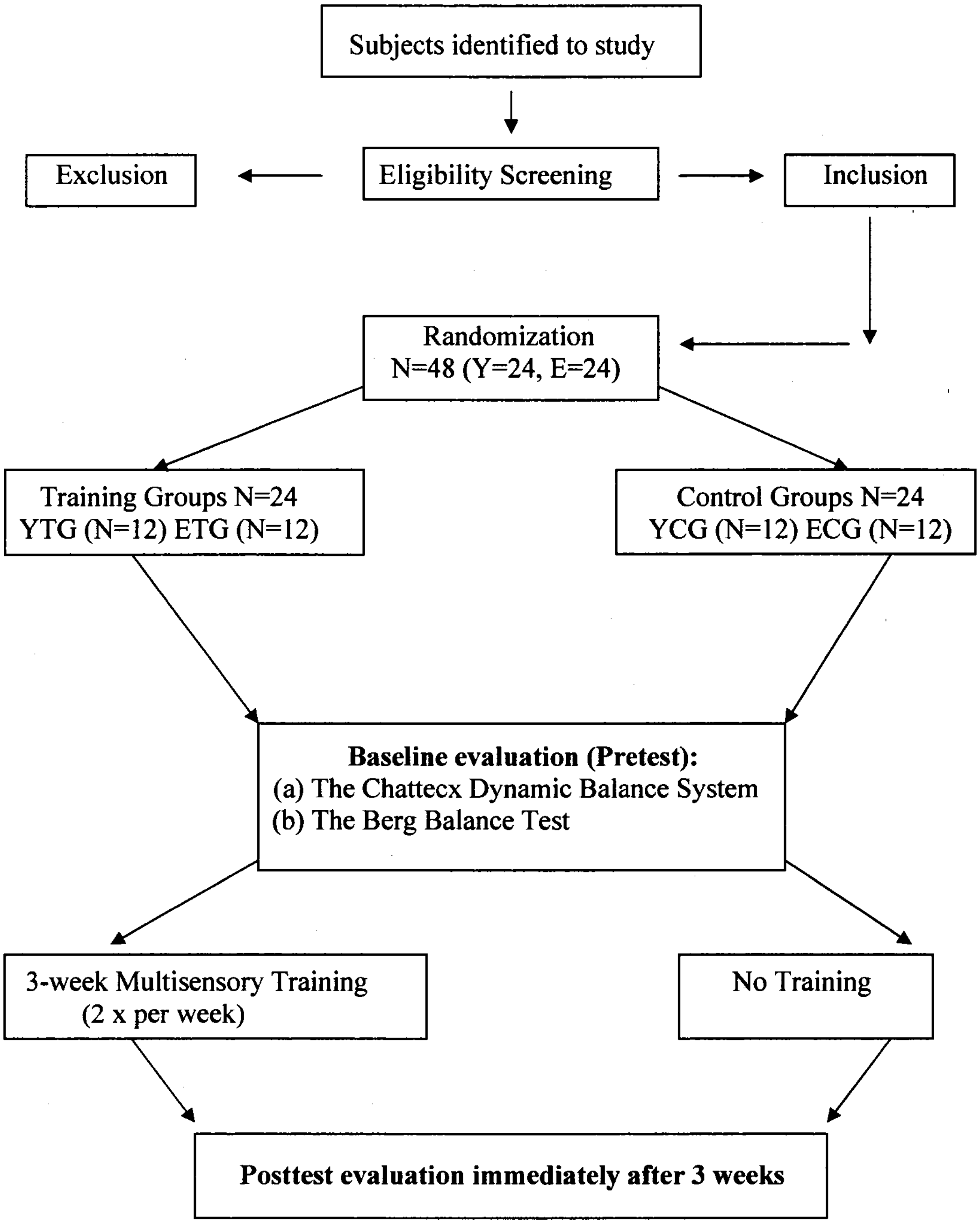
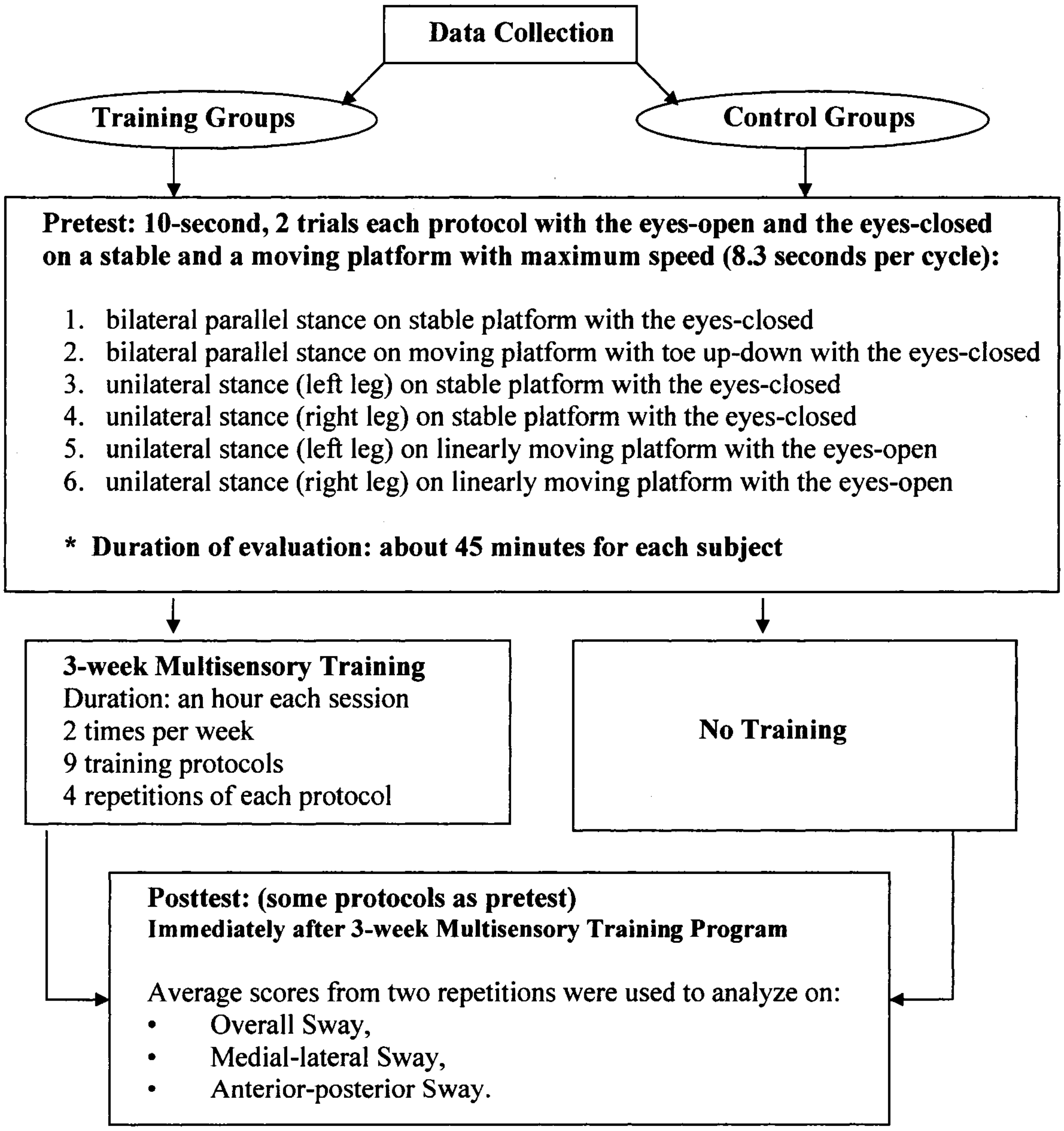
Appendix 4.H
Project Administration for Study 2

STUDY DESIGN: True Experimental Study



Appendix 4.I

Data Collection Process for Study 2



Pretest: 10-second, 2 trials each protocol with the eyes-open and the eyes-closed on a stable and a moving platform with maximum speed (8.3 seconds per cycle):

1. bilateral parallel stance on stable platform with the eyes-closed
2. bilateral parallel stance on moving platform with toe up-down with the eyes-closed
3. unilateral stance (left leg) on stable platform with the eyes-closed
4. unilateral stance (right leg) on stable platform with the eyes-closed
5. unilateral stance (left leg) on linearly moving platform with the eyes-open
6. unilateral stance (right leg) on linearly moving platform with the eyes-open

*** Duration of evaluation: about 45 minutes for each subject**

3-week Multisensory Training
Duration: an hour each session
2 times per week
9 training protocols
4 repetitions of each protocol

Posttest: (some protocols as pretest)
Immediately after 3-week Multisensory Training Program

Average scores from two repetitions were used to analyze on:

- Overall Sway,
- Medial-lateral Sway,
- Anterior-posterior Sway.

Appendix 4.J

The Boundaries of a *t*-ratio for the Significance of a *t* Statistic for Study 2

A *t*-ratio with the significant level of $\alpha_2 = 0.05$ was used to determine the statistical significance of a *t*-test.

To calculate the critical value of *t* and to identify the boundaries to be significant:

Steps:

a. Find the degrees of freedom, df

$$\Rightarrow df = N - 2$$
$$= 24 - 2 = 22$$

b. Find the *t* critical value for df of 22.

c. Refer to 0.05 level of significance for a two-tailed t-test (α_2) with df of 22.

d. Therefore, the t critical value was ± 2.074.

* If $t_{obs} \geq t_{crit}$, reject H_O.

* If $t_{obs} \leq t_{crit}$, do not reject H_O.

OR

*Results were considered to be statistically significant when the $p \leq 0.05$.

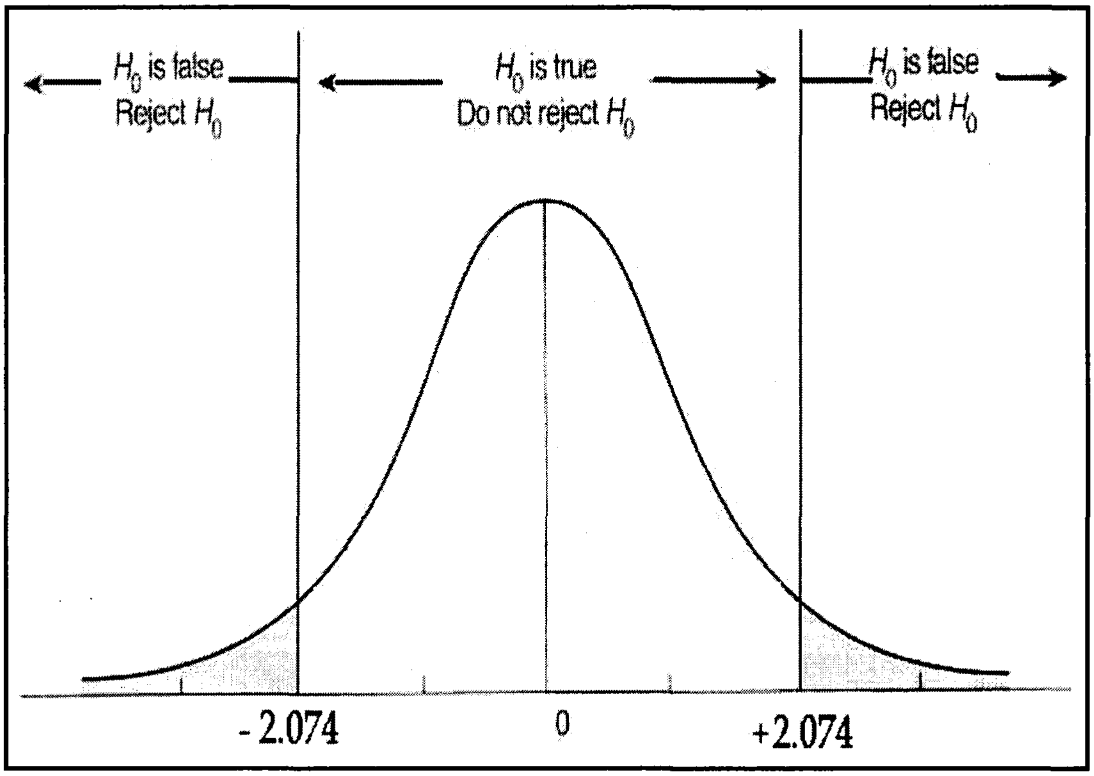


Figure 4.4: The boundaries showing critical values of a *t*-test: t_{crit} (22) = ± **2.074** for a two-tailed at $\alpha_2 = 0.05$ for Study 2.