LIMITS OF STABILITY AND POSTURAL SWAY IN YOUNG AND OLDER PEOPLE

by

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With love to my parents

ABSTRACT

Balance impairment in older persons may contribute to falls resulting in serious physical and psychological consequences. Objective measures of balance are needed to determine who is at risk of falling and to measure the effectiveness of programs designed to improve balance. Limits of Stability (LOS) measure the range over which individuals can transfer their center of gravity (COG) within their base of support (BOS). LOS may be a superior measure to postural sway in distinguishing balance impairment since this task provides a greater challenge to the postural control system. The purpose of this study was to compare LOS and sway measures in a young and older population. The reliability of all measures was also assessed. Twenty-nine healthy young subjects (18 female, 11 male, mean age 25.7 years) and 27 healthy, older subjects (13 female, 14 male, mean age 72.5 years) participated in the study. A force plate was used to measure the position of center of pressure (COP) when subjects stood still and leaned in anterior, posterior, left and right directions as far as possible with hips and keens straight and heels and toes in contact with the plate. The COP data was used to calculate the angle of center of gravity (COG) from the vertical plane during standing and maximum leaning and the proportion of the base of support subjects used for maximum leaning. Sway was measured as the percentage of the COP movement range relative to the base of support in anterior-posterior and medial-lateral directions and expressed in percent. Interclass Correlation Coefficients (ICCs) and t-tests were used to determine the reliability of measures and compare older and young groups, respectively. Results demonstrated that the test-retest reliability of LOS measures were good (ICCs 0.70-0.92). ICCs for sway measures ranged from 0.34 to 0.83. Average COG position during stance was more anterior in the older subjects ($p<0.05$, with eyes closed). The average COG position in the medial-lateral direction was centrally located and there was no difference between the two groups. LOS measures in all four directions were significantly lower in the older subjects when expressed relative to the BOS. Sway measures were also significantly higher in the older subjects compared to the young subjects in three of four measures. It was concluded that the LOS measures expressed as the percentage of the base of support were more reliable and provided more sensitive measures of balance impairment than measures of sway.

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LIST OF ABBREVIATIONS

ABOS	anterior limits of stability relative to the length of base of support
ALOS	anterior limits of stability expressed in degrees from the YZ plane
APBOS	anterior and posterior limits of stability relative to the length of the base of support
BOS	base of support
COG	center of gravity
COGXEC	center of gravity position along X-axis with eyes open
COGXEO	center of gravity position along X-axis with eyes closed
COGYEC	center of gravity position along Y-axis with eyes open
COGYEO	center of gravity position along Y-axis with eyes closed
COP	center of pressure
LLOS	left limits of stability expressed in degrees from the XZ plane
LOS	limits of stability
LRBOS	left and right limits of stability relative to the width of the base of support
PBOS	posterior limits of stability relative to the length of the base of support
PLOS	posterior limits of stability expressed in degrees from the YZ plane
RALOS	relative anterior limits of stability measured from the start position
RLOS	right limits of stability expressed in degrees from the XZ plane
RPLOS	relative posterior limits of stability measured from the start position
SWAYXEC	sway along the X-axis with eyes closed
SWAYXEO	sway along the X-axis with eyes open
SWAYYEC	sway along the Y-axis with eyes closed
SWAYYEO	sway along the Y-axis with eyes open

1. INTRODUCTION

Falling is a leading cause of morbidity and mortality in the elderly and a leading cause of institutionalization in this age group (96). It is estimated that each year, one in three seniors over the age of 65 and living in the community will experience a fall. Ten to 15% of falls result in serious injury (132). Around 1 % of all falls among those 65 years of age and over result in hip fracture (93). Approximately 15% of persons with hip fracture will die within one year of injury, 60% will experience decreased mobility and 25% will become more functionally dependent (129). Given the aging Canadian population, the incidence and costs related to falls is projected to increase.

Falls are usually the result of the interaction of many factors. Typically, these factors are grouped into categories that are either intrinsic or extrinsic to the person (129). Intrinsic factors, responsible for 56 percent of falls in the elderly (27), encompass age-related changes in visual function, balance and gait, diseases, cognitive disorders, and use of medications (12,42,72). Extrinsic factors contribute to approximately 36 percent of falls in the elderly (27). They include aspects of the physical environment, such as slippery surfaces, uneven pavement or flooring, poor lighting or unsuitable use of ambulation aids (37,48). The type and condition of shoes worn by older persons may also be an important extrinsic factor in fall causation (131).

Deterioration of balance is a dominant intrinsic cause of falling (53,66,87). Balance is defined as the maintenance of the body center of gravity (COG) in a gravitational field within the edges of the current or anticipated base of support (BOS) (2,57,68). Balance control involves maintenance of a position, postural adjustment prior to voluntary movement (anticipatory control) and reaction to external perturbation (10). Several studies have reported that fallers have greater postural sway or unsteadiness than non-fallers (21,36,69,77). Fallers have also scored significantly lower than non-fallers ($p < 0.0001$) on the Berg Balance Scale, which is a functional measure of balance (117). In studies which were performed to identify the risk factors for falling among populations of elderly persons, a low score on the Tinetti Mobility test, which also provides a functional measure of balance, was shown to be significantly associated with fall incidence (110,131).

It is well documented that balance deteriorates with aging. Subjects over 60 years of age were unable to balance on one leg for as long a period as younger subjects (13). Postural sway and sway velocity have both been shown to increase with age (25,62,73). Several studies have suggested that healthy elderly subjects differ significantly from healthy young adults in their responses when stance is perturbed (6,18,46). For example, the latency of electromyographic (EMG) response is greater in older subjects and the sequence of muscle activation is altered following perturbation. (88,148) Similarly, the sequencing and timing of EMG responses which occur in preparation for voluntary movement also differ in older subjects (25,149).

The measurement of balance is important for prediction of fall risk and evaluation of effectiveness of balance-training programs in preventing falls. Quantitative, sensitive and convenient balance measurement is desired. Due to the complexity of postural control there is no single comprehensive measurement method that can test all aspects of the balance control system (23). Available instruments measure either static or dynamic balance, or a combination of the two. The most commonly used tools to measure static balance include clinical tests, such as one-legged standing and the sharpened Romberg test (137) or postural sway measurement on a force plate (125). Tests of dynamic balance include measurement of response to unexpected perturbations that are applied by moveable force platforms or weight pulley systems (6,121). The Sensory Organization Test includes six test conditions to determine the relative contribution of visual, vestibular, and proprioceptive senses involved in posture maintenance (121). These tests involve changes of the base of support (tilt of the force plate) or changes in the visual field. Functional tests of balance involve measurement of performance in common daily activities. They include the Berg Balance Test (9), the Get-up and Go scale (81), and the Functional Reach Test (31).

Another indicator of balance, which has received less attention, is measurement of Limits of Stability (LOS) (17,65,82). LOS are defined as the points at which the center of gravity (COG) approach the limits of the base of support (BOS) and a correction strategy is required to return the COM to within the BOS (92). Limits of Stability (LOS) are measured using a force plate. Subjects are required to shift their weight forward, backward, and from side to side as far as possible from the ankle joints without losing balance (65,86,114). Brouwer et al. (17) found that LOS were a reliable measure of balance in healthy young subjects. Limited data are available about LOS in an older population, particularly in left and right directions (65,86). King et al., (65) found that the anterior-posterior LOS as a percentage of foot length was significantly lower in subjects over 60 years of age compared to younger subjects. Another study performed by Murray et al., (86) showed that the center of pressure (COP) position related to the outline of the feet during maximum weight shifting was significantly different between young and older subjects. Limits of stability may be a better measure of balance than sway because it provides greater challenge to the postural control system. It may be a sensitive measure of postural control in older subjects and be useful for prediction of risk of falling and measurement of effectiveness of exercise programs designed to improve postural control.

The purpose of this study was to compare the COG position during stance, LOS in anterior, posterior, left, and right directions and postural sway in healthy older subjects and healthy young subjects. The values delimited by the 5th and 95th percentile were determined for COG position during stance, LOS and sway in the two groups. In addition, the test-retest reliability of COG position, LOS, and sway measures was determined.

2. LITERATURE REVIEW

2.0 Balance

Balance is defined as the maintenance of the body center of gravity (COG) in a gravitational field within the edges of the current or anticipated base of support (BOS) (2,57,68). It is a baseline requirement necessary to carry out activities of daily living. The relationship between the COG and BOS is regulated by the postural control system (68). Structurally, the postural control system has three components: the sensory input system, the central processing control system, and the effector system (100). The central processing control system functions to assess and integrate sensory input from the visual, vestibular, and somatosensory senses. The vestibular system provides information about the position of the head relative to gravity as well as information regarding the linear and angular acceleration of the head (130). The somatosensory system, including proprioceptive, cutaneous, and joint inputs, provides information concerning movement of body segments with reference to each other (130). The body's position in the environment is monitored by the visual system (116). Musculoskeletal responses are selected by the central processing control system and executed by the effector systems to adjust the COG position or the BOS (100). These responses should be appropriate, in terms of timing, direction and magnitude, to the characteristics of the disturbance and the constraints of the surrounding environment (78).

2.1 Measurement of Balance and Age Related Changes

Objective measures of balance are important to assist with differential diagnosis, to provide an indication of risk of falling, and for assessing the effectiveness of treatment and training programs. In order to understand the cause of falls and reduce the frequency of injurious falls in older individuals, research is needed to identify the age-related changes in the balance control system (47). Age-related changes in sensory systems, neural processing and musculoskeletal mechanics could all potentially impact on postural control in the older population (78). Postural control has been measured in a number of ways. These include measures of ability to maintain a position such as in one-limb stance, tandem stance or postural sway measures. Electromyographic and COP responses to internal and external perturbations provide an indication of the feedforward and feedback postural control mechanisms (58,77). The relative contribution of the visual, somatosensory and vestibular sensory systems to the maintenance of balance can be determined using the Sensory Organization Test. Functional Tests such as the Berg Balance Scale and Get-up and Go Test measure the global output of the system. Limits of Stability provide a measure of the degree to which a subject can shift their center of gravity toward the edge of the base of support.

2.1.1 Timed Stance Tests

The Romberg test is a simple test of balance in which the patient stands upright with feet together and hands at the sides with eyes open and eyes closed. The examiner subjectively documents the patient's stability. As a static test it's not quantitative and not very specific (8). Two other timed stance tests, the Sharpened Romberg test (SR) and One-Limb Stance test (OLST), have been developed as substitutes for the Romberg test (43). In the SR test the subjects are required to maintain balance while standing in a tandem heel-to-toe position with eyes open and eyes closed, and in the OLST, the subjects are required to maintain balance while standing on one leg, with eyes open and eyes closed. The time that subjects can maintain the posture is recorded (43). In a study which measured the reliability of the SR test and the OLST (38), the Intraclass Correlation Coefficients (ICC) were 0.99 for inter-rater reliability for both measures with both eyes open and eyes closed. Test-retest reliability ICC's for two observers for both tests with eyes open and eyes closed ranged from 0.74 and 0.91.

Heitmann et al. (50) reported that the best trial of the SR in the eyes-open condition of fallers was significantly lower than that of nonfallers ($p<0.05$). In a longitudinal cohort study over 3 years, the OLST was found to be a significant predictor of falls and injurious falls in community dwelling seniors over 60 years of age (132). Conversely, another study comparing the SR and OLST between elderly female fallers and nonfallers found no significant difference in mean balance time (14). These tests are difficult to perform even by healthy older individuals (14), and therefore may not be the best tests for accurately predicting individuals at risk of falling (14,31).

Performance of the One-limb Stance Test (OLST) and the sharpened Romberg test (SR) are significantly affected by aging (13,14,35,50). One-limb standing with closed eyes was considered the most sensitive to the aging process (105). The time in one-limb standing with open eyes was found to decrease 30 percent between 20 to 80 years of age (105).

2.1.2 Reaction to External Perturbations

Recording the behavioral reactions to postural perturbations is a useful approach to understanding postural control. A postural perturbation is a sudden change that disrupts the stable posture from equilibrium (59). The most commonly used approach is mechanical perturbation of the support surface (77,123). This perturbation is similar to a trip, a slip, or acceleration or deceleration of a moving surface such as occurs when standing on a moving bus. Other perturbations include a force applied to the trunk or waist (67,146), visual perturbations caused by a moving room or moving visual image (18) and somatosensory perturbations caused by vibration of muscles. The latency, sequencing and response patterns are examined as outcome measures (77,122).

2.1.2.1 Postural Stress Test

Wolfson et al. (146) developed a safe and semi-quantitative balance test called the Postural Stress Test (PST). A pulley weight system attached to the subject's pelvis was used to deliver a sudden destabilizing force which displaced the subject's center of gravity posteriorly. The subject's postural responses were graded on an ordinal scale as a Balance Strategy Score (BSS) from one to nine. Wolfson et al (146) found the older fallers had significantly lower BSS's than older controls from nursing homes. The artificially created external perturbations, the ordinal scoring, and the subjects' knowledge of perturbation direction are considered as disadvantages of the PST (31,52).

A modified PST was developed by Lee et al. (67). Instead of producing a sudden perturbation to the subjects, they added the perturbation weight slowly and in four directions, anterior, posterior, left and right. The maximum weight that the subjects could withstand before they moved their feet was recorded. The difference in maximum weight tolerated between hemiparetic subjects and normal subjects was significant ($P<0.05$). A similar comparison between healthy young and older healthy subjects was not significant ($P>0.05$).

2.1.2.2 Response to a Movable Platform

Movable platforms are used to produce external perturbations to standing subjects including a series of rotations in toes-up or toes-down directions and translations in anterior and posterior directions (77). Postural control depends on the appropriate initiation of the automatic postural responses, which are usually measured by surface electromyography (EMG). Several motor strategies are used by the postural control system to maintain stance balance during external perturbation (58).

Platform Translation

Lower extremity muscle activation in response to anterior and posterior platform perturbation depends on the magnitude of the perturbation and size of the support surface. When the perturbation caused by a translating plate is small and the support surface is large, the most commonly used strategy to maintain balance is the ankle strategy (146). It is characterized by muscle activity beginning in the distal muscles around the ankle joints. In order to restore the COG to a stable position during an anterior translation of the plate, the order of activity is typically tibialis anterior, quadriceps, and abdominal muscles (56). For loss of balance in the anterior direction during posterior plate translation, the common order of muscle recruitment is gastrocnemius, hamstrings, and paraspinal muscles (5). The muscles in the lower leg are normally activated at about 100 ms following the perturbation and the upper leg muscle is activated 10-20 ms later on the same side of body (89,148).

When the translation perturbation is larger or faster or the support surface is small, the hip strategy was adopted (58). The muscle activity started in the abdominal muscles, followed by the quadriceps, to restore the forward COG displacement due to backward translation. When the plate shifted forward, the muscle activity started in erector spinae followed by hamstrings. If the perturbation was so strong that the COG was moved outside the BOS, a step was used to change the BOS and bring the COG within the edge of BOS. This is called the step strategy (146). Normal adults usually use the same strategy initially for a new perturbation and they can gradually adapt a new, more efficient strategy which could be a blend of two strategies (56).

Studenski et al. (123) compared the automatic responses to external translation perturbation between 10 fallers (70-95 years old) and 24 older controls (60-102 years old). They used a platform that could move backward and forward in a sequence unknown to subjects. The platform could move a distance of 5.08cm forward or backward at a maximum velocity of 12.7cm/sec with an acceleration of 88.9 cm/sec^2. Surface electrodes were placed bilaterally on the tibialis anterior, quadriceps, gastrocnemius, and hamstring. There was no significant difference in the sequencing of the responses during anterior and posterior perturbations between the two groups. The automatic postural response latency in tibialis anterior during forward linear perturbation was significantly prolonged in fallers compared to control subjects (P=0.03). The difference in gastrocnemius latency between fallers and non-fallers during backward linear perturbations was not significant.

The latency of automatic responses following platform translation has been found to be increased in healthy older subjects compared with young controls (115,124,147,148). Wolfson et al. (147) stdied the balance performance of 234 community-dwelling healthy elderly subjects (mean age, 76 ± 5 years) and 34 young controls (mean age, 34 ± 12 years). Ground reaction force was used to determine response latency (time from perturbation onset to shift of COP position) during posterior and anterior translation perturbation on a forceplate. Older subjects demonstrated latencies of 157 ± 16 msec and 155 ± 17 msec in anterior and posterior directions, respectively, while young controls had latencies of 146 ± 31 msec and 143 ± 11 msec in the two directions, respectively. The differences during the posterior perturbation were significant ($p<0.05$).

Woollacott et al. (148) reported similar finding. They compared the automatic responses of older and young subjects on a platform that could be translated anteriorly. Onset of response in the tibialis anterior (TA) muscle was 102 ± 6ms for the young group, and 109 ± 9 ms for the older group ($P< 0.05$). The other finding of their study was the disruption of the temporal sequence of the distal-proximal response. Five of the twelve older adults showed quadriceps firing before tibialis anterior during the backward sway. Stelmach et al (124) found that after the onset of an anterior translation perturbation, TA was activated in 100ms on average for young adults, and in 123ms for older adults ($p<0.05$). Gastrocnemius latency during backward translation perturbation did not differ between the two groups.

Platform Rotation

During a rotation perturbation, Allum et al (3) found there were three relatively fixed phases in the response pattern after the onset of a toes up rotation. EMG was measured in triceps surae and tibialis anterior muscles of four healthy male subjects on a platform which could be rotated about an axis collinear with the ankle joints. The rotation velocity was 30-50 degrees/sec in the range of 1-4 degrees. In the toe-up rotation, the first short-latency response occurred in the stretched triceps surae muscle 40 msec after the rotation. The second medium-latency response occurred approximately 130 msec after the rotation in the stretched triceps surae. Forty msec later, a long-latency response was observed in the antagonist muscle -- tibialis anterior. The toe-down rotation only produced two phases of muscle activity. The first short-latency response occurred in the stretched tibialis anterior muscle at 90 msec, followed a long-latency response in the triceps surae muscle 40 msec later (3).

The stretch responses in triceps surae and tibialis anterior during toe-up and toe-down rotation respectively are inappropriate because they significantly increased sway by pulling the body in a direction which enhanced the loss of balance (30). The long-latency responses in antagonist muscles, tibialis anterior and triceps surae during toes-up and toes-down rotation respectively were true compensatory responses. These long-latency responses could reduce the sway and stabilize the posture (30). Normal subjects adapt to repeated exposure to the tilt perturbation. The short and medium-latency stretch responses became progressively weaker concurrent with a significant decrease in the resulting body sway (89). Patients with vestibular deficits failed to attenuate the inappropriate postural response (89).

Few studies have compared the difference in response to rotation perturbation in fallers versus non-fallers or investigated age related change in response patterns. Smith et al (121) examined the responses in sixty-two community-dwelling adults aged 60 years or older, 32 with a history of two or more unexplained falls in the past year and 30 with no history of falls in the past year. The platform provided a 10-degree dorsiflexion perturbation at a velocity of 100deg/sec. The EMG of gastrocnemius and tibialis anterior were recorded bilaterally during the perturbations. No significant difference was found between the two groups for mean latencies and magnitudes of either gastrocnemius or tibialis anterior response. Non-fallers showed attenuation of the gastrocnemius magnitude over the first five trials, whereas fallers did not demonstrate the normal adaptation response to the perturbation.

2.1.2.3 Responses to Altered Sensory Input

The responses to altered visual and somatosensory input involved in posture maintenance are evaluated using the Sensory Organization Test (SOT) (18). The visual surround and the platform can both be coupled with the subject's sway with a coincident similar directional change, thus altering visual or somatosensory input or both. These condition are called sway-referenced vision and sway-referenced support surface respectively (147). The SOT includes six tests. The first three involve the subject standing on a fixed platform with eyes open (SOT 1), eyes closed (SOT 2), and using sway-referenced vision (SOT 3) to make the visual input inaccurate. In the SOT 4, vision is normal and a sway-referenced support surface is used to make the somatosensory input inaccurate. The SOT 5 condition is similar to SOT 4, except that subjects close their eyes. In the SOT 6, both sway-referenced vision and support surface are used. Postural sway is measured in each of six components. Performances during the SOT are scored two ways. First, the equilibrium score is a measure of maximum sway in the anterior-posterior direction relative to 12.5°, the maximum range that the average subject can sway in the anterior-posterior plane (8.5° anteriorly and 4° posteriorly). A score near 100 represents a very stable stance (no sway), while scores approach 0 as the subjects near the limits of stability and are at risk of falling (18). Trials in which the patient loses balance are scored as 0. The other way to score the SOT is the balance strategy score (BSS) (147). It is derived from the horizontal shear force on the support surface, which usually occurs with flexion-extension movements at the hip (hip strategy). An increase in balance strategy score reflects a decrease in horizontal shear force which is associated with the ankle strategy which is considered to be the most effective strategy for control of balance. The interrater agreement of the equilibrium score of the six tests in the SOT ranged from 68% to 100% (29). The results of SOT were associated with scores in one-limb standing ($r = 0.26$-0.46, $P < 0.05$) (18).

Age-related changes in performance on the SOT were studied by Shepard et al. (115). They compared the SOT equilibrium scores and BSS of 15 healthy older subjects (66-79 years old) with the normative data for young adults (20-59 years old) provided by the manufacturer of the instrument (NeuroCom International Inc.). Differences between the two groups were significant for equilibrium score in SOTs 1, 3, 5, and 6 conditions

(P<0.01-0.05). Older subjects swayed more than young subjects did during the test. The differences were also significant for the BSS in SOT 2,3,4,5 and 6 conditions between the two groups (P<0.01). Older subjects used the hip strategy more than young subjects did in these conditons. These results were supported by two other studies (56,147). However, conflicting results were reported (18). When equilibrium scores of thirty-three healthy old old subjects (average age 85 ± 5 years) were compared with the equilibrium scores of 15 subjects younger than 80 years (average age 72 ± 3 years), the only significant deterioration found in old old subjects was in the SOT 4 test condition.

2.1.3 Response to Internal Perturbation

The performance of coordinated voluntary movement depends on the precise interaction between the anticipatory postural adjustment and voluntary movement (4,80). Anticipatory postural adjustment doesn't involve feedback from the sensory systems and thus permits an isolated assessment of the organization of postural synergies (145).

Studies have shown that voluntary movements are preceded by postural adjustments from postural muscles and there are consistent sequences in certain postural-voluntary interactions (25,39,79). For example, when 17 normal standing subjects performed a rapid elbow flexion task (39), the order of the recruitment of the involved muscles was consistent for all subjects and was ipsilateral biceps femoris, contralateral erector spinae and ipsilateral biceps brachii as the voluntary muscle. In another study, Cordo and Nashner (25) found that when standing subjects were asked to pull on a handle, the gastrocnemius muscle in young subjects was activated consistently before the biceps muscles in the arm.

Average response latencies from a light signal to the activity of gastrocnemius and biceps were 190 ± 45ms and 260 ± 97ms respectively. The activation of the gastrocnemius muscle, termed the postural muscle, served to compensate for the change of COG caused by the biceps activity during the handle pulling. Likewise, when young subjects were required to push a handle, the tibialis anterior muscle was activated consistently before the triceps (161 ± 35ms and 248 ± 90ms after the signal, respectively). Similar studies, in which EMG activity in several lower extremity and trunk muscles was monitored, revealed that posterior muscles, activated during a handle pulling task, and anterior muscles, activated during a pushing task, were activated in a distal-to-proximal sequence (25). The sequence is similar to that observed to the ankle strategy seen following anterior and posterior platform translation suggesting that similar postural strategies are used for both internal and external perturbations (145).

Responses to internal perturbation have been compared between young and older subjects (25). During the pull action, onset of the gastrocnemius and biceps occurred 27 ms ($p>0.05$) and 118ms ($p<0.05$) later in the older compared to the young subjects respectively. During the push action, older subjects were 73ms later ($P<0.05$) in tibialis anterior onset and 124 ms later ($P<0.05$) in triceps onset compared to the younger group. Though both postural and voluntary latencies increased in older subjects, the voluntary responses were more affected by aging than the postural response and the interval between the two responses increased in older subjects (25).

Anticipatory posture adjustment has also been measured during leg movement (79,111). A general characteristic of leg movement is that it consists of a sequence in which the center of gravity (COG) is transferred to the supporting limbs and thus the voluntary movement is delayed. For example, Rogers and Pai (111) required eight healthy young subjects to flex the lower limb at the knee at a normal and a fast speed and EMG from the both lower limbs was measured. During the fast leg flexion task, the onset of EMG activity in rectus femoris of the supporting leg and biceps femoris of the flexing leg was 293ms and 251ms, respectively before the onset of the earliest decrease in vertical force beneath the flexing limb. During normal speed leg flexion, the EMG onset of the two muscles was 306ms and 245ms respectively before the flexion. Rectus femoris, working as postural muscle to the support the transferred COG position, always preceded activity in the voluntary movement muscle, the biceps femoris.

Man'kovskii et al. (79) performed the similar study. Performance was compared between young (20-29 years) and older subjects (69-99 years). The quadriceps of the support leg were always activated 100ms before the hamstrings of the flexing leg in young subjects. Older subjects were slower in both postural and voluntary responses ($p<0.05$). However, the interval between two responses also decreased. This finding differs from that reported by Cordo and Nashner (25) who found an increase in the time between the postural and voluntary response on older subjects during an upper extremity movement task.

2.1.4 Activity Based Tests

Balance tests for geriatric patients have shown a trend to performance oriented assessment (9), such as Berg Balance Scale (10), Get-up and Go Test (81), the Tinetti Gait and Balance Scale (131), and Functional Reach (31). These measures were considered more suitable compared to laboratory measures as an outcome of treatment programs with specific goals (11). However, it has been suggested that some activity-based balance measures could lack sensitivity when balance deficits are subtle or not readily detectable through simple tests (133). These activity based tests may be more suitable in dealing with the frail elderly or more impaired subjects (133).

2.1.4.1 Berg Balance Scale

The Berg Balance Scale (BBS) was designed to evaluate balance performance in the elderly and neurologically impaired individuals (10). This functionally based assessment consists of 14 items, each graded on a 5-point ordinal scale. Tasks include sitting to standing, standing unsupported, sitting unsupported, standing to sitting, transfers, standing with eyes closed, standing with feet together, reaching forward with outstretched arm, retrieving on object from the floor, turning to look behind, turning 360 degrees, placing alternate feet on a stool, standing with one foot in front of the other, and standing on one foot (R or L) (Appendix III).

Berg et al. (10) have found high interrater and intrarater reliability (intraclass correlation coefficients (ICCs) of interrater and intrarater reliability = .98 and .99, respectively) when the BBS was administered to 14 patients aged 65 and over with varying degree of balance impairment. A Cronbach's alpha of 0.96 indicated strong internal consistency. The average time to administer the scale in these studies was 10 to 15 minutes.

Thorbahn and Newton (128) used the cutoff score of 45 in the BBS as a guideline to identify individuals at risk of falling. The specificity of the cutoff score of 45 in the Berg Balance Scale was 92%, while the sensitivity was only 53%. The results demonstrated that those persons who score 45 and above on this assessment have a high probability of not falling. Piotrowski and Cole (102) reported that older subjects' scores on the Falls Efficacy Scale, a scale which measured fear of falling, was related to their BBS performance ($r=0.86$, $p< 0.01$). The Berg Balance Scale may not be a suitable measure for looking for age related changes in balance. This scale has ceiling effect in which the maximum score is achieved by young adults and many healthy seniors (94).

2.1.4.2 Get-up and Go Test

The Get-up and Go test was first developed by Mathias et al. (81). The subjects are observed while they rise from an armchair, walk 3 meters, turn and return to the chair and sit down. The performance is rated on a scale of 1 to 5 according to the observer's perception of the patient's risk of falling. Podsiadlo and Richardson (104) found that while the 1 and 5 were easy to score, the intermediate numbers, 2 to 4, were less clear. They developed a modified timed version of the Get-up and Go test. The subjects are asked to perform the same tasks and the score is the time taken in seconds to complete the test. This modified version, measured in 22 frail, community-dwelling, elderly subjects (above 70 years age), had both high intrarater (ICC = 0.99) and interrater (ICC=0.99) reliability.

The patients' time score on this test related well to their scores on the Berg Balance Scale (r= - 0.72) and the correlations became even stronger when the Balance Score was log-transformed (r= - .81) (104). It was considered as a quick and reliable balance measure for a senior population.

2.1.4.3 Tinetti Gait and Balance Scale

In the Tinetti Gait and Balance Scale, thirteen standardized everyday task are carried out, such as arising from and sitting in a chair, reaching up and bending and standing on one leg. The examiner uses an ordinal scale to rate the performance. The total balance scale is graded out of 24 and the total gait scale is graded out of 16. Tinetti et al. (131) reported interrater agreement of 85 percent on the scoring of individual items, and overall scores have been noted to differ by no more than ten percent between examiners. Information about the test-retest reliability is not available. Despite limited clinical experience, student physical therapists learned to perform the assessment with fair to excellent between-rater reliability (kappa coefficients 0.40-1.00) (20). Abnormal Tinetti scores (the total less than 28 or 34) were significantly more common in those with falls compared with those without falls (p=0.02) (6,70). Two prospective studies, one among subjects who lived in the community (131) and one among institutionalized subjects (110), have found that poor performance in the Tinetti Gait and Balance Scale predicts increased risk of future falls. No comparison of scores between young and older subjects was found.

2.1.4.4. Functional Reach

Functional Reach (FR) was developed by Duncan and colleagues (31) to measure balance. The score represents the maximal distance a person can reach beyond arm's length while standing and leaning forward as far as possible without changing the base of support. This balance measurement is safe and easy to administer. Strong intrarater reliability (ICC = 0.92) and test-retest reliability (ICC = 0.98) (31) has been reported. Functional Reach has predictive validity in identifying recurrent fallers (32). The concurrent validity of FR was established by Weiner et al. (140). Functional Reach, measured by yardstick, was significantly correlated with the performance in some physical tasks, such as Physical Activities of Daily Living (PADL), Instrumental Activities of Daily Living (IADL), 10-foot walking speed, one-foot standing, and tandem walking ($P<0.001$) (140). The correlation between FR and clinically significant changes in balance measurements such as the Mobility Skills Protocol and the Functional Independence Measure in patients in a rehabilitation program, suggested that FR is a sensitive balance measurement (141).

There are limited data about the age-related change in scores in the Functional Reach (FR) test. Hageman et al. (47) compared the performance in FR between young (20-35 years of age) and older subjects (60-75 years of age). Functional Reach was significantly less in the older subjects ($P=0.0004$). Duncan et al. (31) also found that as age increased, FR decreased. Controlled for height, the correlation coefficient between age and FR measured with electronic instruments was -0.54 and with a yardstick was –0.45.

2.1.5 Postural Sway

The body of an apparently motionless standing man undergoes continuous micromotions of which he is unaware (125). These motions occur as both front-to-back and side-to-side oscillations, in the sagittal and frontal planes. At first glance, these oscillations are erratic. They are, however, the only external evidence of complex regulatory processes taking place within the CNS which are responsible for the maintenance of balance (125). Sway is most often measured as the excursion of the COP on a stationary force plate (95). Sway parameters include sway path length over a period of time (86), sway area occupied by the COP excursion over a specified time (49) and average velocity of the COP excursion along the sway path (49). Collins and De Luca (24) analyzed sway measures using a novel mathematical technique developed from Brownian particle motion theory. They stated that though sway of center of pressure on the force plate was a random process which is unpredictable, it was still possible to obtain definite expressions for the probabilities of various aspect of this stochastic process. The mean square displacement of COP in X-axis and Y-axis over time intervals and sample times were called diffusion coefficient and scaling exponent, respectively. The intersection points where the COP significantly changed the sway direction were called critical point coordinates. Mathematical analyses demonstrated the advantage of these COP parameters, compared to other sway parameters, in which they could reveal the difference between open-loop and closed-loop mechanisms underlying postural control.

Test-retest reliability of sway measured in 12 subjects (age 24-68 years, mean 42.2 years) on a force plate has shown high test-retest reliability for sway area with eyes open (ICC =

0.91) and eyes closed (ICC = 0.97) (47). Brouwer et al (17) used the Balance Master to assess the test-retest reliability of postural sway measures in 70 healthy young subjects. The area of sway was calculated and expressed as a percentage of the theoretical limits of stability. Limits of Stability is the area over which the COG could be safely moved and are estimated to be 6.25°, 4.45°, and 8.00° from vertical in anterior, posterior, left and right directions, respectively without changing the base of support. The ICC was 0.45 for eyes open and 0.38 for eyes closed. Liston et al. (71) performed a similar study with 20 subjects with hemiparesis associated with unilateral stroke. The ICC's were 0.56 and 0.63 for eyes open and eyes closed conditions, respectively. The mathematical measures used by Collins and Luca (24) were also found to be quite reliable with ICCs ranging from 0.59 to 0.92.

Platform measures of sway have been reported to be significantly associated with performance on the Tinetti Gait and Balance Scale (70) and other indices of balance and mobility (2,33,34). Conversely, other researchers found no relationship between postural sway and functional balance measures either in community dwelling (61) or nursing home residents (127).

Used as a screening tool, postural sway has been found to differentiate between fallers and non-fallers (15,69,72,73,97). For example, Maki et. al (73) found that sway velocity could successfully distinguish fallers from nonfallers. However, others have not found sway measures to be predictive of falls (6,7,36). For example, Baloh et al. (7) followed a group of healthy older subjects over 3 years to see if sway was related to falls. They found that there was no significant difference in sway velocity and sway amplitude between fallers and nonfallers. Fernie et al. (36) and Baloh et al. (6) also found there was no relationship between increasing sway velocity and the increased frequency of falls. Based on their study results, Hughes et al. (61) concluded that postural sway might be used as an indicator of sensorimotor impairment, but not as an indicator of functional performance.

Studies regarding age-related change in balance have most frequently focused on postural sway measured on a static force plate (1,5,22,47,62,73). Colledge et al. (22) reported that the length of sway path increased linearly with increased age ($P < 0.001$). Hageman et al, (47) found that older subjects had a larger sway area measured by the Balance Master® with both eyes open ($p=0.001$) and eyes closed ($P=0.002$) compared to younger subjects. In several similar studies of spontaneous-sway, older subjects were found to have significantly higher velocity of sway compared with young subjects ($P < 0.05$) (1,62,66,73,106). The ratio of sway area to the area occupied by two feet was found to be significantly increased with increasing age ($p<0.05$) in a group of healthy older subjects aged from 69 to 99 years (119). Ring et al (108) examined sway during standing in 39 healthy active persons aged 17 to 79 years and found the anteroposterior sway range increased with age, but lateral sway range showed no change. Duncan et al. (33), however, reported that age showed only a weak and inconsistent relationship to sway. They suggested that the relationship between age and sway may result from the prevalence of disease in the older subjects. In addition, Maki et al. (73) found that the mean frequency of sway was not different between healthy young and older subjects.

2.1.6 Limits of Stability

2.1.6.1 Definition and Measurement

Balance represents the ability to coordinate the relationship between the center of gravity (COG) and the base of support (BOS) (2,57). Alexander (2) defined the maximum range in which COG could be moved safely without changing the BOS as the Limits of Stability (LOS). During normal standing the BOS is the area beneath and between the two feet (86). In order to obtain limits of stability, measures of the base of support and movement of the center of gravity are required. Determination of COG position and motion requires a sophisticated and expensive motion analysis system (122). Though studies have shown that the line of COG and COP of the support force are distinct measures during dynamic activity (84), for activities such as quiet standing, which require maintenance of a stable BOS, the COP moves around the line of COG (99). In these circumstances, COP is considered as representing the vertical projection of the COG of the body on the force plate (65). Therefore, LOS are usually assessed by the displacement of COP and its derivatives, measured on a force plate, when the subjects are required to lean as far as possible from the ankles in anterior, posterior, left and right directions (55,86,143). These LOS are perceived limits of stability, rather than the physiological limits of stability. It is the willingness of subjects to transfer their COG that is being measured.

The COP can be measured as the distance in centimeters relative to a fixed point, for example, the center of the force plate, the Y or X-axis of the force plate, the average position of COP, and anatomical sites of the foot (58,90). In order to compare individuals of different height and foot size, LOS have also been expressed as a percentage of foot length (65,86,114).

Alternatively, assuming the COG movement around the fixed ankle during sustained maximal forward, backward, and side to side leaning reflects an inverted cone, the LOS have also been represented by the angle from the origin point in some studies (17,64,82). According to anatomical theory, the height of COG is 55% of body height (98). Since the COP can be considered as the vertical projection of the COG of the body (65), the degree of leaning angle can be calculated using trigonometry when the individual's height of COG and the distance of COP displacement on the force plate are known.

2.1.6.2 Center of Pressure Position in Stance

In order to correctly interpret LOS measures it is important to know the average stance or start position of the center of pressure. When measured as an angle from the vertical, the mean COP position in the anterior-posterior plane with eyes open and closed has been found to be reliable (ICC's =0.75 and .76, respectively) (17). The test-retest reliability of the measurements in medial-lateral plane was poor (ICC's = 0.55 and 0.59 for eyes open and eyes closed respectively) (17).

Several studies have measured average anterior-posterior COP position during standing in healthy young subjects (17,51,114,143). Hellebrandt et al (51) measured the COG position using a platform with a weight scale and found the weight line was 5 cm anterior to the lateral malleolus. Brouwer et al (17) reported a mean inclination of COG position of 1.81°

anterior the vertical in 70 young subjects over a 20 second time period using the Balance Master. Kaufman et al (64) found that the mean inclination of COG position in standing was 2.3° anterior to the coronal plane passing through the center of the medial malleoli in healthy subjects over a wide age range. Whitney (143) reported a COP position value of 11.1 cm anterior to the heel line using anatomical and photographic measurements.

Similar studies were performed in older populations (28,86,114). Murray et al (86) measured the COP position using a force plate in eight men in each of three decades: third, fifth, and seventh. During standing with eyes open, the mean COP position was 11.5 cm anterior to the heel line. This value was equivalent to 43.07% of the foot length. The average COP position in the medial-lateral plane was very close to the midline between two feet. The average distance between COP position and midline was only 0.6 ± 0.9 cm. Data were not provided for the individual groups. Danis et al. (28) used anatomical measurements to calculate the COG position in 26 healthy adults (age 20-88 years), 12 of them older than 65 years. They found the mean inclination of COG position was 4.4 cm anterior to the ankle joints. Data were not provided for older subjects independently. Schieppati et al (114) measured the COP from the heel line in 18 healthy older subjects (42-79 years of age) and 18 young subjects (18-42 years of age). The distance was 43.2 % and 45.5% of the foot length in young and older groups, respectively but no statistical analysis was provided. Woodhull-McNeal (150) measured the inclination of COG position during standing in 15 healthy college-age subjects and 41 healthy older subjects between 65 to 80+ years of age. The inclination of COG of the body was calculated by measuring the relative positions of the limbs and trunk using photography. Though healthy older adults had greater spinal kyphosis and greater anterior trunk lean above the waist, the overall COG was not significantly different between the two groups. However, data on the reliability, validity and sensitivity of the measurement method were not presented.

The center of pressure position can be affected by changes in vision and support surface conditions, as well as confidence in stability (75,77). Maki et al (75,77) used a movable force plate to provide continuous (n=15) perturbations in an anterior-posterior direction with frequencies ranging from 0.13 to 5 Hz. The root-mean-square acceleration and velocity were 0.05m/s and 2 cm/s, respectively, and the displacement was 8 cm. Twenty healthy male subjects, between 25 and 45 years of age, were found to increase their anterior lean by 4mm during this perturbation compared to the COP position during quiet stance ($p<0.05$). There was a tendency for anterior lean to increase with perturbation magnitude and when subjects were blindfold (75). Older subjects who were afraid of falling, and who experienced falls within one year of testing, tended to lean further forward than other subjects during both quiet stance and continuous perturbation (P's ≤ 0.009). The average forward displacement distance was one cm (77).

2.1.6.3 Age Related Measures of LOS

As early as 1962, Whitney et al. (143) used the force plate to analyze the LOS when subjects were required to lean forward and backward as far as possible, without raising the heels and toes, and maintain that posture for 30 seconds. The subjects were ten male medical students from 18 to 21 years of age and 170.6 to 188.9 cm in height. The displacement of the COP in an anterior direction was limited to the heads of the metatarsals which corresponded to 7.3 cm anterior to the average COP position in normal standing. Posteriorly the COP could be moved only as far as the axis through the lateral malleoli, 5.2 cm posterior to the position in normal standing. A significant correlation ($r = 0.456$) was established between foot length and the COP displacement range.

Murray et al (86) measured the COP displacement distances relative to the perimeter of the BOS during maximum body inclination in anterior, posterior, left and right directions. Eight men were selected from each of three age groups: 20-30 years, 40-50 years, and 60-70 years. Subjects were required to stand on the force plate for one minute with their feet apart in comfortable stance, and then shift their body as far as possible in four directions and hold this posture for 15 seconds. The outline of the feet was traced on the force plate to mark the perimeter of the BOS. The mean positions of COP with respect to the perimeter of BOS during maximum body inclination were recorded and they were significantly different between the groups (Table 1). Conversion of the data to percent of foot length and width revealed that the maximum COP displacement range extended 54% of the fore-aft dimensions and 59% of medio-lateral dimensions of the BOS using data from all subjects (86).

Shieppati et al. (114), measured LOS in 18 healthy young subjects (5 women and 13 men, age range 18-42 years, mean age 27 years) and 18 healthy older subjects (5 women and 13 men, age range 42-79 years, mean age 59). Subjects were required lean forward and backward as far as possible without lifting toes and heels and with minimal bending at the hip and knees. The average maximum anterior-posterior COP displacement range was 57.4

± 10.4 % of the foot length in young group. This was significantly larger than the measure in older group, which was 38.8 ± 6.2 % of foot length. The authors stated that, in the young group, the distance from the COP starting position (COP position during stance) to the maximal forward lean COP position was 30-40% of foot length. The final position of the COP was a little in front of the first metatarso-phalangeal joint. In maximal backward leaning, the COP movement (distance from start position to maximal backward lean) was 20% of foot length and was near the medial malleolus.

King et al. (65) also measured the excursion of the COP during forward and backward leaning as a percentage of foot length. The percentage of the anterior-posterior (AP) dimension of the BOS used during maximal forward and backward inclination was called the functional base of support (FBOS). Forty-eight women and 65 men participated in this study. The young group was 29 to 59 years of age and the older group was from 60 to 91 years of age. Subjects stood on a force plate with a comfortable distance between the feet. The medial malleoli were aligned with the medial-lateral axis of the force plate. After 20 seconds of quiet standing with eyes open, subjects were asked to lean as far as possible forward and then backward and to maintain the position for 8 seconds. FBOS during the forward maximum COP displacement was 39% and 26% in young and older groups, respectively. During the backward maximum COP displacement, the FBOS was 21% and 16% in the two groups, respectively. No statistical analysis was performed. The total range of the BOS used during maximum anterior-posterior COP displacement was 60% and 42% of the foot length in young and older groups, respectively. This total range was

Table 1. The COP Displacement Distance in Different Age Groups ¥

Age Group (years)	Forward Maximum COP displacement distance posterior to the tip of the great toe (cm)	Backward Maximum COP displacement distance anterior to heel line (cm)	Lateral Maximum COP displacement distance from lateral border of the 5^{th} metatarsal (cm)
20-30	6.2 ± 0.8	4.0 ±1.5	6.2 ±1.0
40-50	7.5 ± 0.9	4.4 ±1.1	6.4 ±1.2
60-70	8.0 ± 1.3	6.2 ±2.4	7.3 ±1.6
P value	< 0.01	<0.05	<0.05

¥ Data from Murray et al. (86)

significantly correlated with height ($r = 0.45$, $p < 0.001$) and foot length ($r=0.28$, $p<0.03$). This total range of AP excursion declined significantly with age in the older group (65). The regression equation was FBOS= 1.21-(0.01)×age (multiple R=0.51, P< 0.001).

The sway path length (length of sway path over 8 seconds) of the COP was measured during the inclined position. Though the length of sway path was significantly related to age ($p = 0.03$), it was not significantly correlated with total COP displacement range ($p = 1.0$). FBOS and sway were therefore considered to be two distinct measurements reflecting two different aspects of balance control. In this study, the repeated FBOS measured in 14 older subjects demonstrated good interrater and test-retest reliability. The intraclass correlation coefficient was 0.80 (65).

Kaufman et al (64) found that the mean inclination of COG position in standing was 2.3° anterior to the coronal plane passing through the center of the medial malleoli. From this start position the average subject could maximally move the line of COG 6.25° anteriorly, 4.45° posteriorly and 8.00° to each side. Brouwer et al. (17) also measured the maximal angular limits of COG displacement in four directions relative to the vertical. The Balance Master™ which consists of two force plates side by side, was used to obtain measures in seventy healthy young subjects (54 females, 16 males), ages 20 to 32 years. When subjects stepped on the force plate, their medial malleoli were aligned with the medial lateral axis of the force plate. The distance between the two feet was determined according to subject height. Relative to the origin plane, young subjects were able to shift the line of COG 7.46°anteriorly, 1.12° posteriorly, 7.04° to the left and 7.46° to the right. The test-retest reliability of the mean maximum leaning angle was good in each of the four directions (ICCs 0.88 – 0.93).

Few studies have investigated LOS in an older population particularly in a medial-lateral direction. In measuring anterior-posterior LOS few studies have taken the COG position during stance into consideration. It is unclear whether the COG position during stance is different in an older versus a younger population. Postural sway and LOS measures have both been used to investigate age related changes in postural control. Age related differences are not consistently found with sway measures and LOS may be a better measure of balance as it provides greater challenge to the postural control system. The purpose of this study was to compare the COG position, LOS in four directions, and sway in young and older subjects. The test-retest reliability of sway and LOS measures was determined in two groups. In addition, the values delimited by the 5th and 95th percentile for COG, LOS and sway measures in two groups.

3. METHODOLOGY

3.1. Research Design

This study used a static-group comparison, pseudo-experimental design, in which subjects were not randomly assigned to groups (60). In this study, the independent variable was age. The dependent variables were the LOS in anterior, posterior, left and right directions, COG position during quiet stance with open and closed eyes, and postural sway with eyes open and eyes closed. The null hypothesis of this study was that there was no difference in the dependent variables between the two age groups. This study was part of a larger research project which compared healthy older subjects to those with balance impairment.

3.2 Sample Selection

The older group consisted of healthy adults, 65 years of age and over and living in the community. Subjects in this group were recruited through advertisements in the local paper. Potential participants were asked to contact one of the investigators who fully explained the nature of the study. If the volunteer was interested in participating an appointment was made with the research assistant who was responsible for subject screening. Outcome measures were obtained from those who met the criteria and signed a consent form (Appendix I).

Volunteers were excluded from participation in the older group if any of the following were present:

- one or more falls in the last year.

  A fall was defined as "an event during which a subject comes to rest on the ground or at some lower level, not as the result of a major intrinsic event or an overwhelming hazard" (83). Major intrinsic events included syncope, a CVA, a seizure, or an acute infection. Overwhelming hazards included slipping on ice or water on the floor or any situations that would precipitate a fall in any normal individuals (94).
- a history of balance or coordination problems, for example, dizziness and lightheadedness;
- any diagnosed neuromuscular disorders (i.e. Parkinson's disease, multiple sclerosis, peripheral neuropathy), or vestibular deficits;
- any injury or surgery of the spine or lower extremities;
- cardiac or respiratory illness that could affect the subject's ability to participate in this study;
- postural hypotension as defined by a drop in systolic blood pressure of > 20 mm Hg or a drop in diastolic blood pressure of > 10 mm Hg that occurs either immediately upon rising from sitting to standing or after two minutes of standing (19);
- scoring 24 or less on the Folstein Modified Mini-Mental State examination (Appendix II);
- a score 53 or lower in Berg Balance Scale (the maximum that can be achieved on the scale is 56) (Appendix III).

The comparison group included individuals, 20 to 35 years old. Young subjects, mostly students, were recruited in the School of Rehabilitation Therapy, Queen's University through personal contact. No subjects in this group had identified musculoskeletal or neurological abnormalities.

3.3 Sample Size

The sample size was determined on the basis of using a two-tailed test with a significance level of 0.05 and a power of 0.80. The formula: $N = K \times 2S^2/(MD)^2$ was used where S^2 was the error variance, MD was the minimum difference we wished to detect, and K = 7.849, was a norm depending on the significance level and power desired (139). The mean body height of subjects was estimated to be 160 cm. The difference of LOS we wanted to detect between young and older subjects was one degree, corresponding to 1.536 cm on the force plate, in anterior and posterior directions. It was assumed that the standard deviation and the sample mean follow a normal distribution in both groups. In the study by King et al. (46), the standard deviation of COP movement in the anterior direction was 1.7 cm in the young group and 2.1 cm in the older group. In the posterior direction, it was 1.4 cm in the young group and 2.0 cm in the older group. The formula used to calculate the pooled estimate of the variance from two independent samples was

$$S^2 = \frac{(n1-1)s_1^2 + (n2-1)s_2^2}{(n1+n2-2)} \qquad (113)$$

where S^2 is the pooled error variance, n1 is the number of subjects in the first group, s_1 is the variance in the first group, n2 is the number of subjects in the second group, and the s_2 is the variance in the second group.

The results of the sample size calculation showed that 27 subjects were required in each group to detect a one degree difference in LOS in the anterior direction with 80% power. A same calculation was done for the LOS in the posterior direction. Twenty-four subjects were required to detect a one degree difference in LOS in this direction.

3.4 Measurement System

The force platform in the Motion Laboratory in the School of Rehabilitation Therapy, Queen's University, was used to measure the center of pressure position. The force platform measured 46 cm x 50 cm footplate rested on four foil strain-gauges attached to load cells at the four corners of the force plate (Advanced Mechanical Technology MAT, Inc., Watertown, Massachusetts, Model: OR-6-5-1). The platform records three force components along the lateral and anterior-posterior horizontal axes and the vertical axis, together with the three respective moments. The force components were measured in newtons (N). The signals were amplified through a six-channel AMTI model SGA6-3 amplifier. All six channels were factory-calibrated and were balanced prior to data collection. According to the instructions provided by the manufacturer, when nothing is on the force plate, the output of six amplifiers for the three force components and moments components in and about the three cardinal axes should be zero. A known weight was put on the force plate to check the plate accuracy. The sample frequency was 60 Hz. According to the manual, when the pressure on the force plate was 490N (50kg), the force plate could detect the position change of center of pressure on the platform with minimum resolution of 0.04cm. The data were collected, saved, and analyzed using the Peak Motus

System (Version 3.0, Peak Performance Technologies, Inc.) and Paradox (Borland Intl. Inc. Version 4.0 1994).

A piece of plexiglas, three-millimeters thick, cut to the same dimension of the force plate, was fitted over the plate. Metal extensions on all four sides of the plexiglas fitted over the edges of the plate, stabilized the plexiglas on the force plate. Grid lines were carved into the plexiglass at 1-cm intervals in anterior-posterior and medial-lateral directions. The line in the anterior-posterior direction that ran through the center of plate was the X-axis. The positive direction was the direction the subject faced when on the plate. The line in medial-lateral direction that runs through the center of plate was the Y-axis. The positive direction was to the right. These axes intersected at the center of the plate (0,0 coordinate).

3.5 Measurement Setup and Procedure

The subjects were instructed to remove their shoes and socks. A standard plastic tape measure, which was vertically attached to a wall in the Motion Laboratory, was used to measure the height of the subject. Subjects were asked to stand with their spine against this tape measure and their height was recorded in centimeters (cm). The weight scale in the same laboratory was used to measure the subject's weight in kilograms (kg).

Subjects stood on the force plate facing forward (+ X-axis). The subjects' feet were positioned in the sagittal plane by aligning the medial malleoli with the Y-axis (Figure 1). The distance between the feet was determined by the subjects' height. A point two centimeters behind the tuberosity of fifth metatarsal bone on the lateral border of the foot

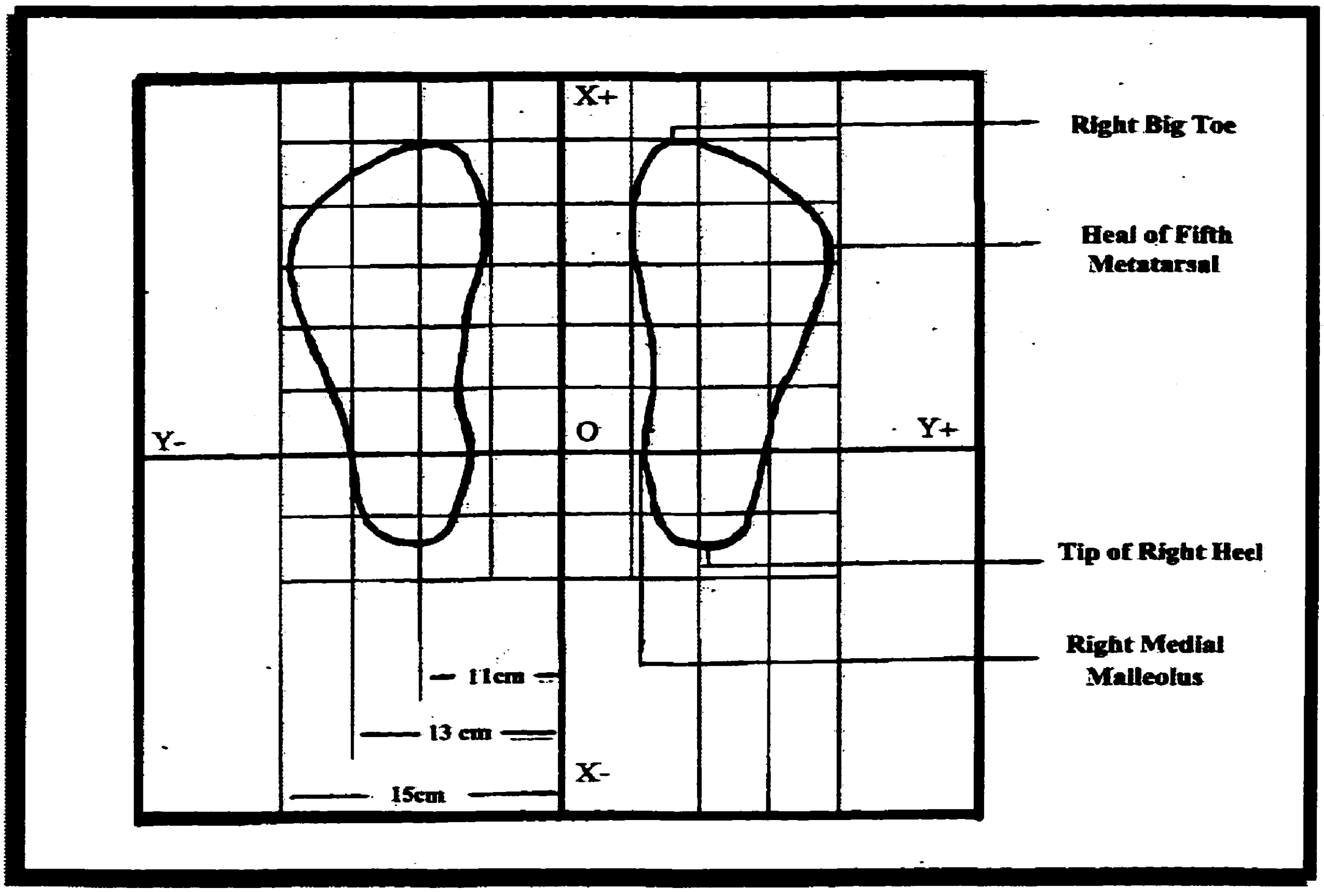

Figure 1. **Measurement Setup. The subject's height in this figure is between 140-165cm.**

was marked. This point was placed 11 cm from the X-axis for subjects who were between 76cm and 140cm in height. The distance from the X-axis to this point was 13 cm for subjects who were between 140.1cm and 165 cm in height. The distance from this point to the X-axis was 15cm for the subjects who were between 165.1cm and 203 cm in height. These distances were adopted from the Balance Master® system (91). The three foot placement positions were to assure a wide enough base of support to allow the normal 8 degrees maximum theoretical left and right transference of center of gravity.

After the subject was positioned on the force plate, the position of the tip of the big toe, the most posterior aspect of the heel, and the head of the fifth metatarsal were marked bilaterally on the plexiglas. The coordinates of these six points were recorded using the grid lines on the plate to define the parameters of the Base of Support (BOS). The length of the BOS was calculated by averaging the X coordinate of tip of the big toes and most posterior aspect of the heels and determining the distance between these mean values. The width of the BOS was calculated as the distance between the fifth metatarsal heads.

3.6 Testing

Subjects performed six tests in total. The first measurement was normal standing for twenty seconds. The subjects, with their arms at their sides, stood as still as possible with their eyes fixed on a target five meters in front of them at eye level. The second test was normal standing with eyes closed for twenty seconds. The subjects were positioned as for the eyes open test.

In the next four tests, the subjects were asked to lean anteriorly, posteriorly, and to the left and right as far as possible from their ankles without bending their hips and knees, with their arms at sides, looking forward at the target. They were asked to hold this position for five seconds. When leaning forward, subjects were instructed to keep their heels in contact with the forceplate. Similarly, when leaning backward, subjects were instructed to keep their toes on the plate. When leaning left and right both feet maintained contact with the plate. If there was any extraneous movement during the five-second data collection period the trial was repeated. The order of these four measurements was randomized to enhance internal validity. All six measurements on the force plate were repeated three times. Subjects could step off the plate and rest between tests. Their feet were repositioned using the marks on the plexiglass when testing was resumed. Data collection took approximately 25 minutes in total. Twelve of the subjects in the younger group and four of the subjects in the older group repeated all the measures one week after the first visit for reliability analyses.

3.7 Outcome Measures

The coordinates of the tip of the big toes, the most posterior aspect of the heels, and the head of the fifth metatarsal were obtained from the plexiglas grid and recorded in Paradox. These coordinates were used to calculate the BOS.

All other outcome measures were obtained from the force plate. The average COP position during stance (over 20 seconds) and maximum inclination (5 seconds) was measured in centimeters on the X and Y-axes relative to the center of the force plate. This value was converted to an angular measure using a trigonometric function and expressed in degrees relative to the vertical plane. The plane perpendicular to the force plate along the X-axis was defined as the XZ-plane and the plane perpendicular to the force plate along the Y-axis was defined as the YZ-plane. Assuming the height of COG is 55% of a subject's height above the ground and knowing the COP position on the force plate, the angular position of the COG position was calculated during stance and maximum inclination in anterior, posterior, left and right directions. The positive value meant that the angle was anterior to the YZ-plane or to the right of the XZ-plane.

3.7.1 Center of Gravity Positions during stance

The average position of the COP was measured during 20 seconds of relaxed standing task both with eyes open and eyes closed. The average of the three trials was used for data analysis. The centimeter value was used to calculate the angle of the inclination of COG relative to the XZ and YZ-plane. Four measures were calculated:

a) COG along X-axis with eyes open (COGXEO);

b) COG along X-axis with eyes closed (COGXEC);

c) COG along Y-axis with eyes open (COGYEO);

d) COG along Y-axis with eyes closed (COGYEC).

For example, the formula used to calculate COGXEO was:

$$\text{COGXEO} = \arcsin \frac{\text{average COP position on X-axis from the origin}}{55\% \text{ of body height}}$$

The other measures were calculated in a similar way.

3.7.2 Limits of Stability

During the LOS testing, subjects were required to lean as far as possible in anterior, posterior, left and right directions with eyes open and hold this position for 5 seconds. The average position of the COP was obtained and converted to an angular measure relative to the XZ and YZ-plane. Since the leaning position was held for 5 seconds, the COP position represented the COG position during these tasks. The highest value obtained in the three trials was used for data analysis since we wanted to use the best performance. Test-retest reliability was equivalent for best trials and average of three trials. The four LOS measures were:

a) Anterior Limits of Stability (ALOS);

b) Posterior Limits of Stability (PLOS);

c) Left Limits of Stability (LLOS);

d) Right Limits of Stability (RLOS).

For example, the formula used to calculate the ALOS was:

$$\text{ALOS} = \arcsin \frac{\text{average COP position on X - axis from the origin}}{\text{55\% of body height}}$$

The other measures were calculated in a similar way.

Anterior and posterior limits of stability were also expressed as the percentage of base of support (ABOS and PBOS). The distance between the COP position and heel line during anterior and posterior maximum leaning was measured on the X-axis and divided by the foot length respectively. In addition, anterior and posterior limits of stability were summed and expressed as a percentage of the length of the base of support (APBOS). Similarly, the distance between average COP position during right and left inclination to midline (X-axis) was determined on the Y-axis and divided by foot width (distance between 5th metatarsal heads) to obtain a summed measure of left and right excursion range relative to the BOS (LRBOS).

The ability of subjects to shift their COG directly forward, backward, left and right was monitored by recording the coordinates of the average COP position during the inclination tasks. These coordinates were converted to an angular displacement by the software used for analysis. The deviation from the X and Y-axes was expressed in degrees on the transverse plane. The angular measure was 90° if the subject's COP was on the X-axis during forward inclination. The corresponding values for left, posterior and right inclinations were 180°, 270° and 0° respectively (Figure 2).

3.7.3 Postural Sway

Measures of postural sway were obtained during the 20 seconds stance task with eyes open and eyes closed. Data were sampled at 60Hz. The average excursion range of all sway waves in each trial was calculated in the anterior-posterior and medial-lateral directions. The value was divided by foot length or width respectively to obtain a measure of sway as a percentage of BOS. The four measures obtained were:

a) Sway along the X-axis with eyes open (SWAYXEO);
b) Sway along the X-axis with eyes closed (SWAYXEC);
c) Sway along the Y-axis with eyes open (SWAYYEO);
d) Sway along the Y-axis with eyes closed (SWAYYEC).

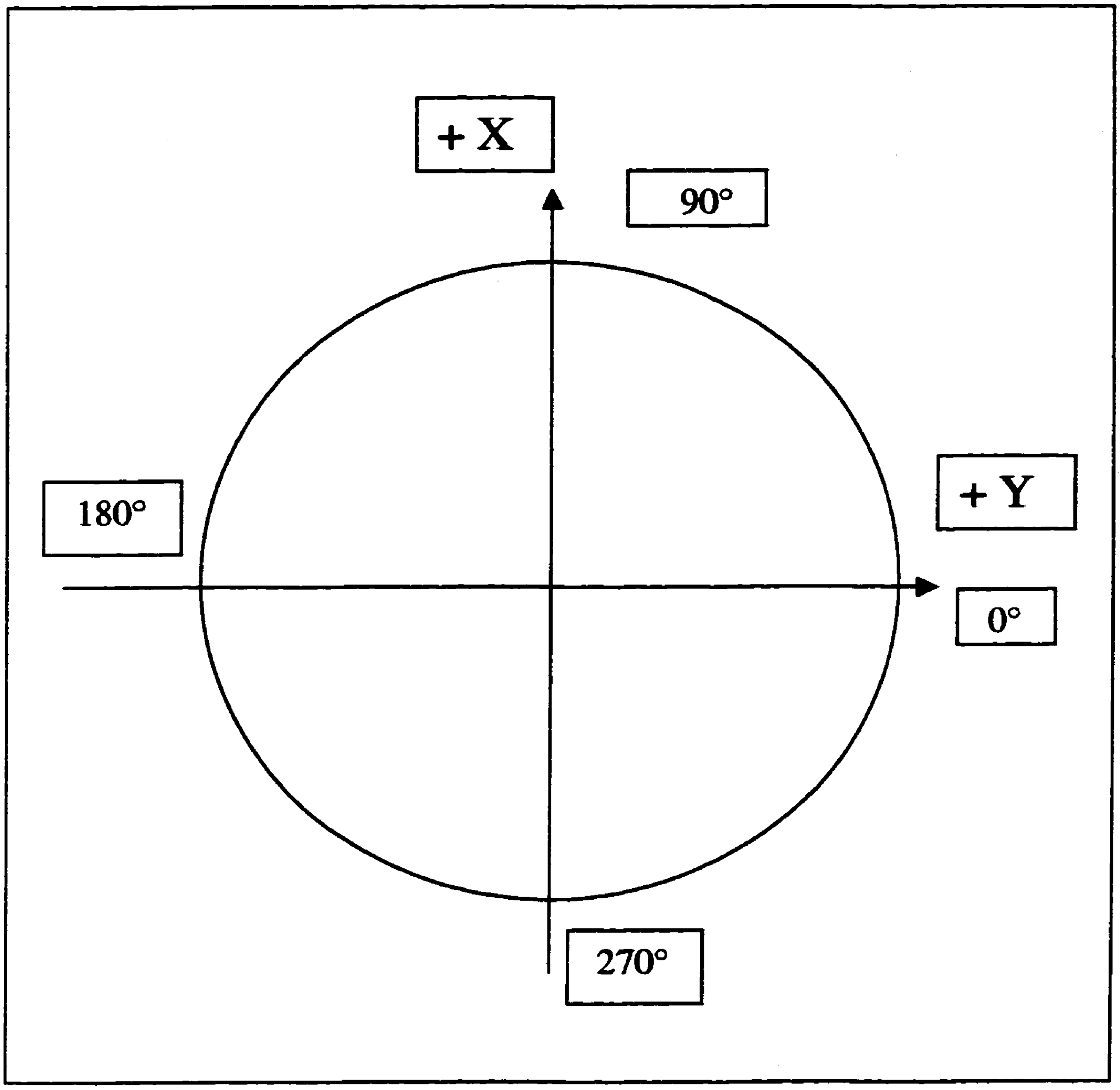

Figure 2. Force plate coordinate system on the transverse plane.

3.8 Data Analysis

Three groups of outcome measures, the COG positions, the LOS measures and sway measures were calculated using software designed for this purpose. T-tests were employed to determine if there were significant age-related differences of the outcome measurements. The alpha levels were corrected by Bonferroni adjustment depending on the number of tests. The 5th and 95th percentiles of COG position, LOS and sway measures were calculated in each group to indicate the span of scores achieved by 90% of the subjects.

The test-retest reliability of the four COG position measures during quiet stance, four LOS measures and sway measures was analyzed using a univariate repeated measures analysis of variance (ANOVA). Intraclass correlation coefficients ($ICC_{1,2}$) were calculated to determine the test-retest reliability. Intraclass correlation coefficients ≥ 0.80 reflected high reliability, 0.60-0.80, moderate reliability, and < 0.60 poor reliability (108).

4. RESULTS

4.1 Subject Characteristics

Twenty-nine subjects were recruited for the younger group. All met the inclusion criteria and were tested. The mean age of younger subjects was 25.7 years and ranged from 21 to 35 years; the mean height was 171 cm and mean weight was 65.8 kg. Thirty-two subjects initially volunteered to participate in the older group. Three chose not to participate in the study after being provided with a detailed explanation of the study. Two volunteers were excluded following screening because of knee deformity and hypotension. The mean age of the 27 subjects in the older group was 72.5 years and ranged from 65 to 82 years; mean height was 168 cm and mean weight was 72.5 kg (Table 2).

4.2 Reliability Study

Twelve of the subjects in the younger group and four of the subjects in the older group had all measures repeated one week after their first visit to obtain data for reliability analyses. The mean age for the young and older subjects was 25.9 ± 3.65 and 72.5 ± 4.79 years respectively. Analysis of variance (ANOVA) and intraclass correlation coefficients (ICC (2,1)) were calculated to determine the test-retest reliability of COG position, LOS, and sway measures. All COG and LOS measures were expressed in degrees from the XZ or YZ plane. ANOVA calculations revealed no differences between days and a significant difference between subjects. The mean value of measures on the two days, standard deviations and ICC's are presented in Table 3. ICC's reflected that all the COG position,

Table 2. Subject Characteristics

Age Group	Gender	Number	Mean Age (SD)	Height* (SD)	Weight* (SD)
Young	Female	16	25.7 years (3.5)	171 cm (8.7cm)	65.8 kg (12.6 kg)
	Male	13			
Older	Female	13	72.5 years (5.2)	168 cm (8.4cm)	72.5 kg (12.6 kg)
	Male	14			

* No difference between young and older subjects.
Independent T-test: $P>0.05$.

Table 3. Test-retest Reliability of COG Positions, LOS and Sway Measures

Measurement	Day 1 Mean ± SD	Day 2 Mean ± SD	ICC (2,1)
ALOS (°)	8.07 ± 1.01	7.96 ± 1.18	0.93
PLOS (°)	-0.87 ± 0.50	-0.84 ± 0.40	0.77
LLOS (°)	-7.05 ± 0.95	-7.03 ± 1.01	0.75
RLOS (°)	7.10 ± 1.11	7.04 ± 0.92	0.89
COGXEO (°)	2.49 ± 0.94	2.41 ± 0.79	0.82
COGXEC (°)	2.45 ± 0.85	2.44 ± 0.79	0.78
COGYEO (°)	0.01 ± 0.39	-0.12 ± 0.44	0.73
COGYEC (°)	0.15 ± 0.44	0.07 ± 0.40	0.69
SWAYXEO (%)	0.84 ± 0.28	0.90 ± 0.25	0.83
SWAYXEC (%)	1.30 ± 0.43	1.42 ± 0.38	0.71
SWAYYEO (%)	0.34 ± 0.12	0.38 ± 0.15	0.55
SWAYYEC (%)	0.42 ± 0.12	0.45 ± 0.13	0.34

ALOS: anterior limits of stability; PLOS: posterior limits of stability;
LLOS: left limits of stability; RLOS: right limits of stability;
COGXEO: center of gravity position on X-axis with eyes open;
COGXEC: center of gravity position on X-axis with eyes closed;
COGYEO: center of gravity position on Y-axis with eyes open;
COGYEC: center of gravity position on Y-axis with eyes closed;
SWAYXEO: sway along the X-axis on the force plate with eyes open;
SWAYXEC: sway along the X-axis on the force plate with eyes closed;
SWAYYEO: sway along the Y-axis on the force plate with eyes open;
SWAYYEC: sway along the Y-axis on the force plate with eyes closed.

LOS measures and sway in the anterior-posterior direction had moderate or high test-retest reliability. ICC's for sway in right and left directions were poor.

4.3 Main Study

4.3.1 Center of Gravity Position

The average COG position was calculated during stance over a 20-second period with eyes open and eyes closed. The average of 3 trials was used for data analysis. One trial of one subject in the eyes-open task was deleted because there was evidence that this subject moved during that data collection. The average of two trials was used for subsequent analysis for this subject. Values were expressed in degrees from the XZ-plane and YZ-plane. Data are presented in Table 4.

The COG position during standing was anterior to the YZ-plane in all subjects. The average COG inclination was more anterior in the older compared to the younger subjects with both eyes open and eyes closed. This difference was significant only for the eyes closed condition using an independent T-test with Bonferroni correction for 4 measures ($P<0.0125$). With eyes open, the COG angular measure corresponded to 39.76 and 42.85 % of foot length measured from the heel line in younger and older subjects, respectively. Since the COG position was further anterior in the older subjects, the measures of LOS in anterior and posterior directions were expressed relative to the line of COG in the standing position, rather than from the XZ and YZ plane in subsequent analysis. In order to distinguish these two measures from ALOS and PLOS, these two values were called relative ALOS (RALOS) and relative PLOS (RPLOS).

Table 4. COG Position Measured from Vertical (Mean ± SD)

Measures	Younger(n=29)	Older (n=27)	P*
COGXEO (°)	2.37 ± 0.82	2.78 ± 0.87	0.073
COGXEC (°)	2.35 ± 0.75	2.93 ± 0.86	0.010[¥]
COGYEO (°)	0.07 ± 0.39	0.01 ± 0.57	0.700
COGYEC (°)	0.07 ± 0.38	0.05 ± 0.62	0.357

* T-test with Bonferroni adjustment, p=0.05/4=0.0125
[¥] the difference was significant
COGXEO: center of gravity position on X-axis with eyes open;
COGXEC: center of gravity position on X-axis with eyes closed;
COGYEO: center of gravity position on Y-axis with eyes open;
COGYEC: center of gravity position on Y-axis with eyes closed.

The COG position in the medial lateral plane was close to the midline in all subjects. The angle to the XZ plane with eyes open ranged from −0.9° to 0.72° in the younger subjects and from −0.8° to 1.61° in the older group. There was no difference in the COG position between groups in this plane in either the eyes open or eyes closed condition. (Table 4). Since there was no difference in COG position between two groups in this plane and all subjects were close to the midline, LOS in the right and left directions were expressed in degrees from the vertical in subsequent analyses.

4.3.2 Limits of Stability

4.3.2.1 Anterior and Posterior Directions

The average position of the COG was determined over a 5-second period as subjects leaned anteriorly and posteriorly as far as possible from their ankles. The data were examined to determine the ability of subjects to shift their COG directly forward or backward (Figure 3). In the anterior direction, the younger subjects deviated on average 2.55 ± 2.00° (range = 0.02° to 8.73°) from the midline (X-axis). The deviation was similar in left and right directions. The corresponding value in the older subjects was 4.19 ± 3.26 (range = 0.08° to 12.26°), with similar deviation in left and right directions (Figure 3). The difference between groups was significant ($p<0.05$). During maximum inclination in the posterior direction, most subjects were close to center of the plate, therefore the range of angles varied greatly between subjects.

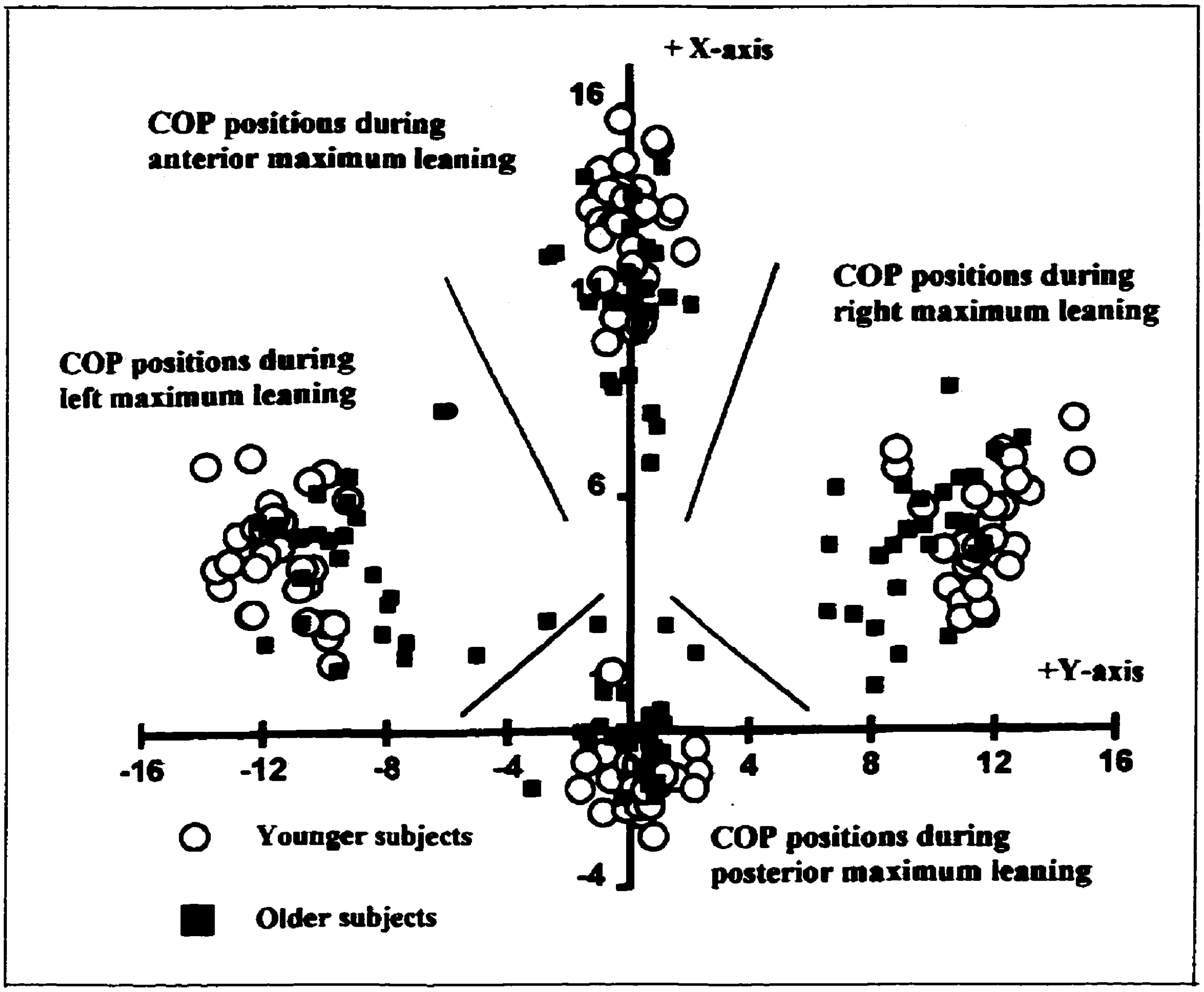

Figure 3. Coordinates of average COP position (over 5-seconds) on the force plate during the best trial of the maximum inclination test in anterior, posterior, left and right directions.

The RALOS indicated the maximum angle which the subjects could shift their COG in the anterior direction relative to the position during stance with eyes open. In the younger group, the RALOS was 5.81 ± 1.16°. This corresponded to 78.1± 4.1% of the foot length measured from the heel line (ABOS). The RALOS for the older subjects was 4.41 ± 0.83°, which corresponded to 71.3± 6.1% of their foot length measured from the heel line (ABOS). The differences in RALOS and ABOS between two groups were significant ($P<0.008$) (Table 5).

The RPLOS indicated the maximum angle which the subjects could shift their COG in the posterior direction relative to the stance position. The younger subjects were able to move the line of COG 3.26 ± 0.86° posterior to the stance position, which was equivalent to 0.89 degrees posterior to the YZ-plane. The average position of COP measured from the heel line corresponded to 18.01 ± 2.75% of foot length (PBOS). The RPLOS value for the older subjects was 3.05 ± 0.93 ° or 23.03 ± 4.47% of foot length. This resulted in an average position which was 0.26 degrees posterior to the YZ-plane (Table 5). While there was no difference between the two groups in RPLOS measures ($P>0.008$), the difference in PBOS was significant ($P<0.008$) (Table 5).

The maximum range over which the subjects could shift their COG in anterior and posterior directions was also expressed as percentage of the foot length (APBOS) (Table 5). The value was 60.10 ± 5.74% in younger group and 48.31 ± 8.32% in older group. The difference of twelve percent between two groups was significant ($P<0.008$).

Table 5. LOS Measures in Four Directions (mean ± SD)

Measures	Young (n=29)	Older (n=27) §	P¥
RALOS (°)	5.81 ± 1.17	4.41 ± 0.83	0.0000*
RPLOS (°)	3.26 ± 0.86	3.05 ± 0.93	0.379
LLOS (°)	7.27 ± 0.76	6.27 ± 0.75	0.0000*
RLOS (°)	7.34 ± 0.77	6.34 ± 0.84	0.0000*
ABOS (%)	78.12 ± 4.06	71.34 ± 6.08	0.0000*
PBOS (%)	18.01 ± 2.75	23.03 ± 4.47	0.0000*
APBOS (%)	60.10 ± 5.74	48.31 ± 8.32	0.0000*
LRBOS (%)	67.44 ± 5.65	56.53 ± 5.21	0.0000*

¥ T-test with Bonferroni adjustment, $p=0.05/6=0.008$
* the difference between two groups was significant ($P< 0.000$)
§ the data for LLOS, RLOS and LRFBOS in older group was for 24 subjects

RALOS: relative anterior LOS measured from the stance position;
RPLOS: relative posterior LOS measured from the stance position;
LLOS: left LOS;
RLOS: right LOS;
ABOS: anterior limits of stability relative to the length of base of support;
PBOS: posterior limits of stability relative to the length of base of support;
APBOS: anterior and posterior limits of stability relative to the length of the base of support;
LRBOS: left and right limits of stability relative to the width of the base of support.

4.3.2.2 Left and Right Directions

Due to technical difficulties with the force plate during the data collection, the data of left and right LOS of three older subjects was inaccurate and was eliminated from analysis. Thus data represents mean values for 24 older subjects for these measures.

When subjects were required to perform the maximum lateral leaning test, they tended to go forward as well as laterally (Figure 3). The deviation angle to the Y-axis in left and right directions were similar between two groups. In the younger group, the mean deviation angle relative to the Y-axis was 21.6 ± 5.66° in left direction and 23.25 ± 5.57° in right direction. In the older group, the mean deviation angles were 23.76 ± 7.35° and 25.17 ± 8.64° in left and right directions, respectively.

The maximum COG inclination angle was similar in left and right directions in both groups (Table 5). In the younger group, the values were 7.27 ± 0.76° to the left and 7.34 ± 0.77° to the right. In the older group, the values were 6.27 ± 0.75° to the left and 6.34 ± 0.84° to the right. The difference between the two groups in both directions was significant ($p<0.008$).

The range which the COG could be maximally shifted in both left and right was expressed as the percentage of the width of the BOS measured as the distance between the heads of the 5th metatarsal (LRBOS). The total medial-lateral excursion range was 67.44% and

56.53% of foot width in young and older groups, respectively. The difference between two groups was significant (P<0.000) (Table 5).

4.3.3 Sway Measures

Sway was measured during twenty seconds standing with eyes open and eyes closed. It was expressed as the mean sway range in the X and Y-axes divided by the length or width of the BOS. Anterior-posterior postural sway with eyes open and eyes closed and medial-lateral sway with eyes open were significantly different between the two groups (P<0.0125) (Table 6).

4.3.4. Score spans of COG Position, LOS and Sway Measures

The score span of measures for both groups was expressed as the data between 5th and 95th percentiles. The 5th and 95th percentile of COG position, the relative LOS in anterior and posterior directions, the LOS in left and right directions, the percentage of the BOS utilized during anterior-posterior and medial-lateral maximum leaning, and sway measures in both directions are found in Table 7.

Table 6. Sway Measures in Younger and Older Groups (mean ± SD)

Measures (%)	Young (n=29)	Older (n=27)	P[¥]
SWAYXEO	0.84 ± 0.28	1.17 ± 0.29	0.0000*
SWAYXEC	1.32 ± 0.49	1.80 ± 0.51	0.0009*
SWAYYEO	0.36 ± 0.14	0.48 ± 0.15	0.0037*
SWAYYEC	0.43 ± 0.15	0.56 ± 0.23	0.015

[¥] T-test with Bonferroni adjustment, p=0.05/4=0.0125
* Difference was significant
SWAYXEO: Sway along the X-axis with eyes open;
SWAYXEC: Sway along the X-axis with eyes closed;
SWAYYEO: Sway along the Y-axis with eyes open;
SWAYYEC: Sway along the Y-axis with eyes closed.

Table 7. 5th and 95th Percentiles of Measures in both Groups

Measures	Younger Subjects		Older Subjects	
	5th percentile	95th percentile	5th percentile	95th percentile
RALOS (°)	2.59	7.11	2.54	5.75
RPLOS (°)	1.83	5.25	1.50	4.78
LLOS (°)*	-8.74	-5.96	-7.69	-5.01
RLOS (°)	6.06	9.16	4.58	7.83
ABOS (%)	71.83	84.57	56.58	83.19
PBOS (%)	14.72	24.89	16.85	33.62
APBOS (%)	48.19	68.22	29.58	61.74
LRBOS (%)	55.99	76.89	47.89	65.54
COGXEO (°)	1.37	4.36	0.76	4.47
COGXEC (°)	1.28	4.25	0.92	4.61
COGYEO (°)*	-0.76	0.71	-0.83	1.36
COGYEC (°)*	-0.80	0.69	-0.89	1.61
SWAYXEO (%)	0.50	1.44	0.75	1.78
SWAYXEC (%)	0.62	2.38	1.03	2.87
SWAYYEO (%)	0.17	0.62	0.29	0.87
SWAYYEC (%)	0.22	0.78	0.27	1.17

RALOS: relative LOS in anterior direction measured from start position;
RPLOS: relative LOS in posterior direction measured from the start position;
LLOS: left limits of stability;
RLOS: right limits of stability;
ABOS: anterior limits of stability relative to the length of base of support;
PBOS: posterior limits of stability relative to the length of base of support;
APBOS: anterior and posterior limits of stability relative to the length of base of support;
LRBOS: left and right limits of stability relative to the width of base of support;
COGXEO: center of gravity position along X-axis with eyes open;
COGXEC: center of gravity position along X-axis with eyes closed;
COGYEO: center of gravity position along Y-axis with eyes open;
COGYEC: center of gravity position along Y-axis with eyes closed;
SWAYXEO: Sway along the X-axis with eyes open;
SWAYXEC: Sway along the X-axis with eyes closed;
SWAYYEO: Sway along the Y-axis with eyes open;
SWAYYEC: Sway along the Y-axis with eyes closed.
* negative symbol means left of the midline (X-axis).

5. DISCUSSION

5.1 Reliability

The test-retest reliability of the four measures of COG position during stance was good with ICC values ranging from 0.69 to 0.82. The ICC values of COG position in the anterior-posterior plane were similar to those reported by Brouwer et al (17) in 54 healthy young subjects using the Balance Master. The ICC's for COG position in the medial-lateral plane were higher than reported by Brouwer et al. (0.55 and 0.59 for eyes open and eyes closed, respectively). The most likely explanation for higher ICC values for COG position in the medial-lateral plane is the decreased homogeneity between subjects for this measure in the current study. ICC's evaluate the relative reliability of repeated measures. When the between-subject variance is great and between-test variance is small, the ICC value is high. However, when the between-subject variance is small, the ICC value would be lower even when the between-test variance is small (108). Both older and younger subjects participated in the reliability phase in the current study which may have resulted in greater variability between subjects and hence higher ICC values for COG position measures, particularly in the medial-lateral plane. The ICC values for COG position in the left and right directions calculated for the younger subject separately were lower than the values for the combined group.

The ICC's for LOS measures in four directions ranged from 0.75 to 0.93 in the current study. Brouwer et al. (17) reported similar ICC values (0.88 to 0.93). No other studies were found in which reliability of LOS measures were investigated. Reliability of all four measures was considered adequate for the purposes of this study.

Sway in the anterior-posterior direction with eyes open and eyes closed had good reliability (ICC's > 0.70). Intraclass correlation coefficients for sway measures in the medial-lateral direction were lower (ICC < 0.60). Sway was measured as the average range of COP excursion on the X and Y-axes expressed as a percentage of base of support. Sway is minimal in the medial-lateral plane and there is little variation between subjects, which would contribute to the lower ICC values for sway in this plane. Reliability of sway has been previously reported (47,54). Hageman et al (47) used the ICC to calculate the test-retest reliability of the sway area. Twelve subjects, aged 24 to 68 years (mean = 42) participated the study. ICC's were 0.91 and 0.97 for eyes open and eyes closed respectively. Hoffman et al. (54) evaluated the test-retest reliability of sway area and sway path length in 10 healthy young subjects. They concluded that these two measures had good reliability. Conversely, Brouwer et al (17) found poor ICC values when the area of sway was calculated and expressed as a percentage of the theoretical limits of stability. The ICC was 0.45 for eyes open and 0.38 for eyes closed in 70 young subjects. Liston and Brouwer. (71) performed a similar study for 20 subjects with hemiparesis associated with unilateral stroke. The ICC values for sway measures were 0.56 and 0.63 for eyes open and eyes closed conditions respectively.

5.2 Main Study

5.2.1. Center of Pressure Position during Stance

Anterior-Posterior Plane

The mean COG inclination with eyes open in the young group was 2.37° anterior to the vertical plane passing through the medial malleolus. This value is equivalent to a center of pressure measure of 3.9 ± 1.2 cm anterior to the medial malleolus on the positive X-axis. Measured from the heel line, this value is equivalent to 9.79 cm or 39.76% of the foot length. This finding supports data reported by Kauffman et al. (64) indicating that the COG inclination was 2.3° anterior to the YZ plane. NeuroCom International Inc. used this value in the software designed for the Balance Master system as the COG position for adults of all ages (91). Many of the balance measures obtained using the Balance Master are expressed relative to this stance position.

Brouwer et al. (17) reported a lower mean COG inclination of 1.81° anterior the YZ plane in 70 young subjects using the Balance Master. The difference between the values in their study and the current study is equal to about 0.8cm difference of COP position on the force platform. It is possible that differences in the alignment of the medial malleolus with the center of the plate accounted for this difference. The central line on the Balance Master force plate is approximately one cm wide which could result in more variability in subject positioning. Slightly greater anterior positioning of the subjects on the plate in the current study would result in a higher COG inclination value. The tip of the medial malleolus was marked with felt tipped pen and every effort was made to align this mark with the medial-lateral axis of the force plate.

Three other studies also measured COP position in standing in healthy young subjects (51,114,143). Hellebrandt et al. (51) found the COP position was 5 cm anterior to the lateral malleolus. The lateral malleolus is more posteriorly located relative to the medial malleolus which would account for the lower value in the present study (3.9 cm anterior to the medial malleolus). Whitney (143) reported a COP position value of 11.1cm anterior to the heel line during quiet stance (40.96% of the foot length). This is similar to the finding of 9.79 cm (39.76% of the foot length) in present study. Similarly, Schieppati et al (114) reported a mean COP position in stance of 43.2% of foot length from the heel line in young subjects.

The mean COG inclination in the older subjects in the present study was 2.78° and 2.93° anterior to the vertical plane with eyes open and eyes closed respectively. The value with eyes open corresponded to a COP measure of 4.5 cm anterior to medial malleolus or 10.66 cm (42.9% of the foot length) anterior to the heel line. Schieppati et al (113) also used the force plate to measure the COP position in 18 healthy older subjects (42-79 years of age) and reported a distance from heel line to mean COP position of 45.5% of the foot length with eyes open. Murray et al (86) used the force plate to measure the COP during stance in 24 subjects in 3 groups aged from 30 years to 80 years. During standing, the mean COP position was 11.5 cm anterior to the heel line (43% of foot length). Data were not provided for the individual age groups. Danis et al. (28) used anatomical measurements to calculate the COG position in 26 healthy adults (age 20-88 years), 12 of them older than 65 years. They found the mean vertical projection of the line of COG on the platform was 4.4 ± 3 cm anterior to the ankle joints. Data were not provided for the older subjects independently. Though different studies utilized various measurement methods, the COG position values obtained in this study are generally in agreement with those reported in previous studies.

The COG inclination in older subjects was more anterior than in the young subjects with both eyes open (2.78° versus 2.37°) and eyes closed (2.93° versus 2.35°). The difference with eyes closed was significant ($P<0.0125$). This finding is similar to research reported by Scheippatti et al (114) who measured the COP position from the heel line with eyes open. This distance was 43.2 % and 45.5% of the foot length in young and older groups, respectively, however, no statistical analysis was provided. Conflicting findings have been reported by Woodhull-McNeal (150). Photography was used to measure the relative positions of the limbs and trunk. Though healthy older adults had greater spinal kyphosis and greater anterior trunk lean above the waist, the overall COG was not significantly different between the two groups. However, data on the reliability, validity and sensitivity of the measurement method were not presented.

A more anterior position of the COP is stance has also been reported in subjects whose balance is challenged by platform perturbations (75). Maki et al (75) found that healthy subjects assumed a more forward leaning position during platform translation perturbations particularly when blindfolded. The forward lean occurred regardless of the direction of the perturbation (anterior-posterior) and whether or not subjects were precued. Subjects also leaned forward during continuous platform translations (76). Older subjects who are afraid of falling and who experienced one or more falls in the year following testing were found to lean further forward during continuous perturbations as well as during stance compared to other subjects (P's ≤ 0.009) (77). The average forward displacement of the COP was 1 cm.

Maki and Whitelaw (76) speculated that the forward lean improved postural stability by increasing tonic activation and lengthening of the ankle extensor muscles. The increased recruitment of motor units and increased stiffness of the connective tissues was proposed to strengthen the effective stiffness of the postural control system at the ankle and enhance the upright stance stability (76). This hypothesis was tested in a subsequent study (119). An increase in plantarflexor activity was found with forward lean. However, a coexistent decrease in the postural "reflex" gain during forward leaning led the authors to conclude that overall postural ankle dynamics was not affected by the forward lean.

In order to control the COG above the base of support, the central processing system uses sensory input from visual, vestibular, and somatosensory senses to control effector output through the musculoskeletal system. Studies have found that ostensibly healthy older individuals have impairments in all components of the postural control system (58,118 142,149). For example, inaccurate sensory inputs, slowing in central processing, slower and discordant postural responses, and weaker muscles especially in lower extremity can challenge the postural control system. A more anterior leaning posture may be more stable when balance was challenged as suggested by Sinha and Maki (119). Leaning forward may put the COG closer to the center the BOS and make stance more stable. Additionally, forward leaning may increase the proprioceptive feedback by the increased pressure on the metatarso-phalangeal joints and associated musculature (134). With eyes closed the visual input becomes unavailable and the COG inclination of older subjects was significantly more anterior than in younger subjects. This finding is consistent with previous research which found that older subjects use an increased weighting of visual input over other sensory input for postural control (101,107,120) compared to younger adults. Absence of vision would therefore increase the challenge to postural control and may lead to the more anterior COP position with eyes closed.

The more anterior leaning stance posture may also be related to the postural changes which occur with aging. The increased kyphotic curvature of the thoracic spine (83) and an increase in knee flexion (16) in some older subjects may change the COG inclination in the anterior-posterior plane. However, the relationship between COG position and balance and skeletal alignment is inconclusive (16,26,94,150). For example, Woodhull-McNeal (150) found that though the healthy older subjects had greater kyphosis, the overall COG inclination was not different in older subjects versus young subjects. O'Brien et al (94) reported a significant but weak relationship between skeletal alignment and balance performance measured on the Berg Balance Scale, the Functional Reach, and modified Timed Get Up and Go Test. Further research is required to explore the relationship between skeletal alignment and COG position in older population.

Psychological factors may be associated with anterior lean in older subjects. Tinetti et al (131) reported that 45% of person over age 75 were afraid of falling. An adaptive response to instability and fear of falling is a lower and more anterior COG inclination in relation to the BOS which can maximize balance (26). Maki et al (77) found, during quiet stance and continuous platform perturbation, older fallers who demonstrated fear of falling tended to lean further forward than other older subjects.

Medial-Lateral Plane

The COG position in the medial-lateral plane was close to the midline. The mean angle relative to the XZ-plane was less than 0.1° with eyes open and eyes closed and there was no difference between the two groups. With eyes open, the mean distance between midline (X-axis) and COP position was 1.67% and 2.04% of the foot width in young and older groups respectively. Murray et al. (86) reported the similar results. Among 24 subjects, age ranging from 30 to 70 years, the value for the same measure was 1.86% of the foot width.

5.2.2 Limits of Stability

During maximum leaning in an anterior direction, the average COP position on the force plate in the older group was further from midline (X-axis) than in the younger group ($p<0.05$, Figure 3). This finding suggests that older subjects have more difficulty moving their COP directly forward. The COP position during the posterior leaning task was near the plate center for most subjects and no obvious differences were observed between the two groups in deviation from the midline. During maximum leaning in left and right directions the COP on the force plate was transferred laterally as well as forward in both groups and the deviation ranges were similar in two groups ($P>0.05$). No studies were found in which the path or deviation angle was reported during maximum-leaning tasks.

In the current study, the total excursion of the COP in the young subjects in the anterior-posterior direction was 9.07° which corresponded to 60.1% of foot length. Brouwer et al. (13) reported a similar total anterior-posterior excursion range of 8.58° in a young healthy population. Murray et al (86), King et al (65), and Schieppati et al (114) reported similar anterior-posterior excursions values of 62%, 57.4% and 60% of foot length, respectively (Table 8a). Whitney (143) reported a lower value of 46% of foot length for sagittal plane movement. The sample size was small in the Whitney (143) study. This study (143) is older and it is likely that force plate technology has improved since this study was conducted.

In the older group, the total maximum leaning angle in the anterior-posterior plane was 7.46°, which corresponded to 48.31% of the foot length. Murray et al (86) reported a similar value for total anterior-posterior excursion (46.8% of foot length) in older subjects. Lower values were reported by Schiepatti et al (114) and King et al (65) for older subjects (Table 8b). The older subjects in the Schiepatti et al (114) were recruited from a group of cardiac patients admitted to a rehabilitation center for clinical follow-up. It was possible that performance on the maximum leaning task was effected by their medical condition.

Table 8a. Limits of Stability Expressed as a Percentage of Base of Support in Young Subjects.

Measures	Present study	Murray et al. (58)†	Schieppati et al. (76)	King et al. (46)	Whitney RJ (143)†
Age range (years)	21-35	20-30	18-42	20-59	18-21
LOS in anterior direction ¥§	78.1%	76.8%			
LOS in posterior direction ¥§	18%	15%			
Sum of AP direction §	60%	62%	57.4%	60%	46%
Sum of ML direction *	67%	61.5%			

Table 8b. Limits of Stability Expressed as a Percentage of Base of Support in Older Subjects.

Measures	Present study	Murray et al. (58)†	Schieppati et al. (76)	King et al. (46)
Age range (years)	65-82	60-70	42-79	60-91
LOS in anterior direction ¥§	71.3%	70%		
LOS in posterior direction ¥§	23%	23%		
Sum of AP direction §	48%	46.8%	38.8%	42%
Sum of ML direction *	56.5%	54.6%		

¥ measured from the heel line;
§ expressed as % of foot length;
* expressed as % of foot width;
† data was calculated from raw results in published paper.

King et al. (65) required their older subjects to hold the maximum leaning position for 7-9 seconds. The anterior and posterior leaning tasks immediately followed each other with no rest between tasks. Fatigue could be a reason for their low value in older group.

Few studies have reported values for anterior and posterior maximum leaning range separately in either young or older subjects. In the current study, young subjects could transfer the line of COG from the start position (stance position) 5.81° and 3.26° in anterior and posterior directions, respectively. The position during maximal lean corresponded to 78% and 18% of the foot length in anterior and posterior directions, respectively measured from the heel line (Table 5). The corresponding value for the older subjects for anterior LOS was 4.41° (71.3% of foot length) and for posterior LOS was 3.05° (23% of foot length). Brouwer et al (17) reported similar anterior and posterior LOS values in young subjects of 5.65° and 2.67° respectively, relative to the stance position. Similarly Murray et al (86) reported anterior and posterior LOS of 76.8% and 15% of foot length and 70% and 23% of foot length in anterior and posterior directions in young and older subjects respectively (Table 8a, 8b).

Total excursion of the COP to the left and right in the young group was 14.61° which corresponds to 67.44% of the width of the base of support. Brouwer et al (17) reported a left right excursion angle of 14.54° in a similar population. Murray et al (86) reported a total left right excursion of 61.5% of foot width in healthy young subjects between 21 and 30 years of age (Table 8a). In that study, subjects stood in a comfortable stance position and the distance between the feet was not standardized (86). The average distance between the metatarsal heads was 32.2 cm in the Murray et al study compared to 34.5 cm in the present study. It is possible that the narrower base of support limited the excursion of the COP reported by Murray et al (86) in the medial-lateral direction. Total medial-lateral movement of the COP in older subjects in the current study was 12.61° or 56.53% of the width of the base of support. Murray et al (86) reported a similar value of 54.6% of the width of the base of support in subjects between 60 and 70 years of age.

In the current study, the anterior LOS and total anterior-posterior excursion of the COP were significantly lower in the older group compared to the younger subjects. Posterior limits of stability, expressed as a percentage of foot length, was also significantly lower in the older group, however, when expressed in degrees from start position the difference between groups was not significant. LOS expressed as a percentage of the foot size may be a more accurate measure than the angular measure. The angular measure requires an additional calculation and assumes that the height of COG is 55% of a subjects height which may introduce error in this measure. By definition, LOS are related to the BOS. It would seem to be more appropriate to express LOS relative to the size of this base, as this measure demonstrates how well individuals are able to utilize their anatomical base of support. In addition, it is easier to obtain LOS measures relative to BOS as precise anterior-posterior alignment of the subjects on the force plate is not necessary.

Other authors have also reported lower anterior-posterior LOS in older versus younger subjects (65,86,114). Murray et al (86) compared the maximum leaning distance in both anterior and posterior directions between three groups of subjects (20-30, 40-50 and 60-70 years of age). Anterior and posterior LOS were lowest in the oldest age group and the difference between the groups was significant ($p<0.05$). No post hoc analysis was reported to determine where the differences were. Schieppati et al (114) also reported a significantly lower total anterior-posterior excursion of the COP in older compared to younger subjects (Table 8a, 8b). Similarly, King et al (65) found the total anterior-posterior range of foot length used during the maximum leaning was lower in older subjects. The correlation coefficient between age and anterior-posterior LOS for 90 subjects over the age of 60 was 0.51 ($p<0.001$).

Right, left and total medial-lateral LOS measures were significantly lower in the older group in the current study. Murray et al (86) measured the distance between COP position during lateral maximum leaning to the lateral border of the feet in subjects in three age groups. The distance was highest in the older group and total medial-lateral excursion was significantly different between the groups ($p<0.05$).

There are several possible explanations for the lower LOS values in the older subjects. All components of the postural control system are known to deteriorate with age. For example, the decrease in muscle strength which occurs with age may contribute to the lower LOS in the older group. By the age of 70 years, it was estimated that muscle mass decreased by 25-35% resulting in a decrease in muscle strength (44). The greatest decline in strength occurs in lower extremity muscles groups, for example in anterior tibialis (142) and ankle plantarflexors (134). Fujiwara et al (40) studied the correlation between anterior and posterior leaning distance and strength of lower extremity muscles in subjects between 20 and 79 years of age. These authors reported significant correlations between maximum anterior leaning distance and plantarflexor muscle strength (r=0.34 and 0.30 for males and females respectively), and flexor digitorum brevis strength (r=0.44 and 0.42 for males and females respectively). Tibialis anterior strength was significantly correlated with posterior leaning distance (r=.27 and .25 for males and females respectively). Similarly, Schieppati et al. (114) found that soleus and flexor digitorum brevis EMG activity increased with forward leaning, while tibialis anterior and extensor digitorum brevis activity increased with backward leaning. These findings suggest a control function for these distal muscle groups during anterior-posterior maximum leaning. As the COG is transferred towards the edge of the base of support more torque is needed around the ankle to counteract the increased momentum due to gravity. Subjects in the current study were required to hold the maximum leaning position for 5 seconds. Older subjects may have more difficulty maintaining the maximum lean for this length of time because of the fatigue. This may have contributed to the lower LOS in the older subjects.

No studies were found in which muscle activity was measured during medial-lateral weight shift. It is probable that medial-lateral balance is under hip abductor and adductor muscle control (144). Decreased strength in hip abductor and adductor muscles in older subjects (85) may be a factor contributing to the lower medial-lateral LOS in the older group.

Differences in sagittal plane ankle range of motion could not account for the lower anterior-posterior LOS in the older subjects. Although range of motion significantly decreases with age ($p<0.01$), changes are small (45,135,136). Vandervoort et al (136) revealed that passive dorsiflexion range of motion was 13.1° and 12.1 for 55-85 year old healthy men and women, respectively. This range is adequate for the older subjects to lean forward the same distance as the younger subjects (8.18° from the vertical). Normal range of plantarflexion range is 30°-50° (45). Only a small range of ankle motion is used for posterior maximum leaning. Though no study has been found that measured the ankle plantarflexion range of motion in older subjects, it is unlikely that this motion would be restricted sufficiently to cause a limitation in posterior limits of stability in the older subjects.

Deterioration in sensory functions may also be related to the lower LOS measures in older subjects. Postural control consists of keeping the body's center of gravity within the edges of the base of support (57). However, no direct sense of the position of the COG exists and thus the relevant information must be derived from peripheral sensory information, including the proprioceptive, vestibular, and visual systems. The proprioceptive sense in older adults is compromised compared to a young population. Older subjects were less sensitive to vibration and touch-pressure (15). The functions of the vestibular system (112) and visual system (103) are also subject to age-related changes. Limits of Stability measure the maximum range which subjects can transfer their COG in different directions. It represents the limits of the ankle strategy and the point beyond where the stepping strategy is required to preserve balance (58). Different muscle synergies are employed in these two strategies. Accurate detection of the point at which the ankle strategy will no longer suffice and a stepping strategy is crucial for successful recovery of balance. Decreased sensory information may affect the perception of the range over which the COG can be safely transferred.

Psychological factors could affect LOS performance. Limits of stability is not the actual biomechanical LOS but the perceived LOS. Maki et al (74) suggested that fear of falling was a potentially confounding factor for postural control measures. Fear of falling is prevalent among community-dwelling older individuals (138). Piotrowski and Cole (102) found two functional assessments, the Berg Balance Scale and self paced walk test, were significantly related to scores on the Falls Efficacy Scale which measured fear of falling in an older population. Subjects who had a high score on the Berg Balance Scale scored lower on the Falls Efficacy Scale. As a functional balance measure, Limits of Stability in the older group could be affected by fear of falling, though no studies have reported the relationship between the two measures.

5.2.3 Sway Measures

Sway measures were significantly different between the two groups, with the exception of the medial-lateral sway with eyes closed (Table 7). These results are in agreement with previous studies in which sway was measured as length of sway path (22), sway range in anterior-posterior and medial-lateral directions (73), sway area (47), and sway area to BOS ratio (120). Increased sway in an older population is related to poor performance in other balance measures (2,33,34,70). Therefore, the greater excursion of the COP during stance is thought to result from poor postural control (2,33,34). However, Woollacott et al. (148) have postulated that the degeneration in sensory systems in older adults could result in a higher detection threshold in sensory systems. Increased sway is necessary to reach this threshold for activation of the necessary stretch reflexes for postural control during stance. Similarly, Patla et al (99) suggested that greater sway was a compensatory function of the postural control system to increase the proprioceptive feedback from the ankle joints, rather than a reflection of poor balance control.

Lower sway magnitude has been reported in below knee amputees (41) and subjects with Parkinson's syndrome (126) compared to healthy subjects. Balance is known to be impaired in these populations, and it would be anticipated that sway would increase rather than decrease. Authors of these studies postulated that the relationship between sway and postural control needs further study (41,126).

Slobounov et al. (120) suggested that postural sway is a relatively poor measure of stability because it doesn't reflect the relation of the COG position to the base of support, which is the basic definition of balance. The correlation between age and the area of the BOS over which COG can be safely transfered with eyes open ($r= 0.91$, $p<0.01$) and eyes closed ($r=0.68$, $p<0.05$) has been reported to be much higher than the correlation of age and sway measures, such as area ($r=0.29$, $p>0.05$), length ($r=0.64$, $p<0.05$), and velocity ($r=0.58$, $p<0.05$) (120). A balance assessment in which the postural control system is challenged and the magnitude of the challenge is controlled and specific to the individual's ability may be a preferred balance measure (100). LOS measurement is considered as a more challenging task than sway and thus may be more sensitive to deterioration in stability control with aging.

In the current study, all LOS measures expressed as percentage of foot size differentiated between the older and young groups, while three of four sway measures were different between the two groups. This may indicate that LOS measures are more sensitive to smaller differences between groups in postural control performance. In addition, the reliability of the LOS measures were generally higher than those of the sway measures in the current study. Johansson et al. (63) also suggested that more challenging balance measures, such as LOS, allowed better reproducibility than tests of spontaneous sway.

Limits of stability and postural sway during stance may measure different aspects of postural control. Sway is a continuous corrective movement which maintains the body in the upright position. Sway is due to the unstable nature of the human body (great height in comparison to the small support base). Sway is mediated by the central nervous system, which is an automatic network system using a feedback principle (125). Sway is controlled by unconscious mechanisms, while LOS is the perception of the limits which the COG cannot exceed during maximum leaning.

5.3 Limitations

Most participants in young group were recruited from the student population in the School of Rehabilitation Therapy at Queen's University rather than from the general population. All older subjects were volunteers who had seen advertisements in the local newspaper. Older volunteers may be more active than those who do not volunteer and have better balance. These limitations in recruitment may restrict the generalization of results to the general population.

The leaning body was considered as a inverse pendulum with the axis at the ankle joints when the LOS were expressed as the angle from the vertical. For the trigonometric calculation of the degree of this angle, the length of the hypotenuse should be 55% of body height minus the height of the ankle joint from ground. However, the computer program did not account for the ankle joint height which would result in some inaccuracy in the angular measure. However, this was true for subjects in both groups so this inaccuracy would not affect comparison between groups. If the ankle joint height is taken into account for the calculation, the leaning angle will increase between 0.3-0.6 degrees depending on the direction. Another limitation in the calculation program was the height of COG. Though there is evidence that the average height of COG in adults is about 55% of body height (51,98), an individual measure of each subject's height of COG could be better than an average assumption. For this reason, measures expressed relative to the BOS may be preferable.

5.4 Recommendations for Future Research

- Limits of stability measured as percentage of BOS is preferred over angular measures because it doesn't required accurate alignment of ankle joint with the platform axis, and no assumptions about the COG position relative to height is made.
- Comparison of LOS between different groups of subjects, for example, the older fallers and non-fallers, patients with balance impairment and healthy subjects, and patients before and after balance training are needed.

- In order to the determine the relationship between foot width and maximum leaning ranges in four directions, LOS need to be obtained using a comfortable stance posture as well as standardized stance posture.

5.5 Summary and Conclusions

Twenty-nine young and 27 older healthy subjects participated in this study. They were required to stand quietly for 20 seconds with eyes open and with eyes closed. They were then encouraged to lean in anterior, posterior, left and right directions as far as they could and hold that position for 5 seconds with eyes open, keeping their knees and hips straight and heels and toes in contact with the ground. The center of pressure position during these postures was measured. The reliability of these measures were calculated and difference were compared between two groups. The conclusions from this study are as follows:

- All measures in this study were reliable (ICC's >0.60) with the exception of sway in the medial-lateral plane with eyes open and closed. ICC's for LOS measures were generally higher than for sway measures.
- During stance the COG average position was further forward in older subjects compared to young subjects with eyes closed.
- In both groups, the mean COG position was near the midline in the medial-lateral direction and there was no difference between groups.
- When leaning anteriorly, older subjects deviated from the midline to a greater extent than young subjects. During maximum posterior leaning task, most subjects were close to the center of the plate (0,0).

- During the maximum leaning in left and right directions, all subjects tended to go forward as well as laterally. There was no significant difference in the deviation degree between the two groups.
- The maximum leaning ranges in anterior, posterior, left and right were significantly lower in the older subjects compared to young subjects.
- Older subjects on average had greater sway in the anterior-posterior plane with both eyes open and closed and in the medial-lateral plane with eyes open.

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APPENDIX I

Consent Form

School of Rehabilitation Therapy, Queen's University

Principle Investigator: Dr. Elsie Culham

Co-Investigator: Dr. Brenda Brouwer

Title of Project: Association of Physical and Psychosocial Factors Related to Falls in the Elderly

Background Information:

The purpose of this research study is to determine the extent of balance impairment, muscle weakness and decreased flexibility and reaction time in individuals who are unsteady and at risk of falling and the impact of this impairment on level of physical and social activity. In order to do this individuals with balance problems (study group) will be compared to individuals in the same age range who have no balance disorder or other neurological or medical problems (control group).

Description of the testing:

Participation in this study will involve one visit to the laboratory in the Louise D. Acton Building at Queen's University. The tests will take approximately a hours to complete.

Questionnaires:
You will be asked to complete three questionnaires: the Human Activity Profile, the Nottingham Health Profile and the Activities-Specific Balance Confidence Scale. These questionnaires measure level of activity, quality of life and fear of falling respectively. You will also be asked questions about your medical history and asked to complete a brief test of your memory and cognitive ability.

Blood Pressure:
Your blood pressure will be measured while in the seated position and again while in standing.

Balance Tests:
Balance will be measured in two ways. The Berg Balance Scale will be used to measure your ability to perform 14 common every day movements. Secondly, your ability to shift your body weight forward, backward and from side to side will be measured using a force platform.

Self-Paced Speed of Walking:
For this test you will be asked to walk four lengths of a 20 meter distance at your usual walking speed.

Muscle Strength:
The strength of the major muscle groups around your ankles, knees and hips will be measured with a Cybex isokinetic dynamometer. Your will be asked to move your ankle, knee or hip joint against a resistance offered by the machine.

Anticipatory Postural Response:
The onset of activity in lower extremity muscle groups in response to a voluntary movement will be measured using electrodes placed over the muscles on both legs. The activity of these muscles will be recorded as you bend one leg at the knee at a natural and fast speed.

Risks:

There are no risks associated with completion of the questionnaires. There is the possibility of loss of balance during the balance, walking and postural response tests. An assistant will always be close by to ensure your safety during these tests. You may experience some fatigue or muscle soreness following the strength testing but this should be minimal and not last more than 48 hours.

Benefits:

You will not benefit directly from your participation in this study. This study will however, provide important information about balance impairment which will be used to better target fall prevention programs for seniors at risk of falling.

Confidentiality:

Personal information and other data will be strictly confidential. A file number will be assigned to the data of each participant and this information will be kept in a secure location. Subject identification will be known only to the investigators and research assistant and will not be released under any circumstances.

Voluntary nature of the study/Freedom to withdrew

Your participation in this study is voluntary. You have the right to withdraw at any time for any reason.

Payment:

You will receive no payment for participation in this study other than reimbursement of travel and parking costs for the test session.

SUBJECT STATEMENT AND SIGNATURE

I have read and understood the information provided about the study and have had the purposes, procedures and technical language explained to me. I have been given sufficient time to consider the above information and seek advice if I choose to do so. I have had the opportunity to ask questions which have been answered to my satisfaction. I am voluntarily signing this form and I will receive a copy of this consent form for my information. I have the right now or later to discuss my concerns about the research with the investigators:

Dr. Elsie Culham	at	(613) 533-6727
Dr. Brenda Brouwer	at	(613) 533-6087

Or the Director of the School of Rehabilitation Therapy:

Dr. S. Olney	at	(613) 533-6102

By signing this consent form I am indicating that I agree to participate in this study.

______________________ ______________

Signature of Subject Date

______________________ ______________

Signature of Witness Date

STATEMENT OF INVESTIGATOR

I, or one of my colleagues, have carefully explained to the subjects the nature of the above research study. I certify that, to the best of my knowledge, the subject understands clearly the nature of the study demands, benefits, and risks to participate in this study.

______________________ ______________

Signature of Investigator Date

APPENDIX II

Instructions for Administration of the Folstein Modified Mini-mental State Examination

ORIENTATION

1. Ask for the date. Then ask specifically for parts omitted, e.g., "Can you also tell me what season it is? One Point for each correct.
2. 2. Ask in turn "Can you tell me the mane of this hospital?" (town/city, county, etc.). One point for each correct.

REGISTRATION

Ask the patient if you may test his memory. Then say the names of the 3 unrelated objects, clearly and slowly, about on second for each. After you have said all 3, ask him to repeat them. This first repetition determines his score (0-3) but keep saying them until he can repeat all 3, up to 6 trials. If he does not eventually learn all 3, recall cannot be meaningfully tested.

ATTENTION AND CALCULATION

Ask the patient to begin with 100 and count backwards by 7. Stop after 5 abstractions (93, 86, 79, 72, 65). Score the total number of correct answers. If the patient cannot or will not perform this task, ask him to spell the word "world " backwards. The scores is the number of letters in correct order e.g. dlrow=5, dlorw = 3.

RECALL

Ask the patient if he can recall the 3 words you previously asked him to remember. Score 0-3.

LANGUAGE

Naming: Show the patient a wristwatch and ask him what it is.Repeat for pencil. Score 0-2.
Repetition: Ask the patient to repeat the sentence after you.Allow only one trial. Score 0-1.

3-Stage Command: Give the patient a piece of plain blank paper and repeat the command. Score 1 point for each part correctly executed.

Recalling: On a blank piece of paper print the sentence "Close your eyes", in letters large enough for the patients to see clearly. Ask him to read it and do what it sways. Score 12 point only if he actually closes his eyes.

PROPOSED SCORING:

Maximum Score = 28
Normal = 24- 28
Moderate to Severe Cognitive Impairment = 189=20
Dementia =<18

Folstein Modified Mini-mental State Examination

Subject Code ____________
Examiner ______________
Date ___________________

Maximum Score	Score	ORIENTATION
5	( )	What is the (year) (season) (data) (month) (day)?
5	( )	Where are we: (province) (country) (town/city) (hospital) (floor)

REGISTRATION

3 ( ) Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he learns all 3. Count trials and record.

Trials:

ATTENTION AND CALCULATION

5 ( ) Serial 7's: 1 point for each correct. Stop after 5 answers. Alternatively spell "world" backwards.

RECALL

3 ( ) Ask for the 3 objects repeated above. Give 1 point for each correct answer.

LANGUAGE

7 ( ) Name a pencil, and watch (2 points). Repeat the following "No ifs, ands or buts" (1 point). Following a 3-stage command: "Take a paper in your right hand, fold it in half, and put it on the floor" (3 points). Read and obey the following: CLOSE YOUR EYES (1 point).

________________ TOTAL SCORE

APPENDIX III

The Berg Balance Scale

Subjects code number:

Date:

BALANCE ASSESSMENT:
(Developed in partial fulfillment of a Master of Science degree, McGill University: K Berg 1988)

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 (R or L)	
14.	standing on one foot (R or L)	

TOTAL SCORE /56

1. Siting to standing

Instruction: please stand up. Try not to use your hands for support.
Grading: please mark the lowest category which applies.

4- able to stand no hands and stabilize independently
3- able to stand independently using hands
2- able to stand using hands after several after several tries
1- needs minimal assistance to stand or to stabilize
0- needs moderate or maximal assistance to stand

2. Standing unsupported

Instruction: stand for two minutes without holding
Grading: please mark the lowest category which applies

4- able to stand safely for 2 minutes
3- able to stand for 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 subjectsis able to stand for 2 minutes safely, score full marks sitting unsupported. Proceed to position change standing to sitting.

3. Sitting unsupported with feet on floor

Instruction: sit with arms folded for two minutes
Grading: please mark the lowest category which applies

4- able to sit safely and securely 2 minutes
3- 2 minutes under supervision
2- 30 seconds
1- 10 seconds
0- without support 10 seconds

4. Standing to sitting

Instruction: please sit down
Grading: please mark the lowest category which applies

4- sits safely with minimal use of hands
3- controls descent by using hands
2- uses backs of legs against chair to control descent
1- sits independently but has uncontrolled descent
0- needs assistance to sit

5. Transfers
Instructions: please move from chair to bed and back again. One way toward a seat with armrests and one way towards a seat without armrests.
Grading: please mark the lowest category which applies

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 cuing and/or supervision
1- needs person to assist
0- needs two people to assist or supervise to be safe

6. Standing unsupported with eyes closed

Instructions: close your eyes and stand still for 10 seconds.
Grading: please mark the lowest category which applies

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 from falling

7. Standing unsupported with feet together

Instructions: place your feet together and stand without holding.
Grading: please mark the lowest category which applies

4- able to place feet together indep and stand 1 min safely
3- able to place feet together indep and stand 1 min with supervision
2- able to place feet together indep but unable to hold for 30 seconds.
1- needs help to attain position, but able to stand 15 seconds with feet together
0- needs help to attain position and unable to hold for 15 seconds.

8. reaching forward without stretched arm

Instruction: lift arm 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the 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 fingers reach while the subjects is in the most forward lean position.)
Grading: please mark the lowest category which applies

4- can reach forward confidently > 10 inches
3- can reach forward >5 inches
2- can reach forward > 2 inches
1- reaches forward but needs supervision
0- needs help to keep from falling

9. Pick up object from the floor

Instructions: pick up the shoe/slipper which is placed in front of your feet.
Grading: please mark the lowest category which applies

4- able to pick up object safely and easily
3- able to pick up object but needs supervision
2- unable to pick up but reaches 1-2 inches from slipper and keeps balance indep
1- unable to pick up and needs supervision while trying
0- unable to try /needs assistance to keep from falling
1-

10. Turning to look behind over left and right shoulders
Instructions: turn to look behind you over toward left shoulder. Repeat to the right.
Grading: please mark the lowest category which applies

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 naintains balance
1- needs supervision when turning
0- needs assistance to keep from falling

11. Turn 360 degrees

Instructions: turn completely around in a full circle. Pause. Then turn a full circle in the other direction.
Grading: please mark the lowest category which applies

4- able to turn 360 safely in < 4 seconds each side
3- able to turn 360 safely one side only in < 4 seconds
2- able to turn 360 safely but slowly
1- needs close supervision or verbal cuing
0- needs assistance while turning

12. Stool touch

Instruction: place each foot alternatively on the stool. Continue until each foot has touched the stool four times.
Grading: please mark the lowest category which applies

4- able to stand independent and safely and complete 8 steps in 20 seconds.
3- able to stand independent and complete 8 steps in > 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

Instruction: (Demonstrate to subject) Place one foot directly in front of the other. If you feel you cannot place your foot directly in front, try to step far enough that the heel of your forward foot is ahead of the toes of the other foot.
Grading: please mark the lowest category which applies

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.

Instruction: stand on one leg as long as you can without holding.
Grading: please mark the lowest category which applies

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 or lift leg unable to hold 3 seconds but remains standing independently
0- unable to try or needs assist to prevent falling

EQUIPMENT: chair with armrests, chair without armrests, stop watch, measuring tape, stool 105 cm in height.

APPENDIX IV

Individual Subject's Data

NO.	Group	G	Height (cm)	Weight (Kg)	ALOS (°)	PLOS (°)	LLOS (°)	RLOS (°)	ABOS (%)	PBOS (%)	APBOS (%)	LRBOS (%)
1	Young	F	169.5	52.32	7.192	-1.23	-8.28	7.5	74.17	18.34	55.82	73.01
2	Young	M	177.5	66.96	8.999	-1.31	-8.21	8.991	85.37	16.75	68.62	76.55
3	Young	F	167.5	56.49	9.54	-0.666	-8.48	9.336	83.75	17.06	66.69	77.24
4	Young	F	169	60.57	8.502	-1.26	-7.77	7.68	82.08	15.61	66.47	72.22
5	Young	F	152	55.01	7.177	-1.01	-7.13	7.53	72.36	15.57	56.79	63.76
6	Young	M	170	72.86	7.677	-1.36	-7.72	7.449	74.72	17.6	57.12	69.84
7	Young	F	172.5	60.07	8.166	-0.622	-7.33	7.842	80.48	20.54	59.94	70.69
8	Young	F	158	45	8.181	-1.17	-7.04	7.004	80.34	17.6	62.74	70.82
9	Young	F	166.5	63	7.028	-0.953	-6.66	7.073	71.87	18.39	53.48	62.96
10	Young	F	171	69.77	8.448	-0.253	-8.18	7.122	78.05	20.54	57.51	69.21
11	Young	F	161	45.75	6.953	-0.979	-7.47	6.311	73.73	18.12	55.6	60.76
12	Young	M	183	94.1	9.109	-1.17	-7.12	7.219	82.77	14.9	67.88	70.5
13	Young	F	156.5	48	6.962	0.8052	-6.84	6.343	71.78	28.88	42.9	57.3
14	Young	M	178.1	66.34	8.386	-0.629	-7.37	7.123	76.77	19.34	57.42	65.07
15	Young	M	185.5	81.26	7.949	-1.67	-6.08	5.807	74.46	14.65	59.82	54.68
16	Young	F	166	62.84	8.841	-0.889	-7.51	8.047	81.59	15.71	65.88	68.97
17	Young	M	183.5	82.34	8.393	-0.755	-6.37	7.331	80.85	18.96	61.9	64.74
18	Young	M	179.5	79.37	7.862	-0.466	-5.85	6.69	74.78	20.89	53.89	63.26
19	Young	M	179.4	70.6	7.934	-1.15	-6.32	6.544	75.07	16.89	58.18	61.43
20	Young	F	168.3	78.08	7.769	-0.969	-6.29	6.962	77.14	18.48	58.66	64.13
21	Young	F	166	64.48	8.752	-1.05	-9	8.615	82.16	19.15	63.01	73.43
22	Young	M	177.4	76.38	8.203	-0.786	-6.63	7.23	80.33	18.8	61.53	62.2
23	Young	M	174	74.33	7.82	-0.721	-6.63	6.44	73.74	19.02	54.71	61.05
24	Young	M	173	54.25	7.653	-0.898	-7.33	7.235	76.52	16.39	60.14	66.37
25	Young	F	164	48	9.591	-1.4	-7.3	7.726	83.78	15.15	68.62	71.7
26	Young	F	176	71	8.1	-0.327	-7.52	6.968	74.66	18.57	56.09	68.76
27	Young	F	161.5	53	8.995	-1.15	-8.06	7.554	81.78	14.79	67	74.93
28	Young	M	176	77	8.205	-0.871	-7.17	7.786	78.4	19.26	59.14	70.59
29	Young	M	182	86	8.953	-0.956	-7.18	7.468	81.89	16.43	65.46	69.53
30	Old	F	158	80	7.176	-0.215	-6.1	5.645	73.23	26.05	47.18	53.23
31	Old	M	166.2	72.5	9.15	-0.343	-7.69	7.315	83.28	21.96	61.32	64.91
32	Old	M	171.7	78.6	6.988	-0.138	-5.99	6.704	70.79	26.41	44.38	51.95
33	Old	M	177.5	93	4.711	-0.714	.	.	58.34	23.62	34.72	.
34	Old	M	161.2	62.5	4.47	0.1177	.	.	55.41	26.53	28.87	.
35	Old	M	171	75	6.715	-0.082	-6.77	6.406	69	24.21	44.79	58.4
36	Old	M	185.8	68	7.812	-0.556	-6.33	6.651	75.15	18.35	56.8	62.27
37	Old	M	166.6	49.55	8.522	1.179	.	.	75.63	30.92	44.71	.
38	Old	F	166.3	78.5	6.836	-0.548	-6.21	6.567	70.38	21.07	49.31	56.49
39	Old	M	176	83	7.719	-1.35	-7.03	6.679	75.01	19.24	55.76	57.56
40	Old	F	156	57	7.523	-0.576	-5.03	6.445	71.45	21.15	50.3	52.14
41	Old	M	168.6	63	7.842	-0.421	-7	6.918	75.12	17.89	57.23	60.29
42	Old	F	175.6	74.5	6.582	-1.2	-6.59	6.758	68.07	18.48	49.59	60.28

43	Old	M	173.7	92	6.996	1.189	-6.25	6.318	68.18	31.89	36.29	58.42
44	Old	M	165.5	66	9.472	-0.527	-6.26	7.577	83.06	21.03	62.02	59.14
45	Old	M	179	76	7.617	-1.08	-7.22	7.913	73.28	16.41	56.87	65.72
46	Old	F	160	55	6.325	-0.311	-5.62	5.518	62.83	18.89	43.94	50.62
47	Old	F	157.5	63.5	7.651	0.0829	-5.52	5.959	70.65	21.9	48.75	55.68
48	Old	M	171.5	81	7.572	-0.138	-5.84	5.806	73.05	23.42	49.63	51.8
49	Old	F	174.4	55	6.883	-0.342	-7.68	7.498	70.91	24.14	46.77	64.99
50	Old	F	171.4	87.4	5.9	1.338	-6.56	6.391	65.4	34.77	30.63	53.02
51	Old	F	162	88	7.21	-0.955	-6.5	6.244	71.42	17.51	53.91	60.09
52	Old	F	165	66	7.799	0.2412	-5.05	4.572	71.95	23.35	48.6	48.88
53	Old	F	161.5	78.5	5.648	-1.67	-5.01	5.468	70.63	20.25	50.39	47.55
54	Old	F	157.2	57	7.948	0.1376	-5.93	6.483	73.5	22.42	51.08	59.29
55	Old	F	153.9	64	8.154	-0.121	-6.49	4.619	78.09	24.66	53.44	52.62
56	Old	M	181.4	93	7.107	-0.2	-5.7	5.709	72.38	25.38	47	51.38

NO.	Group	COGXEO (°)	COGXEC (°)	COGYEO (°)	COGYEC (°)	SWAYX EO(%)	SWAYX EC(%)	SWAYY EO(%)	SWAYY EC(%)
1	Young	2.6846	2.6539	-.6571	-.8950	.8155	.8875	.5204	.4947
2	Young	1.8664	1.5332	-.1670	-.2663	.5076	1.0836	.2225	.3812
3	Young	2.4574	2.2195	.0965	.4083	.6708	1.1625	.3227	.4414
4	Young	1.7979	1.9197	-.8660	-.5861	1.3965	2.6054	.6183	.6986
5	Young	2.2307	2.4863	-.2136	-.2220	.9273	1.1477	.3044	.4131
6	Young	1.6693	1.9032	-.4073	-.3260	.5018	.6140	.1900	.2184
7	Young	2.8110	2.6569	-.1226	-.1107	.5884	1.3807	.2355	.3431
8	Young	3.1407	3.0312	-.2321	-.2037	1.4157	1.9820	.4622	.4925
9	Young	1.5810	1.8274	.0692	.3220	.9810	2.1559	.6274	.8598
10	Young	1.4464	1.8255	-.2761	-.4736	.8575	1.3848	.2961	.2686
11	Young	4.6131	4.3058	.7206	.0719	.8930	1.0164	.5065	.5015
12	Young	2.3166	2.6101	-.3176	-.1232	.8488	.9852	.4631	.5219
13	Young	4.1128	4.1887	-.5084	-.2301	1.4682	1.8484	.5242	.5642
14	Young	1.5905	1.4759	.7006	.9220	.5149	.9285	.2923	.3278
15	Young	2.4068	2.2435	.3911	.4004	.6577	1.2139	.2133	.3050
16	Young	4.0186	3.8743	-.2930	-.3069	.8130	1.4429	.1916	.2794
17	Young	2.2833	2.2342	-.0705	-.0871	.6000	.6322	.2414	.3416
18	Young	1.9487	2.1182	-.2701	-.6955	.8472	1.7819	.3111	.3744
19	Young	1.4174	1.9934	-.1396	-.0378	.6440	.9793	.2649	.2156
20	Young	1.3254	1.0836	.1112	.0908	.6293	1.4137	.2123	.3447
21	Young	2.3822	2.3255	.0656	.0054	1.2666	1.6536	.5396	.4946
22	Young	1.7043	1.5710	-.6006	-.5347	.8861	2.0341	.3886	.6295
23	Young	2.6577	2.4682	-.0052	.0432	1.3157	1.0995	.4727	.4342
24	Young	2.3697	1.8953	.3488	.2330	.8671	1.8410	.4214	.5663
25	Young	2.8700	2.6750	.0200	-.0521	.6375	.9879	.1520	.2404
26	Young	1.6429	2.0143	-.1911	-.1075	.6845	1.1173	.4450	.3869
27	Young	2.5173	2.3491	-.1093	-.1351	.7422	1.3748	.4225	.5344
28	Young	2.8417	2.6437	.5254	.4585	.7418	.8971	.2407	.4081
29	Young	2.0816	2.0999	.5056	.3022	.5764	.7902	.3624	.4167
30	Old	2.3118	3.0035	.5624	.4742	1.0011	1.5748	.3993	.4891
31	Old	4.6128	4.7043	-.6313	-.7915	1.0623	1.2362	.3258	.3195
32	Old	3.6152	3.8333	.3421	.4023	.6953	1.0245	.2886	.3215
33	Old	1.0671	1.2220	.0051	.1321	1.2775	2.6817	.4339	.4695
34	Old	2.2615	2.3103	-.0366	.2620	1.3367	1.6538	.5776	1.3245
35	Old	2.5995	2.7561	.0042	.1048	1.6665	1.8374	.4971	.4482
36	Old	3.9626	3.8956	-.3489	-.2909	.9535	1.6826	.3409	.5164
37	Old	3.5244	4.4638	1.6101	1.8284	1.7327	3.0063	.6982	.7405
38	Old	2.1863	2.0976	.4416	.4527	.9657	1.4700	.3541	.4752
39	Old	2.9013	2.9408	-.3466	-.8695	1.3884	2.0996	.6962	.8952
40	Old	2.1929	2.3221	.9869	1.2709	1.4050	1.3481	.5684	.4943
41	Old	2.3749	3.0527	-.2806	-.1024	1.1056	2.4298	.4809	.6123
42	Old	2.0899	2.8427	-.1379	-.2344	1.2583	1.8680	.5176	.4344
43	Old	2.6784	3.3762	-.5696	-.4114	1.3036	2.1931	.7450	.8194
44	Old	3.5378	3.3374	.2459	.1703	1.2877	1.9170	.5276	.4080
45	Old	3.2562	2.5110	-.1303	-.0859	.8980	2.4116	.4122	.9434

46	Old	2.9580	3.0037	-.2254	-.0903	1.0305	1.0588	.5160	.4140
47	Old	2.7826	2.9763	-.5454	-.0258	1.0401	1.7222	.4542	.5647
48	Old	2.2142	2.8096	-.6520	-.9012	1.8177	2.3155	.9579	.5325
49	Old	2.7155	2.6782	-.2605	-.2910	.8260	1.2648	.2994	.3725
50	Old	2.8636	3.0017	-.8452	-.6341	1.3619	2.2478	.4366	.8072
51	Old	2.6504	2.2373	-.8117	-.3620	1.0890	1.3969	.4454	.4858
52	Old	3.5388	3.4280	.2038	.2133	.8558	1.0455	.3018	.2416
53	Old	.5546	.7249	.8450	.9469	1.5007	1.7476	.4215	.4896
54	Old	2.5622	2.4875	.2585	.4784	1.0736	2.1043	.4518	.6769
55	Old	4.2673	4.0582	.2384	.2368	.8968	1.3910	.3293	.4155
56	Old	2.8959	3.0134	-.3048	-.4229	.8818	1.7805	.4562	.5071

G: gender;
ALOS: anterior limits of stability;
PLOS: posterior limits of stability;
LLOS: left limits of stability;
RLOS: right limits of stability;
ABOS: anterior limits of stability relative to the length of base of support;
PBOS: posterior limits of stability relative to the length of base of support;
APBOS: anterior and posterior limits of stability relative to the length of base of support;
LRBOS: left and right limits of stability relative to the width of base of support;
COGXEO: center of gravity position along X-axis with eyes open;
COGXEC: center of gravity position along X-axis with eyes closed;
COGYEO: center of gravity position along Y-axis with eyes open;
COGYEC: center of gravity position along Y-axis with eyes closed;
SWAYXEO: Sway along the X-axis with eyes open;
SWAYXEC: Sway along the X-axis with eyes closed;
SWAYYEO: Sway along the Y-axis with eyes open;
SWAYYEC: Sway along the Y-axis with eyes closed.