Evaluating a Clinical Tool to Assess Balance Disorders in Community-Dwelling Seniors

by

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A Thesis submitted to the Faculty of Graduate Studies of

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MASTER OF SCIENCE

TABLE OF CONTENTS

ABSTRACT

Purpose: The aim of the study was to determine the ability of a new dynamic standing balance assessment test to identify fallers in community-dwelling seniors (older adults). Relevance: Poor balance, mobility restrictions, fear of falling and fall injuries are serious problems for many people over 65 who reside in community-dwellings. Routine clinical balance assessments incorporate a range of static and dynamic tasks. However, most of these tests are self-paced and performed in a predictable environment. Laboratory-based instruments can identify balance impairment but require expensive setup and special training. There is a critical need for a clinical tool which can assess both predictive and unpredictive balance control. Examining community-dwelling older adults in both control (normal surface) and unpredictable (compliant surface) environment can provide valuable insight and help in designing appropriate interventions to reduce fall risk in this population. Participants: Seventy-two community-dwelling older adults who were being treated for balance and mobility impairment in a day hospital setup. Methods: Based on the concept of the modified Clinical Test of Sensory Interaction and Balance (mCTSIB), a *Dynamic Balance Assessment (DBA)* test was developed. The DBA test consists of six graded balance tasks performed first on a normal surface then on a compliant sponge surface. The DBA test evaluates contribution of sensory interactions to balance control by eliminating or distorting sensory information. Each task was performed for 20 seconds and if the participant failed to complete the task, it was recorded as a loss of balance (LOB). Balance performance was quantified by a flexible pressure mapping mat - FSA (Verg Inc., Winnipeg, Canada), which measured centre of foot pressure (COP). The participant's balance performance was also evaluated by routine clinical balance assessment tools, in particular, the Berg Balance Scale (BBS), the Time up and Go test (TUG), gait velocity (GV) and the 6-minute walk test (SMWT). Analysis: For each completed task, peak excursion and pathlength for COP signals were computed. Frequency of LOB and a *"Composite"* score was calculated to index balance performance in the DBA test. The Mann-Whitney U test was used for the non-normally distributed variables and independent t-test was used for the normally distributed variables to determine difference between fallers and non-fallers based on history of falls in the last one year. The Spearman correlation was computed to determine the relationship between experimental and clinical variables. Results: No significant difference was noted between the two groups for age, gender, use of assistive device for walking, home care (assistance), medication and walking half a mile. The fallers in this study showed higher (low composite score) COP excursions and swaypathlength than non-fallers. All COP experimental variables for composite scores and compliant surface scores ($p \leq 0.02$) and LOB ($p = 0.04$) in the DBA test were able to distinguish fallers from non-fallers. However, on the normal surface, only the COP ML excursion scores showed a significant difference between fallers and non-fallers ($p = 0.02$). Only the TUG was able to differentiate people who fell once from those who had not fallen ($p = 0.03$). The clinical balance assessment tools showed poor correlation with the experimental variables of the DBA test. Conclusion: The findings of this study indicate that measuring COP is an appropriate method to assess dynamic standing balance control in older adults. Further, the DBA test can be used in community-dwelling older adults to distinguish fallers from non-fallers.

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LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ABC:	Activities Specifics Balance Confidence Scale
ADL:	Activities of Daily Livings
AP:	Antero-posterior
BADL:	Basic Activities of Daily Livings
BBS:	Berg Balance Scale
BF:	Biceps Femoris
BOS:	Base of Support
BT:	Backward Translations
CAPE:	Composite AP COP Excursion
CC:	Cross Correlations
CMLE:	Composite ML COP Excursion
CNS:	Central Nervous System
COM:	Centre of Mass
COP:	Centre of Foot Pressure
CSPL:	Composite Swaypathlength
CTSIB:	Clinical Test of Sensory Interaction and Balance
DBA:	Dynamic Balance Assessment
EC:	Eyes Closed
EMG:	Electromyography
ENG:	Electronystagmography
EO:	Eyes Open
FES:	Falls Efficacy Scale

FR:	Functional Reach
FT:	Forward Translations
GA:	Gastrocnemius
GTO:	Golgi Tendon Organs
GV:	Gait Velocity
HA:	Hamstrings
HR:	Head Rotation
IADL:	Instrumental Activities of Daily Livings
ICC:	Intraclass Correlation Coefficients
IQR:	Inter Quartile Range
LED:	Light Emissions Devices
LHS:	London Handicap Scale
LOB:	Loss of Balance
LOS:	Limits of Stability
mCTSIB:	Modified Clinical Test of Sensory Interaction and Balance
ML:	Medio-lateral
MVIC:	Maximum Voluntary Isometric Contraction
NEO:	Normal Surface Eyes Open
NEC:	Normal Surface Eyes Closed
OLS:	One Leg Standing Task
PF:	Power Spectrum
POMA:	Performance-Oriented Mobility Assessment
QU:	Quadriceps

RF:	Rectus Femoris
RS:	Romberg Stance
RT:	Rotational Translations
SD:	Standard Deviation
SF:	Shoulder Flexion
SMWT:	Six-Minute Walk Test
SOL:	Soleus
SOT:	Sensory Organization Test
ST:	Semitendinosus
TA:	Tibialis Anterior
TF:	Trunk Flexion
TPD:	Two-point Discrimination
TR:	Trunk Rotation
TUG:	Timed-up and Go
UC:	Unable to Complete

INTRODUCTION

Poor balance, mobility restrictions, fear of falling and fall injuries are serious problems for many seniors (older adults). Reduced mobility and falls among people over 65 are public health problems that result in death, injury and loss of independence. The incidence of falls rises steadily from middle age, and peaks in people above the age of 80 years (Rubenstein & Josephson, 2002). Falls are one of the leading causes of injury and injury-related death (Grisso et al., 1991). In addition, the psychological trauma and fear associated with falling produce a substantial decrease in physical activity, which leads to further loss of strength, flexibility and mobility, thus increasing the risk of future falls (Tinetti, 1989).

Each year, between 30 and 40% of community-dwelling adults older than 65 years fall (Tinetti, Speechley, & Ginter, 1988). Forty percent of admissions to nursing homes are the result of falls and fall related injuries (Tinetti et al., 1988). In 15% of the cases, falls caused fractures, bruises, soft tissue injuries and loss of independence (Powell & Myers, 1995). A greater percentage of older adults fall indoors than outdoors (Tait, 1993). Falls can be caused by intrinsic and extrinsic factors. Intrinsic factors associated with falls are age, impaired mobility, previous fall, dizziness, musculoskeletal problems, balance problems, vision problems, orthostatic hypotension, cognitive problems, depression, incontinence and physical inactivity. Extrinsic factors associated with falls include poor lighting, slippery walking surfaces, clutters in pathways, stairs and medications. Age-related declines in musculoskeletal, cardiovascular, visual and central nervous system functions limit the adaptive ability of older people and increase risk of falls. The decline in balance control, commonly observed in older people, is a major factor in reduced mobility and activity levels and to greater risk of falls and injuries. Physiotherapists have a special interest in recognizing and treating balance problems that contribute to falls. Early identification of the exact cause of restricted mobility and increased fall risks allow health care professionals to implement appropriate interventions and minimize the development of secondary problems such as reduced confidence, physical dependence and decreased quality of life.

REVIEW OF LITERATURE

Balance Control

Balance can be evaluated either in static or dynamic forms. Static balance is a person's ability to uphold the body's centre of mass (COM) vertically over the base of support (BOS) at rest. Dynamic balance is the ability to maintain control over the position and movement of the COM relative to the BOS during voluntary movements, transfers, turning, stepping and walking on different terrains. This active movement of COM may result from self-generated movements or responses to externally-generated forces. A change in the position or motion of COM may be planned and expected as, for example, when stepping over a puddle, or unexpected as, when stumbling.

Balance control or body stability is the ability to maintain control over the position and motion of the COM relative to the BOS (Johansson & Magnusson, 1991; Maki & McIlroy, 1996), which can be either static or dynamic. It refers to a person's ability to maintain stability of the body and body segments in response to forces that disturb its equilibrium. Balance control has two purposes.

1. To maintain balance at rest or during voluntary movements including ones in which the BOS changes through feedforward predictive process.
2. To restore balance in response to a sudden disturbance or unexpected loss of balance by using feedback process to deal with uncertainty.

The major goals of balance control in the static standing position are to control a body's orientation in space, uphold the body's COM over the BOS and stabilize the head vertically to orient eye gaze. Although only a minimal amount of muscular activity is needed to keep a stable erect standing posture, balance control is a complex process and requires equilibrium between internal and external forces acting upon the body. The internal forces are as follows: a) active muscular forces, b) passive tension in the tissues spanning a joint, and c) bony contact forces. The external forces are as follows: a) gravity; b) inertia which represent the inertial acceleration effect of one body segment on other body segments, and c) ground reaction forces. The stability of the body during a dynamic task is the direct result of these forces (Refer: Levangie and Norkin, 2001).

SENSORY ASPECTS OF BALANCE CONTROL

Maintenance and restoration of balance depend on the integrity of the central nervous system (CNS), which receives spatial information from sensory systems, especially from the visual, vestibular, proprioceptive and musculoskeletal systems. Thus, balance is not the outcome of a single system but a complex integration of multiple sources of spatial information with both internal and external frames of reference (Creath, Kiemel, Horak, & Jeka, 2002; Peterka, 2002; Szturm & Fallang, 1998; van der, Jacobs, Koopman, & van der, 2001).

The vestibular system, located in the inner ear, consists of two classes of sensors. The otolith end organism is composed of linear accelerometers and provides input concerning the position of the head relative to gravity or vertical and linear motion of the head in space. The semicircular canals sense angular acceleration of the head. Spatial information from the vestibular sensors is important for balance control, eye-head coordination, or gaze control. Signals from the vestibular system resolve visual and somatosensory conflicts (Refer: Kandel, Schwartz and Jessel, 2000). However the vestibular system alone cannot provide the information needed to ensure balance. Knowing where the head is in space or how it is moving does not tell one anything about where the trunk or foot is or the characteristics of the support surface and requires the use and integration of the other sensory inputs (Zupan, Peterka, & Merfeld, 2000).

Vision provides an external frame of reference for balance control. It also provides information of surrounding environment. However, the visual system uses a relative frame of reference and therefore sensory conflicts or illusions can arise (Refer: Kandel et al., 2000).

Proprioceptors provide an internal frame of reference for balance control. These include a) muscle spindles, which encode muscle length and rate of change of muscle length, and b) Golgi tendon organs (GTO) which encode muscle tension. This information is important in determining the relative position and motion of one body segment to another. Muscle spindles provide this information through the change in length of muscles and velocity at which muscle stretch occurs. Muscle spindles are small encapsulated sensory receptors that have a spindle-like or fusiform shape and are located within the fleshy part of the muscle. Their main function is to signal changes in the length of the muscle within which they reside. Changes in the length of muscles are closely associated with changes in the angles of the joints that the muscles cross. Thus, muscle spindles provide information about the body position to the CNS. The GTO is the sensory receptor located at the junction between muscle fibres and tendon. Whereas muscle spindles are most sensitive to changes in length of muscle, GTO provides information about the total muscle tension, which can develop either by muscle contraction or stretching of a tendon (Refer: Kandel et al., 2000). Mechanical receptors which are located in joint capsules and ligaments provide spatial information related to segment rotations. The proprioceptive component of the somatosensory system provides information about orientation and motion of body segments relative to each other (internal reference frame) but does not provide any information about vertical or location and characteristics of the ground surface (Fitzpatrick & McCloskey, 1994; Szturm et al., 1998). The cutaneous afferents of the feet provide information about external reference points such as location, characteristics of supporting surfaces and distribution of foot pressure, which allow additional sensory information about ground reaction forces to assist in balance control (Rogers, Wardman, Lord, & Fitzpatrick, 2001).

The balance control has two components (Black, Shupert, Horak, & Nashner, 1988). The first is accurate sensory and perceptual information about body movements relative to external references such as vertical; the second is timely motor action to correct the COM position and movement relative to earth vertical. Under normal conditions, all spatial information from the body sensors integrates within the CNS to determine the state of balance. If a balance disturbance is identified (type, direction and magnitude) then a corrective balance reaction is initiated (Horak, Nashner, & Diener, 1990; Teasdale, Stelmach, & Breunig, 1991a). If one of the inputs is diminished or absent, then other sources of redundant sensory information can partially compensate for the loss (Allum & Honegger, 1998). Lowlight or visual conflicts make it harder for the CNS to maintain balance, and this is reflected by an increased body sway (Brooke-Wavell, Perrett, Howarth, & Haslam, 2002). Body sway is found to be increased by 30% when the eyes are closed (Lord, Clark, & Webster, 1991). Similarly, an irregular or compliant surface will also pose a threat to maintaining balance by altering the somatosensory inputs from the foot (Redfern, Moore, & Yarsky, 1997). An abnormality in these sensory inputs will lead to abnormal postural responses and hence balance disturbances. Problems arise when two or more components are compromised. An inability to organize sensory information properly can result in instability in environments where visual, vestibular and cutaneous sensations are diminished or misleading. The correct organization and integration of sensory information are therefore important for maintaining balance in the different environments that a person encounters in daily life.

AGE-RELATED CHANGES IN THE SENSORY NERVOUS SYSTEM

The changes in various body systems associated with aging are as follows. Central Nervous System: Scheibel (1985) noted progressive loss of upper motor neurons and reduction of neurotransmitters within the basal ganglia. This can result in decreased nerve conduction velocity (Stelmach & Worringham, 1985). Musculoskeletal System: There is a decrease in the size and number of muscle fibres which causes reduction in muscle strength (Myers, Young, & Langlois, 1996; Hakkinen et al., 1996). Reduced muscle flexibility and joint range of motion are also noted with aging. These may affect rapid balance reactions (Hakkinen et al., 1996). Visual System: The visual system shows reduced acuity, contrast sensitivity, depth perception and adaptation to darkness (Sekuler & Hutman, 1980). Vestibular System: There are structural changes in the vestibular system involving loss of labyrinthine hair cells, ganglion cells and nerve fibres. There is also a blunting of the ocular reflex (Paige, 1991). Cutaneous System: Cutaneous sensations show increased threshold for excitability (Stelmach et al., 1985). Blunting of cutaneous and proprioceptive sensations is also found with advanced age (Kenshalo, Sr., 1986; Skinner, Barrack, & Cook, 1984; Stelmach et al., 1985). These physiological changes associated with aging, affect the prospects of compensatory balance reactions (Judge, Ounpuu, & Davis, III, 1996).

The laboratory tests that have been developed to assess age-related changes on balance target one or more aspects of sensory information, either together or individually. One of the most popular tests is the sensory organization test (SOT) developed by (Nashner, 1971) which was later commercialized as the 'Equi test'. The test apparatus consists of a moveable platform which rotates about an axis co-linear with the ankle joint and movable visual surroundings. In this test, force plate recordings are recorded to measure the centre of foot pressure (COP). When the body sways at a low frequency, it behaves as an inverted pendulum, and measurement of COP is approximately equal to the COM movement (Allum & Shepard, 1999). The test consists of six conditions in which sensory information is distorted to challenge one's ability to maintain balance.

- Sensory Condition 1: The participant stands on a firm stable surface with eyes open.
- Sensory Condition 2: The participant stands on a firm stable surface with eyes closed. Information from the visual source is thus eliminated.
- Sensory Condition 3: The participant stands on a firm stable surface, and the visual surround sways in proportion to the body sway (visual-sway referencing). Here there is no relative motion between the head and visual surround but the body sways back and forth. The visual information is misleading or in conflict with this reality. In this case, if the participant relies upon visual cues, then he/she

will fall. However, vestibular and somatosensory cues can provide accurate and functionally appropriate information to overcome the visual conflict.

- Sensory Condition 4: The support surface on which the participant is standing is swayed. As the participant sways, the platform rotates forward or backward to null the displacement about the ankle joint (support surface sway-referenced). Here the somatosensory inputs provide distorted information about body sway. Vision and vestibular inputs provide accurate information in this condition.
- Sensory Condition 5: The participant stands on a sway-referenced support surface with eyes closed. Here the somatosensory inputs are distorted and visual inputs eliminated. Vestibular inputs provide accurate information.
- Sensory Condition 6: The participant stands on sway-referenced support surface. The visual surround is also sway-referenced. Here the visual information is conflicting and somatosensory information is distorted. The vestibular information is the only available system to provide accurate information about body position.

Whipple, Wolfson, Derby, Singh, & Tobin (1993) used the SOT to compare balance control between young and older adults. The study included 34 young participants (56% female) with a mean age of 35 years and 239 older adults (53% female) with a mean age of 76.5 years. All participants were independent in ambulation, with no history of skeletal or joint abnormalities, visual impairments, neurological diseases affecting motor function, episodic loss of consciousness or deafness. Body sway was measured by the dynamic force platform (EquiTest, NeuroCom International, USA). During the test, participants were asked to stand barefoot for 20-seconds with arms relaxed by their sides and look straight ahead. The participants completed a total of 14 trials (1 trial of SOT 1 and 2 conditions, 3 trials of SOT 3 through 6 conditions).

The equilibrium score and loss of balance (LOB) were computed for each condition to index balance performance. An equilibrium score is based on a theoretical normal value of 12.5° of anterior/posterior sway about the ankle joint, typically 8° forward and 4.5° backward (Nashner, Black, & Wall, III, 1982). Thus, the equilibrium score is a percentage score representing the maximum magnitude of sway in the anterior-posterior (sagittal) plane for each trial based on the peak-to-peak excursions of the COP in this plane. The measure is computed by using following formula,

$$\text{Equilibrium Score} = \frac{12.5^\circ - (\Theta\text{max} - \Theta\text{min})}{12.5^\circ} \text{ X } 100$$

Here a score of 100 represents no sway, while a score of 0 represents a LOB or exceeding the 12.5° estimated maximum range of sway. Here, the LOB is defined as an event in which a subject exceeds the limits of stability and takes steps and/or requires external support to prevent an unwanted fall. For the SOT test, it is assumed that this range of movement is available to participants during the test. However, physical restrictions or voluntary stiffness secondary to fear of a potential fall can affect the accuracy of the score (Allum et al., 1999).

The study found that older adults produced significantly more sway than the younger group in the SOT conditions 2 to 6. The differences between groups became progressively greater as the conditions became more difficult. There was a statistically significant difference found ($p < 0.004$) for equilibrium scores between the groups in conditions 4, 5 and 6 for all three trials. For the LOB, no significant difference was found for the first trial of condition 4 (only 6% in the older group lost their balance as compared to 0% in the younger group). However, the percentage of participants with LOB in the two groups was statistically significant for conditions 5 and 6 ($p < 0.05$). Six percent in the younger group had a LOB on the first trial of condition 5 and 9% on the first trial of condition 6, while 32% of the older adults had a LOB on the first trial of condition 5 and 52% on the first trial of condition 6. Repeated measures ANOVA were used to determine the influence of group, support surface and vision on equilibrium scores. There was statistically significant ($p < 0.0001$) difference found for the between-participants factor (group), indicating that there was an effect of age group on sway scores, with older adults producing greater sway. Within the participants, there were significant effects noted for support surface (sway-referenced vs. fixed surface) and visual conditions (sway-referenced vs. vision normal).

In a similar study by Cohen, Heaton, Congdon, & Jenkins (1996), 94 asymptomatic, ambulatory, community-dwelling older adults were tested on the SOT. The study was designed to develop normative data and determine differences between community-dwelling older adults and younger adults. The participants were independent in activities of daily living (ADL) and had no prior history of vestibular, neurological or orthopedic problems. Participants were divided into four groups: 32 young (18 - 44), 30 middle-aged (45 - 69), 19 old (70 - 79), and 13 elderly (80 - 89). The study found a significant age-associated effect on equilibrium score ($F(3, 90) = 23.24$, $p < 0.0001$), test condition ($F(5, 90) = 355.91$, $p < 0.0001$) and a significant age by test condition interaction ($F(3, 5, 15) = 8.1$, $p < 0.0001$). Repeated measures ANOVA on the number of falls per condition showed a significant effect of age ($F(3, 90) = 11.0$, $p < 0.0001$) and test conditions ($F(5, 90) = 12.5$, $p < 0.0001$) with young and middle-aged participants having significantly fewer falls on conditions 5 and 6 than elderly participants, while on condition 6 old participants had significantly fewer falls than elderly participants. Here, a fall was defined as a loss of balance and required the use of a safety harshness to prevent an unwanted fall. The findings were virtually the same as those of Whipple et al. (1993).

Simmons, Richardson, & Pozos (1997) used the SOT to examine the impact of cutaneous deficits in the feet on the balance control. The study included a sample of 50 participants aged 30 to 70 who were divided into the two groups. The first group (n1) included 27 participants with a history of insulin dependent diabetes mellitus (IDDM) and had no cutaneous deficits. The second group (n2) consisted of 23 participants (17 IDDM, 6 NIDDM) with bilateral cutaneous deficits. A control group (n3) consisted of matched 50 non-diabetic participants to control effect of age, sex and weight on balance control. All participants were pre-screened to exclude people who used medication or having pre-existing conditions that would affect balance. The study found that the cutaneous deficits group (n2) experienced significant ($p < 0.05$) decrease in balance scores on the SOT conditions 1 to 6 and the composite score compared to the control group (n3) as the difficulty of the conditions increased . The differences were more evident in conditions 5 and 6. No differences were found between the control group (n3) and non-cutaneous deficits group (n1) for any of the SOT conditions. In similar studies by Di Nardo et al. (1999), 24 controls, 45 participants with IDDM (N1 = 30 without peripheral neuropathy, N2 = 15 with peripheral neuropathy) were recruited. The electronystagmography (ENG) was used to evaluate vestibular impairments in all participants. The ENG results were found normal in all groups. Compared to control participants, only IDDM patients with peripheral neuropathy (N2 group) but not patients without peripheral neuropathy (N1 group) showed lower scores for test conditions SOT 1 (ANOVA F = 8.3; Scheffe test: p = 0.0007), SOT 2 (F = 6.6; p = 0.004), SOT 3 (F = 3.4; p = 0.04), and SOT 6 (F = 3.4; p = 0.04). The results of these two studies reflect the ability of the SOT to identify specific balance impairment.

Wallmann (2001) examined 15 non-fallers and 10 idiopathic fallers (aged > 60 years) to determine the relationship between the functional reach (FR) test, the Limits of Stability (LOS) test and the SOT between non-fallers and fallers in older adults. There was no significant difference found between non-fallers and fallers in the FR scores (p = 0.82) and the anterior LOS test (p = 0.06). A significant difference was found between non-fallers and fallers for the mean SOT composite score (p = 0.03). Fallers showed a decrease mean composite score for conditions 3 through 6 in the SOT and showed significantly greater sway compared to non-fallers in condition 4 (p = 0.02). In addition, there was a significant positive correlation between anterior displacement on the LOS test (maximum anterior end-point excursion of COM) with the SOT composite score for fallers (r = 0.79, p = 0.006) compared to non-fallers (r = 0.43, p = 0.11). There was no significant relationship found between performance on the FR test and anterior displacement on the LOS test in either non-fallers (r = - 0.009, p = 0.98) or fallers (r = 0.17, p = 0.65). The study showed that the FR alone is not an appropriate indicator for differentiating elderly non-fallers from fallers, and that using the SOT protocols can help to differentiate balance impairments in non-fallers and fallers. However, the sample size of this study was small. A large sample size is required to verify statistical significance.

A number of other studies have shown that older adults sway more than young adults while simply standing (Horak, Nutt, & Nashner, 1992; Melzer, Benjuya, &

Kaplanski, 2004). To support this theory, body sway of young and older adults during standing was examined under altered and conflicting sensory conditions. Proprioceptive information was manipulated by tendon vibration or by having; participants stand on a compliant surface, which alters somatosensory inputs while visual information was either available or unavailable. Although healthy older adults could compensate for the reduction of a single source of sensory information, they demonstrated substantially increased sway when two sources of information were distorted or absent (Hay, Bard, Fleury, & Teasdale, 1996; Woollacott, Shumway-Cook, & Nashner, 1986). Furthermore, when one source of information was repeatedly withdrawn and reapplied, older adults were unable to reintegrate the information quickly enough to recover and regain their stability. In contrast, the young adults were able to quickly integrate this new information and stabilize their balance (Teasdale, Stelmach, Breunig, & Meeuwsen, 1991b; Woollacott et al., 1986).

Shumway-Cook & Horak (1986) developed the Clinical Test of Sensory Interaction and Balance (CTSIB) based on the same principles as the SOT. The CTSIB is less expensive test and also known as the Foam and Dome test. This test is performed on a medium-density foam pad, 50x50x8 cm. The foam, unlike the platform in the SOT, can be sway-referenced in any direction. The foam tends to distort ground reaction forces, as a result the participant receives distorted information from the foot and ankle cutaneous and pressure sensors. The six conditions under which balance is assessed in this test are as follows:

Condition 1: Quiet standing on floor

Condition 2: Quiet standing on floor, eyes blindfolded

Condition 3: Quiet standing on floor, wearing visual conflict dome

Condition 4: Quiet standing on the foam, eyes open

Condition 5: Quiet standing on foam, eyes blindfolded

Condition 6: Quiet standing on foam, wearing the visual conflict dome.

The sway is quantified using

- A numeric ranking system (1= minimal sway, 2=mild sway, 3= moderate sway, 4= fall).
- Use of a stopwatch to record the amount of time the patient maintains standing erect in each condition.
- Using grids or plum line to record body displacement.

El Kashlan, Shepard, Asher, Smith-Wheelock, & Telian (1998) evaluated the correlation between the CTSIB and the SOT. They used a sample of 69 healthy participants and 35 participants with vestibular dysfunction for more than four months. The former were divided into four groups based on age; 20 to 49 years (n = 20), 50 to 59 years (n = 19), 60 to 69 years (n = 19) and 70 to 79 years (n = 11). This study found correlations (r) of 0.41 to 0.89 between the SOT and the CTSIB conditions.

Allum, Zamani, Adkin, & Ernst (2002) evaluated the similarities and differences between the SOT and a compliant foam pad on balance control in 25 healthy young adults (range 25 – 35 years). Trunk sway was measured for 20 seconds in the standing position with and without vision on the following three conditions: (a) a foam support surface (b) an anterior-posterior (pitch) sway-referenced condition of the SOT and (c) standing on the same sway-referenced surface as in second condition but with the body turned 90° so that sway was in the medio-lateral (roll) plane. The eyes open and eyes closed conditions emulated SOT 4 and 5 respectively. The trunk sway was measured at the L2 level using two angular velocity transducers (one for each plane), with a sampling frequency of 100 Hz. Peak-to-peak angular velocity and displacement were computed for pitch and roll planes. The study found higher trunk roll angular displacement and velocity in roll sway – referenced condition (condition c) than the foam condition (condition a) for both the eyes open and closed conditions ($p < 0.01$ to $p < 0.05$). For eyes closed condition both pitch angular displacement ($p < 0.01$) and velocity ($p < 0.05$) were higher for the pitch-referenced condition (condition b) than the foam (condition a) or roll sway-referenced condition (condition c). There was no statistical difference found in pitch angular displacement and velocity for the eyes open foam condition and the roll/pitch sway-referenced conditions. Power spectrum analysis centred at frequencies of 1.2, 2.4, 3.6 and 4.8 Hz, revealed that for almost all frequencies trunk angular velocity amplitudes were highest for the foam and least for the pitch sway-referenced condition ($p < 0.01$ to $p < 0.05$). The results obtained from the roll sway-referencing and foam support surface were comparable. The findings of this study advocate the use of a foam material as a more comprehensive balance assessment tool and a roll sway-referenced condition as an alternative way to test multidirectional control of sway. Also, the authors noted that the use of sponge/foam can induce sway in both pitch and roll directions, which is not possible with uni-axial sway referenced conditions of the Equi-test.

In another study, Teasdale et al. (1991a) studied the effect of the loss of vision and the somatosensory systems on healthy young and older adults. They examined body sway behaviour of older (n = 18, mean age 74 years) and young (n = 10, mean age 21.5 years) adults. The older participants had no musculoskeletal or neurological deficits or history of falls. The postural sway behaviour was examined for 80 seconds, under altered visual and/or support surface (5 cm thick foam surface) conditions, and compared with normal stance. The COP was calculated from the force plate signals. A number of dependent variables were computed to quantify performance, including COP deviation range, COP variability, COP sway velocity and COP sway density histograms. The sway range, variability and velocity were significantly greater (ranging from $p < 0.001$ to 0.05) in the older adults during vision eliminated and surface distorted conditions. Exclusion or disruption of one of the sensory inputs alone was not sufficient to differentiate between older and young adults. Sway density histograms showed that older adults spent 14% of the time in an "at risk" area (outside 20 mm of their COP) as compared to 7% in young participants. Thus, both visual and surface alterations together had a substantially greater effect upon the older than upon the young adults. The results of this study showed that combining a foam surface with occluded vision can have a significant effect on balance and elimination of just one sensory system is not sufficient to differentiate between the older and younger population.

Creath, Kiemel, Horak, Peterka, & Jeka (2005) examined the in- and anti-phase relationships between upper and lower body segments during a simple stance task. They argued that upper and lower body segments have an in-phase relationship (ankle strategy) at low body sway frequencies and an anti-phase relationship (hip strategy) at high body sway frequencies. An unperturbed stance on a solid surface was used to investigate the phase relationships. A foam and sway-referencing surface were used to evaluate the influence of somatosensory information on balance strategies. The study included eight healthy participants, four male and four female, between the ages of 22 and 37 with no known musculoskeletal injuries or neurological disorders. Participants were asked to assume a shoulder-width parallel stance on a variable pitch platform. Shoulder and hip displacements were recorded using rigid rods attached to a fixed position on one end and to the participants by a harness on the opposite end. The amount of displacement was determined by the change in voltage of potentiometers located on the fixed ends of the shoulder and hip rods. Participants wore a safety harness that was secured to fixed brackets by two connecting straps. The straps were adjusted to allow for the participants' body sway before becoming taut. The platform displacement signal and potentiometer voltages were sampled at 100 Hz. Participants were asked to stand upright with eyes closed in blocks of three-364 second trials in the following sequences (1) fixed surface; (2) sway-referenced surface; and (3) foam surface. The platform position was stationary on the fixed and foam surface trials. For the sway-referenced trials, the platform rotated in the A-P direction an amount equal to the angular hip displacement which was determined by the hip rod potentiometer signal. For the foam surface trials, participants stood on a 4-inch thick piece of medium density foam placed on the platform. Headphones were used to mask background noise. The authors observed both in- and anti-phase patterns during quiet stance. They found that the trunk and leg segments act in-phase (ankle strategy) for frequencies below 1 Hz and anti-phase (hip strategy) for frequencies above 1 Hz. They also noticed that the shift from in-phase to anti-phase was abrupt for the fixed and foam surfaces and gradual for the sway-referenced condition. They concluded that both in-phase and anti-phase patterns could be present during quiet stance and depending upon the characteristics of the available sensory information, task or perturbation, one might predominate over another. The findings support the idea of using a foam surface to assess balance control; however, this study has following limitations: (1) the sample size was small, (2) use of body harnesses might have affected natural balance reactions, and (3) balance reactions in medio-lateral directions were not measured.

MOTOR ASPECTS OF BALANCE CONTROL

There are two mechanisms for balance control. The first is an anticipatory or predictive response, known as feedforward control. It plays a significant role in maintaining stability during voluntary movements. Through feedforward mechanism, one can plan the stability requirements before the movement. These voluntary movements are planned and predictive postural adjustments made in advance or simultaneously with movements to ensure stability.

To understand feedforward mechanism, several studies have used posturography with sinusoidal platform translations to assess motor coordination (Dietz, Trippel, Ibrahim, & Berger, 1993; Corna, Tarantola, Nardone, Giordano, & Schieppati, 1999). In this technique the platform can be swayed forward and backward. In normal healthy individuals, as the platform moves forward there will be contraction of tibialis anterior, quadriceps and the abdominal muscles in an attempt to regain upright posture. Similarly if the platform moves backward the gastrocnemius, hamstrings and the back muscles will contract. In the condition of the platform moving backward the participants' forward lean stretches the gastrocnemius. The same kind of stretch can be produced by dorsiflexing the ankle by tilting the anterior edge of the platform; however in this case contracting the gastrocnemius would result in further destabilization. Since the ankles are already dorsiflexed, contracting the gastrocnemius would push the subject posteriorly. After a few trials, normal participants learn to control the gastrocnemius contraction and therefore preserve balance (Refer: Kandel et al., 2000).

Dietz et al. (1993) studied human stance and its feedforward control through a treadmill moving forward and backward (sinusoidally) at different frequencies. The sinusoidal frequency was changed, stepwise and randomly, between 0.5, 0.3 and 0.25 Hz. Twelve normal participants (mean age 29.6 ± 8.2) were asked to stand upright on the treadmill, first with and then without vision. During the stepwise sinus cycle, the maximum leg muscle electromyography (EMG) activity was recorded in the tibialis anterior (TA) and rectus femoris (RF) around the posterior turning point and in the gastrocnemius (GA) and biceps femoris (BF) around the anterior turning point in the treadmill cycle. The anterior turning point was defined as the time when the body changed direction from traveling forwards to backwards, and the posterior turning point was defined conversely. The spatial acceleration of the head was recorded by two accelerometers fixed to the forehead and positioned perpendicular to one another. Both the degree of body inclination and the corresponding EMG activity were dependent upon the sinusoidal frequency. There was a significant increase in GA activity from slow to fast movements and a moderate increase in TA between 0.25 and 0.33 Hz and strong increase during 0.33 to 0.5 Hz movements. The EMG amplitudes for TA and GA muscles were found to be higher during the eyes closed than in the eyes open condition. The difference was significant at each frequency (at 0.25 Hz: $P < 0.01$; at 0.33 Hz: $P < 0.05$; at 0.5 Hz: $P < 0.05$) and taking all frequencies together: $P < 0.001$) suggesting a higher degree of co-contraction in the eyes closed condition. In addition, during the eyes open condition, participants adapted to different frequencies within four cycles after the change by using visual information for feedforward processing. That means after four cycles, there was a strong anticipatory contraction in the TA muscle during the anterior turning point of the sinusoid and in the GA during the posterior turning point. No such changes in TA or GA were noted when vision was eliminated. This showed that visual information of the relative body motion was important in predicting sinusoidal platform motion. The authors concluded that while standing on a sinusoidally moving platform, the nervous system could control the position of the body's COM by using visual information in a feedforward manner to balance the body.

In a similar study, Corna et al. (1999) described the influence of vision on displacement of the head and hip while standing on a moving platform with and without vision. The platform was continuously moving sinusoidally in the antero-posterior direction with frequencies ranging from 0.1 – 1 Hz. The study included eight young adults (three females and five males) with a mean age of 29.3 ± 9.7 years. Body movement in the sagittal plane was recorded by an optoelectronic device. Light emissions devices (LEDs) were placed on the lateral malleolus (malleolus), the great trochanter (hip) and the temporo-mandibular joint (head). The signals were sampled at a frequency of 50 Hz. The displacement of LEDs was quantified by (1) the measure of the shift during each cycle of translation, (2) the standard deviation (SD) of the path traveled during the whole trial, (3) the power spectrum (PS) of the signal and (4) the cross-correlation (CC) between pairs of body segments. The study found that at each frequency of platform translation, the displacement of head was smaller than that of hip, and the displacement of hip was smaller than that of malleolus in eyes open (EO) condition. Thus, when vision was allowed, participants behaved as a non-inverted pendulum, and were able to stabilize their heads in space. But without vision (EC), participants behaved as an inverted-pendulum, where the head oscillated more than the platform. At high frequencies of platform translation, the body segments were also less coupled. The CC between the pairs of malleolus/head, malleolus/hip and hip/head was decreased by passing from low (0.1 – 0.2 Hz) to high frequency (1 Hz) of platform translation for both visual conditions. The decrease was more marked for the malleolus/head than for the malleolus/hip pair. The fast Fourier transformation of hip and head displacement showed larger power spectrum with EC than EO. The findings provide evidence that balance control uses visual information in a feedforward manner. However, during sensory conflict, there is the possibility of using a functionally incorrect source of spatial information while planning upcoming motor actions (Schieppati, Giordano, & Nardone, 2002). Under these circumstances, one needs another mechanism, which can rapidly restore balance and prevent a fall.

The second mechanism of balance control is referred to as automatic or corrective balance reaction. These reactions are based on a timely sensory feedback system. This system is responsible for restoring body stability following sudden unexpected balance disturbances and only occurs after a destabilizing external force. It helps us to respond to sudden perturbations such as stumbling or tripping (Carpenter, Allum, & Honegger, 1999; Fujisawa et al., 2005; Horak & Nashner, 1986; Pavol & Pai, 2002; Winter & Eng, 1995). It has a rapid onset (around 60-100 ms onset latency) and is specific to the nature and direction of the disturbance (Pavol et al., 2002). A failure of a timely correction will result in a stumble or a fall. Restoring balance requires regulation of the position and motion of the COM relative to the BOS. Balance reactions therefore must require either deceleration of the COM movement and/or change in BOS in response to perturbations. Many studies have analyzed corrective strategies, which the body follows with sudden disturbance.

Three common strategies that are used in the feedback system depend on the amount of disturbance and the type of surface. On firm or large surfaces, when a small disturbance is applied to the body, an "ankle strategy" takes place in which the body pivots around the ankle joint. All body segments move as a single inverted pendulum with the earliest muscle responses occurring at the ankle muscles, followed by thigh and then trunk muscles (Horak et al., 1986). When the body faces a larger disturbance and/or is on a narrow/unstable surface, a "hip strategy" is recruited (Horak et al., 1986). Here the body breaks up into a two-segment model, the upper body (trunk-head-arms) and lower body (pelvis and legs). The motion of the two segments is in opposite directions; as the trunk bends forward, the ankles plantarflex so that the lower legs move backwards (Horak et al., 1986; Fujisawa et al., 2005; Runge, Shupert, Horak, & Zajac, 1999). It consists of discrete bursts of muscle activity on the side of the body opposite to the ankle pattern in a proximal to distal pattern. This allows for quick and large amplitudes of COM motions while maintaining a stationary BOS.

Szturm et al. (1998) examined movement strategies accompanied with sudden balance disturbances caused by rapid platform translations and rotations. The study included 13 healthy participants (8 male, 5 female, mean age 25.8 ± 6.6 years) with no history of neurological or orthopaedic deficit. The participants stood barefoot on the force plate of platform which had two degrees of freedom to provide balance disturbance in forward/backward translations (FT/BT) and upward rotational translations (RT). All participants underwent three blocks (V1 = 14.2 (0.6) cm/s for translations and 35.5° (0.8°)/s for rotations, V2 = 19.3 (0.7) cm/s for translations and 55.7° (0.9°)/s for rotations and V3 = 28.7 (0.7) cm/s for translations and 69.2° (1.1°)/s for rotations) in nine random trials. EMG was recorded for soleus (SOL), gastrocnemius (GA), tibialis anterior (TA), hamstrings (HA) and quadriceps (QU). Force platform and 2-D video motion analysis systems were used to compute COP and COM movements respectively. They found activity in recorded muscles within a range of 60 to 170 ms from onset of platform displacement and did not vary as a function of platform acceleration/velocity. However, an increased magnitude of muscle activity and corrective peak hip/knee/ankle displacements were noted for FT, BT and RT as the accelerations/velocity increased. They found that the relationship between COM and COP was fundamentally different for FT/BT as compared to RT. For FT and BT, the timing, peak magnitude, and time to peak COM displacement did not vary as a function of platform acceleration/velocity. However, for RT, the peak magnitude and time to peak COM displacement did increase with increasing platform acceleration/velocity. Multi-segment distinct balance corrections were observed rather than pure ankle or hip strategy for both translations and rotational disturbances.

Carpenter et al. (1999) examined balance reactions in young healthy adults (n = 14) while standing on a platform, which randomly rotated in multiple directions at constant amplitude (7.5 degrees) and velocity (50 degrees/second). Each participant was randomly presented with 44 support surface rotations through 16 different directions separated by 22.5 degrees first under eyes-open, and then, for a second identical set of rotations, under eyes-closed conditions. The authors observed that balance corrections were specific to the magnitude and direction of perturbations. They found higher muscle activity in the roll perturbations than in the pure pitch perturbations. They also observed balance corrections in both roll and pitch directions in the roll perturbations tasks, which was not evident in pure pitch perturbations tasks. This study also challenged the idea of a pure ankle synergy because simultaneous activity (60 ms) in both paraspinal and soleus muscles were noted in response to a sudden perturbation. The researchers recommended the use of multidirectional perturbation as a tool to analyze balance responses.

As a disturbance becomes fast or large, it is not possible to use an in-place strategy; instead, a quick step is used to change the BOS. Maki & McIlroy (1997) suggested that the "hip synergy" primarily used in situations when stepping or grasping synergies not accessible. When the disturbance is too large, the previous in-place strategies are inadequate to maintain balance and a stepping strategy results. This strategy simply means taking a step to move the BOS to meet the COM. It includes stepping in any direction or grasping other fixed supports to restore balance. It is the only successful strategy to maintain stability for large perturbations in both young and older populations. Comparisons of the stepping strategies used by the young and old show that the younger participants have a tendency to take only one-step, whereas the older participants have a tendency to take multiple shorter and shallower steps (Luchies, Alexander, Schultz, & Ashton-Miller, 1994; Maki et al., 1997).

CENTRE OF FOOT PRESSURE (COP) AND TRUNK SWAY RECORDINGS TO QUANTIFY BALANCE CONTROL

Amiridis, Hatzitaki, & Arabatzi (2003) examined the balance requirements of quiet standing tasks of increasing difficulty in 39 participants (19 older adults 70.1 ± 4.3

years, 20 young adults 20.1 ± 2.4 years) who had no neurological and musculoskeletal impairments. Peak-to-Peak COP excursions, standard deviation of COP oscillations, EMG activity of tibialis anterior (TA), rectus femoris (RF), gastrocnemius (GA), semitendinosus (ST) and peak-to-peak range of hip, knee and ankle angles were recorded for quiet standing, the Romberg Stance (RS) and the One Leg Standing task (OLS). The data were recorded for 5 seconds. Both groups showed significant increased in peak-to-peak amplitude and variance in COP for AP as well as ML directions as the tasks difficulty increased ($p < 0.001$). The older adults had significantly greater and more variable COP excursions (COP max: F (1, 37) = 43:85, $P < 0.001$, F (1, 37) = 26:18, P < 0:001, COP SD: F (1, 37) = 29:00, $P \leq 0.001$, F (1, 37) = 18:90, $P < 0.001$ in both antero-posterior (AP) and medio-lateral (ML) directions, respectively) than younger adults. With increased balance requirements, there were higher levels of ankle and hip muscle activity in both groups TA, GA, RF ($p < 0.001$) and ST ($P < 0.01$). However, the older adults showed significantly greater activity ($p < 0.01$) in RF and ST than the younger adults in the RS and OLS tasks. The older adult group also exhibited significantly greater joint excursions than did the younger group across all the tasks. Mixed hip-ankle activation was observed in the older adults, while young participants accommodated the increased balance requirements by increasing activity of ankle muscles only. The authors argued that this could be related to the insufficient torque production by ankle muscles in the older adults to counteract the great moment of inertia in the AP direction. Older people are more likely to have decreased proprioceptive sensation in addition to atrophy of distal muscles due to peripheral neuropathy. This could make older adults to rely more on proximal muscles and a hip strategy instead of ankle muscles and an ankle strategy in more challenging balance tasks.

In another experiment, Gill et al. (2001) conducted tests on participants with three different age groups: (young 15 – 25 years; n = 48, middle-aged 45 – 55 years; n = 50 and older adults 65 – 75 years; n= 49). Each participant performed a series of 14 tasks similar to those included in the Tinetti and Clinical Test of Sensory Interaction in Balance protocols. The test battery comprised stance, and gait tasks performed under normal, altered visual (eyes closed), and altered proprioceptive (foam support surface) conditions. Two angular-velocity transducers at the level of the lower back measured the trunk sway. All participants performed the trials without shoes to avoid the effect of different shoe types. The data were collected for 20 seconds for one and two-legged tasks. A trial was repeated once if the subject lost balance within 20 seconds, and the longest trial was used for the analysis. The stance-related tasks consisted of walking eight tandem steps, first on a firm and then on a foam surface. The gait-related tasks included walking five steps with (1) eyes closed (2) rotating the head horizontally (3) pitching the head vertically (4) walking on barriers and (5) walking up and down stairs. Quantification of trunk sway was performed for angular velocity and position in the roll (lateral) and pitch (fore-aft) planes of movement. The sampling frequency was 100 Hz. The study found that older participants could be distinguished from both middle-aged and young participants through the measurement of trunk angular sway and velocity. The most significant age group differences were found for standing on one leg on a normal floor or on a foam support surface with eyes open (F = 30, $p < 0.0001$). For two-legged stance tasks, trunk sway and velocity measures for pitch and roll positions were increased as the tasks became more difficult and sensory information was changed. Thus, magnitudes of trunk sway and velocity were less for eyes open normal support than with eyes closed normal support, which was in turn less than eyes open on foam support and eyes closed on foam support. The young and middle-aged groups performed better than the older adult group on all conditions except on foam with eyes closed, where there were no differences noted between the middle-aged and the older adult. The study suggests that measuring trunk sway during stance and gait tasks to detect subtle changes in balance control could be useful for screening balance disorders in people who are prone to falls. The main drawback of this study is that the angular velocity sensors were placed in the lumbar region, which is close to the axis of rotation of the trunk segment. Any change at the proximity of the joint axis (lumbar) would require large displacements of the distal segment (trunk). Hence, minimal to moderate changes in trunk displacement or velocities could have been missed.

Melzer et al. (2004) explored COP movements to identify fallers in community-dwelling older adults. The study included 19 participants (78.4 ± 1.3 years old) who reported having fallen unexpectedly at least twice in the last six months, and 124 non-fallers (77.8 ± 0.53 years old). Balance measurements were made in the upright position under six different conditions using a force platform (AMTI, Watertown, Massachusetts, USA). Six stability tests were completed over a period of 20 seconds, started with wide stance (1) eyes open, (2) eyes closed and (3) eyes open standing on foam. The tests were then repeated with narrow stance (heels and toes touching). COP data during the stability tests were sampled at a frequency of 100 Hz. In addition, the LOS Test was measured in wide and narrow stance. In the LOS test, participants were instructed to lean as far forward, backward, left and right as they could, without bending the hips or lifting the heels or toes off the ground. The mean differences between the two groups in the following dependent variables: (1) COP path length; (2) COP velocities; (3) elliptical area; (4) ML sway; and (5) AP sway were assessed. For the LOS Test, repeated measures ANOVA measures for the two groups (fallers versus non-fallers) and two postural conditions (narrow versus wide stance) were carried out to evaluate differences in maximum COP path length (cm) in AP and ML directions. Strength measurements were made by having the participants achieve Maximum Voluntary Isometric Contraction (MVIC) for five seconds, in ankle plantar and dorsi flexors, and knee flexors and extensors on the dominant leg using an isokinetic dynamometer. To evaluate differences in MVIC (Newton meters) of the four lower limb muscles, repeated measures ANOVA (two groups × four muscle groups) was used. Static two-point discrimination (TPD) testing to the underside of the first toe was made to evaluate the innervation density of the slowly adapting receptors. TPD values of groups were compared using an independent t-test. A Chi-square test was used for categorical variables.

The authors found no significant difference between fallers and non-fallers in balance stability in wide stance tasks. In narrow stance eyes open condition, the fallers showed significantly higher ML sway ($p = 0.005$), COP velocity ($p = 0.01$) and COP path ($p = 0.01$). With eyes closed foam condition (narrow stance), the fallers group showed significantly higher ML sway ($p = 0.009$), COP velocity ($p = 0.03$), COP path ($p = 0.03$) and elliptical area ($p = 0.03$). With eyes open standing on foam (narrow stance), the fallers showed a significantly higher ML sway ($p = 0.014$) and elliptical area ($p = 0.047$). The authors argued that people with higher ML sway had three times greater risk of falling. No significant difference was found between groups in the LOS test for AP and ML displacement for the wide and narrow stance conditions. No significant differences were found in knee flexors, extensors and ankle plantar/dorsiflexors MVIC between fallers and non-fallers. Fallers had significantly poorer TPD with a value of 14.93 ± 1.1mm compared with 12.98 ± 0.3mm in the non-fallers group ($p < 0.05$). The study findings suggest that simple and safe laboratory quantitative measurement like COP in narrow stance condition can differentiate older adults between fallers and non-fallers and use in as a preliminary screening tool for predicting future risk of falling.

CLINICAL BALANCE ASSESSMENT TOOLS

Clinical balance tests fall into two broad categories: (i) static and (ii) dynamic. Static balance tests include single limb stance, tandem standing, the Romberg test and the sharpened Romberg test. Dynamic tests include the Timed Up and Go (TUG) (Podsiadlo & Richardson, 1991), the Berg Balance Scale (BBS) (Berg, Wood-Dauphinee, Williams, & Maki, 1992b), the Six-Minute Walk Test (SMWT) (Guyatt et al., 1985), the Functional Reach (FR) (Duncan, Weiner, Chandler, & Studenski, 1990) and the Tinetti's Performance-Oriented Mobility Assessment and Dynamic Gait Index (POMA) (Tinetti, 1986). Also, tests such as the Falls Efficacy Scale (FES) (Tinetti, Richman, & Powell, 1990) and the Activities Specifics Balance Confidence Scale (ABC) (Powell et al., 1995) are based on the concept of self-efficacy or confidence in one's ability to perform a given task or behaviour and have been used in clinical balance assessment. Simple clinical tasks like sit to stand, standing with eyes closed, standing with reduced BOS, turning around, standing on one leg, stepping, walking on a solid surface, tandem walking or waking on a compliant surface are typically measured by subjective grading scales. They range from single three-point ordinal ranking (absent, impaired, present) to a scale with grades of normal, good, fair, poor and absent or objective grading (i.e. time to finish task, distance able to reach or walk). Reliability measures are lacking for most subjective grading scales (Goldie, Bach, & Evans, 1989; Horak, 1987) and the tasks are voluntary and self-paced in nature and always performed in predictable environments i.e. on flat, hard, non-slippery indoor surfaces with normal lighting conditions. Some of the more commonly used clinical balance assessments are described in the following paragraphs.

Tinetti's Performance Oriented Mobility Assessment (POMA):

Using performance-based evaluation criteria; Tinetti (1986) developed a clinical test to measure balance and gait in both frail and community-dwelling older adults. The original test consisted of thirteen balance and nine gait tasks. However, a slightly modified and more commonly used version has nine balance tasks and seven items to assess gait (Galindo-Ciocon, Ciocon, & Galindo, 1995). It includes both static and dynamic balance items, organized into two subtests of balance and gait. The balance tasks (Balance POMA) include balance during sitting, rising, attempting to rise, immediate standing (first five seconds), standing with alterations in base of support, sternal nudge, standing with eyes closed, turning 360°, and standing to sitting. The seven gait (Gait POMA) characteristics examined include initiation, step length and height, step symmetry, step continuity, path, trunk stability, and walking stance (step width). The test is easily administrated, requires 10 – 15 minutes and does not need any special instruments. The test uses two different ordinal subscales 0 to 1 and 0 to 2 for scoring. The maximum score for the balance component is 16 points and 12 points for the gait component. The total score range is 0-28 with higher scores indicating greater independence and less risk of falls.

Tinetti (1986) reported scores of 14 ± 6 for recurrent fallers and 21 ± 4 in older adults with one or no incidence of falls ($P < 0.0001$). In addition, a gait score of less than 9 and a balance score of less than 10 had been reported to be an independent predictor for recurrent falls (Tinetti, 1986). Cipriany-Dacko, Innerst, Johannsen, & Rude (1997) found fair to excellent interrater reliability (0.40 – 1.00) for novice physiotherapy students and fair to good (0.40 - 0.75) interrater reliability among physiotherapists with varied experience. The Balance POMA was reported to have a high correlation ($r = 0.91$) with the BBS (Berg, Maki, Williams, Holliday, & Wood-Dauphinee, 1992a). The gait component of POMA was reported to have a moderate correlations ($r = 0.78$) with the 9-item Physical Performance Test (Reuben & Siu, 1990) and total ankle range of motion ($r = 0.63$) (Mecagni, Smith, Roberts, & O'Sullivan, 2000). The Balance POMA, Gait POMA and total POMA were found to have a moderately high correlation ($r = -0.73$ to -0.78) with a functional obstacle course measure (Means, Rodell, O'Sullivan, & Winger, 1998).

The main disadvantages of the POMA are that it is not sensitive to detect subtle changes in balance and the sensitivity for the least detectable difference or clinically meaningful changes have not been established. The POMA does not measure the effects of altered vision or environmental hazards on balance. Users should be wary of using the tool as an outcome measure, especially for higher-functioning older adults, because of the likely ceiling effects of the ordinal scales used in the tool. The number of versions and the lack of clear identification of which version is used in a specific study also complicate the evaluation of the psychometric properties of this tool (VanSwearingen & Brach, 2001).

Berg Balance Scale (BBS)

Berg et al. (1992a) developed this test to measure balance impairment. The test is based on the principle that a person's balance can be challenged by decreasing his or her base of support. The tasks included in this test are almost identical to the ones used in Tinetti's POMA. The BBS tests 14 common movement tasks: sitting to standing, standing to sitting, transferring from bed to chair, sitting and standing unsupported, standing with eyes closed, standing with feet together, tandem standing, single limb standing, reaching, picking up an object from the floor, alternating foot on stool, looking over the shoulder and turning 360°. The tasks are graded on a 5-point ordinal scale (0 to 4), where a score of 4 indicates that the patient performs independently, needs no cues and meets time or distance criteria; a score of 0 indicates inability to perform. The total score can range from 0 to 56, with higher scores indicating greater independence. The test can be easily administered and no special training or instruments are required. The authors support a cut-off score of 45 of 56 for independent safe ambulation (Berg et al., 1992a). The criterion validity has been supported by moderate to high correlations with other clinical performance measures (Tinetti, Barthel Mobility subscale, TUG, and gait speed), but low to moderate correlations with laboratory postural sway measures using COP recordings (Berg et al., 1992a).

Shumway-Cook, Baldwin, Polissar, & Gruber (1997) conducted a retrospective study to predict fall rate in community-dwelling older adults. Fourty-four adults aged over 65 years with two or more falls in the last six months or without history of falls participated in the study. Participants with co-morbidities that could have affected balance were excluded. The authors found a sensitivity of 91% and a specificity of 82% when the score of the BBS combined with a self-reported history of imbalance. In another experiment, Bogle Thorbahn & Newton (1996) assessed balance in 66 nursing home residents (Age = 69 – 94) of two independent life-care communities. Total 38% of the participants in the study reported having co-morbidities. The BBS was found to have 53% sensitivity with a cut-off score of 45. They concluded that the older adults who scored above the cut-off scores were less likely to fall than older adults who scored below the cut-off score, however more decreased scores did not predict increased frequency of falls. They concluded that the BBS has poor sensitivity for predicting future falls. They identified the need to improve the BBS sensitivity, particularly for older adults scoring closer to cut-off score of 45.

The BBS is better at identifying individuals who are not at risk of falling than those at risk for falls. In a perspective study, Riddle et al. (1999) combined the data of Shumway-Cook et al. (1997) and Bogle Thorbahn et al. (1996) to look at the validity of the test for predicting falls using the cut-off score of 40, 45, 50 and 55. The analysis revealed a sensitivity of 45% and a specificity of 96% with a cut-off score of 40, a sensitivity of 64% and a specificity of 90% with a cut-off score of 45, a sensitivity of 85% and a specificity of 73% with a cut-off score of 50 and a sensitivity of 97% and a specificity of 26% with a cut-off score of 55. Kornetti, Fritz, Chiu, Light, & Velozo (2004) stated that the BBS has poorly defined operational categories. To support their arguments, the authors discussed the dissimilarity noted amongst various tasks of the BBS. For example, in the transfers test, a score of 2 suggests an individual's ability to transfer with verbal cues and/or supervision whereas in the unsupported standing on one leg test, a score of 2 suggests an individual's ability to lift and hold one leg independently for three seconds or more. The authors argued that it is not appropriate to combine scores from ratings that have different functional implications. They also pointed out that the passing criteria for different tasks is not the same. For example, one will get four points after passing the sitting task, which requires sitting safely for two minutes. In contrast, one will get two points for passing the standing on one leg task that is able to lift a leg independently and hold it for three seconds or more. They argued that even though the BBS does not comment on specific passing for each item, it can be assumed that successful completion of the task without physical/verbal cues or supervision would be considered as passing. Thus, completing the task of sitting unsupported would earn more points than standing on one leg. They recommended using the Rasch measurement technique to provide a relationship between the total BBS score and functional status thereby improving the rating scale structure for each task. However, since the authors had only used this technique on a previously collected database, its reliability and validity need to be determined.

The total score of the BBS offers only limited guidance for clinical intervention. With a score of 45 to 55, one can say that a person has a low risk of fall, however the cause for a low score (i.e. motor problems, sensory problems, medications and/or environment) cannot be identified. Therefore, the BBS is not very useful in designing a client-tailored exercise program and predicting future falls.

Time Up and Go Test (TUG)

The test was designed by Podsiadlo et al. (1991) to measure the mobility skills of frail older adults between the ages of 60 – 90 years. The study included 60 patients from a geriatric day hospital with a mean age of 79.4 years. The participants were diagnosed with mild dementia, cerebrovascular accident, Parkinsonism, cerebellar degeneration, rheumatoid arthritis or osteoarthritis. The TUG requires the patient to get up from a regular armchair, walk for three meters, turn, walk back to the chair and sit down. The patient can wear regular shoes and use an assistive device. The test does not require any special equipment and takes approximately 15 minutes to complete. The older version used a 5-point ordinal scale based on the observer's assessment of the patient's risk of falling, with scores of 1 suggesting normal, 2 very slightly abnormal, 3 mildly abnormal, 4 moderately abnormal and 5 severely abnormal. The newer version (TUG) records the time (in seconds) required for completing the task.

Most adults can complete the test in 10 seconds; scores of 11 to 20 seconds were considered within normal limits for frail older adults and scores over 20 seconds were suggested for impaired functional mobility. Scores of 30 seconds or more corresponded to functional dependence in people with pathology. Criterion validity has been determined as moderate to high with scores of the BBS (r = - 0.81), gait speed (r = -.061), and the Barthel Index of Activities of Daily Living Scale (r = - 0.78) (Podsiadlo et al., 1991).

Podsiadlo et al. (1991) reported high test-retest and interrater (physiotherapist, physician, and patient attendant) reliability (Intraclass Correlation Coefficients (ICC) = 0.99). In another study of test-retest reliability, the ICC was reported 0.97 (Steffen, Hacker, & Mollinger, 2002). Construct validity had been explored by examining differences in scores for patients who were independent and dependent in basic transfers. All participants who completed the TUG in less than 20 seconds were independent in transfers, whereas participants who required 30 or more seconds were dependent (Podsiadlo et al., 1991).

The TUG scores for community-dwelling participants (65–95 years old) with a history of fall were found to be higher than in people with no history of falling (Shumway-Cook, Brauer, & Woollacott, 2000; Gunter, White, Hayes, & Snow, 2000). Shumway-Cook et al. (2000) examined the sensitivity and specificity of single (TUG) task against dual (TUG with manual or cognitive) task to identify the older adults at risk of falls. They found sensitivity of the TUG 80% with specificity of 100% to predict falls for a cut-off score of greater or equal to 13.5 seconds. The sensitivity was 86.7% and specificity was 93.3% for the TUG with manual task for a cut-off score at greater or equal to 14.5 seconds. The sensitivity was 80% and specificity was 93.3% for the TUG with cognitive task for a cut-off score at greater or equal to 15 seconds. The study found that adding a secondary task increased the time taken to complete the TUG by 22 to 25%. Results of this study confirmed that simultaneous performance of a secondary task has a detrimental effect on older adults' functional mobility. This effect was independent of the type of secondary task performed (either manual or cognitive). The ability to predict falls was not enhanced by adding a secondary task when performing the TUG. The authors suggested a cut-off score of 13.5 seconds or more to predict falls in community-dwelling frail old adults.

The TUG is easy to administer and has good sensitivity, but one should note that many factors could affect performance on the TUG. Type of footwear worn, chair used (with or without armrest) and height of chair or different gait aids can affect the end score. The test is not appropriate for cognitively-impaired patients and measures only limited aspects of balance.

Gait velocity

Gait velocity is customarily measured in clinical environments to assess functional mobility. Gait velocity is used in both research and clinical situations because of its simple clinical application. The test has some modified versions which, include either time to walk different distance (Grace et al., 1988; Marks, 1994;Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995; Schwartz et al., 1999; Kennedy, Stratford, Pagura, Walsh, & Woodhouse, 2002) or a distance walked in a specified time at maximum or comfortable pace (Spiegel et al., 1987; Marks, 1994). It is a performance-based test and does not require any specialized equipment.

The usual reference value for healthy adults is approximately 1.33 meters/second (Bohannon, 1997; Waters, Lunsford, Perry, & Byrd, 1988). Velocities of 1.2–1.4 meters/second are desirable for healthy older adults (Hageman & Blanke, 1986; Ostrosky, VanSwearingen, Burdett, & Gee, 1994). Construct validity was reported through correlations between measurements of gait speed and the TUG ($r = -0.75$) (Mathias, Nayak, & Isaacs, 1986). The intrarater reliability was reported high, ranging from 0.91 to 0.99 (Grace et al., 1988; Marks, 1994; Steffen et al., 2002) and test-retest reliability had ICC values ranging from 0.80 to 0.88 (Marks, 1994).

Maki (1997) found gait velocities of 0.66 ± 0.19 meters/second in "fearful fallers" while (Kressig et al., 2004) reported gait velocities of 0.97 ± 0.23 meters/second in older adults who were in transitioning to frailty. Maki (1997) argued that the older adults, who had fear of falls, were less likely to comply with instructions to walk as quickly and safely as possible. Tinetti et al. (1990) showed that the usual walking pace significantly correlated with the Falls Efficacy Scale (FES) scores with $p < 0.0001$. Guralnik et al. (1995) studied predictive validity of gait velocity in community-dwelling older adults. They found that when baseline scores increased from ≤ 3.1 seconds to 5.7 seconds to walk eight feet, a greater percentage of participants had more restricted activities of daily living four years later. Potter, Evans, & Duncan (1995) examined the relationship between gait speed and functional independence in older adults. The study included 160 (101 females, 59 males, mean age = 78.5) participants who were selected randomly from the in-patient and outpatient departments of a geriatric unit in a general hospital in Scotland. The participants had a wide range of disabilities and functional states. All participants were independently mobile with or without gait aids. Their cognitive functions were assessed by an abbreviated mental test. Patients were described as cognitively intact if they scored more than 7 out of 10. Gait speed was measured by a portable ultrasonic accelerometer on three separate occasions over one day. Participants were asked to walk on a carpeted or vinyl floor. Their ability to perform ADL was assessed by an occupational therapist using the Modified Barthel ADL index. The study found that participants with gait speeds of less than 0.25 meters/second were more dependent in one or more ADL function. Participants with a gait speeds between 0.35 and 0.55 meters/second were found more independent in all ADL functions. Participants with a gait speeds greater than 0.55 meters/second were found independent in all ADL functions. In addition, the authors found no relationship between gait speed and floor surface or cognitive function. Though this article establishes a good relationship between gait speed and ADL, the results cannot be generalized to the older population. Pre-existing and co-morbid conditions such as previous stroke and contracture could have impacted the performance of these participants. In addition, the floor surface used in the study was not identical for all participants, which could have affected their ability to walk more quickly.

Gait velocity measurement has a number of limitations. First, there is no guarantee that an increase in gait velocity will denote a meaningful improvement in performance; since it is usually measured inside, in a predictable, uncluttered, controlled environment, therefore the skills required cannot be assumed to transfer to outside mobility. Second, many factors can affect gait velocity. Buchner, Larson, Wagner, Koepsell, & de Lateur (1996) found that loss of strength and aerobic capacity cause reduction in gait speed in a nonlinear manner and modest changes in fitness could not be expected to produce clinically meaningful change in gait speed. Kressig et al. (2004) did not find any relationship between age and gait speed amongst frail older adults. They argued that factors such as depression, fear of falling, and/or lower extremity leg strength might have more effect on gait performance. Improvement in depressive symptoms and health status could improve gait speed with no significant relationship between changes in fitness (strength and aerobic capacity) (Buchner et al., 1996). Ostchega et al. (2000) also found a significant relationship between depression and cognitive status over lower gait speed.

Six-Minute Walk Test (SMWT)

The SMWT is used to measure the maximum distance that a person can walk in 6 minutes after being instructed to walk as quickly as possible (Guyatt et al., 1985). The SMWT is a commonly used physical performance measure in clinical research and is used to assess function in patients with cardiovascular, pulmonary disease or chronic lung disease (Butland, Pang, Gross, Woodcock, & Geddes, 1982; Kadikar, Maurer, & Kesten, 1997) or peripheral occlusive arterial disease (Montgomery & Gardner, 1998). It is a useful instrument because of its ease of administration and similarity to normal daily activities. Studies have shown good test-retest reliability for measurements obtained with the SMWT in patients with cardiovascular disease, with ICC from 0.94 (61 men, 3 women; mean age = 68 years, SD =7) (Montgomery et al., 1998) to 0.96 (40 men, 5 women; mean age = 49 years, SD = 8) (Cahalin, Mathier, Semigran, Dec, & DiSalvo, 1996). Other studies have shown construct validity through correlations ($r = 0.63 - 0.79$) between distance walked in 6 minutes and peak oxygen consumption in patients with heart failure (Cahalin et al., 1996) or pulmonary disease (Cahalin, Pappagianopoulos, Prevost, Wain, & Ginns, 1995). The SMWT has been recognized as a general indicator of physical performance and mobility in older populations.

Cho, Scarpace, & Alexander (2004) found a correlation (r) of the SMWT with the POMA (0.617), the ABC Scale (0.631), the TUG (-0.752), Tandem Walk (-0.524), Tandem Stand (0.519), Unipedal Stance (0.527) with $p < 0.01$, in 167 older adults (mean age 78, range 65–90 years) with mild balance impairments. Duncan, Chandler, Studenski, Hughes, & Prescott (1993) reported that performance on the SMWT differed significantly between older men with varying levels of mobility impairment. Harada, Chiu, & Stewart

(1999) reported moderate correlations between the SMWT distance and mobility measures, including standing balance, chair stands, and gait speed in people at or over the age of 65 years.

These results suggest that rather than being a specific measure of cardiovascular exercise capacity, performance on the 6-minute walk test may also be influenced by a range of factors associated with mobility. In particular, physiologic factors such as strength, balance, speed, peripheral sensation, vision, and chronic pain, which determine mobility levels, may have a significant impact on six-minute walk performance in older people (Lord, Lloyd, & Li, 1996). Psychological factors are also found to play an important role on SMWT performance, as the presence of depression has been associated with reduced walking speed (Lamb et al., 2000). To determine the extent to which physiological, psychological, and health-related factors predict six-minute walk distance in older people, Lord & Menz (2002) assessed sensorimotor function, balance, cognitive function, mood, pain, health status and physical activity of 515 frail older adults between the ages of 62 and 95 years (79.5 ± 6.4) residing in retirement villages in Australia. They found that after normalizing six-minute walk distance for height, it was inversely correlated with age ($r = -0.45, P < 0.01$). Other than age, visual contrast sensitivity, lower-limb strength, simple reaction time, sway with eyes open on the floor, maximal balance range, Positive and Negative Affect Schedule, SF-36 pain score, medications, and SF-36 general health subscale score were significant and independent predictors of performance in SMWT. Of these measures, strength, maximal balance range, medication use, and age explained the largest proportion of variance in the SMWT distance. They concluded that in older people, six-minute walk distance depends on multiple physiological, psychological, and health factors.

Functional Reach (FR)

The Functional Reach test (FR) was developed by Duncan et al. (1990). It is used to assess dynamic balance of basic standing activity. It is the maximal distance one can reach forward beyond arm length while maintaining a fixed BOS in the standing position. It uses a leveled yardstick mounted on the wall positioned at shoulder height. The individual stands next to the wall (without touching it) with the shoulder flexed to 90 degrees, elbow straight and hand in a fist. An initial measurement is recorded of the position of the third metacarpal along the yardstick. The measurement is repeated in the forward reach position. This measurement is then subtracted from the initial measurement. Three trials of FR are performed and the average of all three trials recorded.

Duncan, Studenski, Chandler, & Prescott (1992) conducted the FR test on 217 community-dwelling, older male veterans (aged 70 to 104) with diagnoses of Parkinson's disease, stroke, cerebellar disease, myelopathy, peripheral neuropathy, Meinere's disease, amputation, joint replacement, and arthritis. The participants were followed for six months to monitor falls. Participants with two or more falls during the six-month follow-up period were classified as recurrent fallers. The authors concluded that the participants who were able to stand but unable to reach were eight times more likely to fall than were participants who could reach 10 inches or farther. Participants who reached less than or equal to six inches were four times more likely to fall than those who reached 10 inches or farther. Participants who reached farther than six inches but less than 10 inches were twice more likely to fall than those who reached 10 inches or farther. The FR test has a test-retest reliability of 0.92 and an intra rater reliability of 0.98 (Berg & Norman, 1996). Age related norms for the FR test have been determined as follows: 20 to 40 years old; 14 to 17 inches, 41 to 69 years old; 13 to 16 inches and 70 to 87 years old; 10 to 13 inches. Score of less than 7 inches is an indicative of a frail individual who is limited in mobility and ADL skills and demonstrated increased fall risk (Duncan et al., 1992). In a study assessing balance in 30 participants of a day hospital (age > 65), Thomas & Lane (2005) found no statistically significant difference in performance on the FR test between fallers and non-fallers. They argued that the FR test is not useful in discriminating amongst participants who may be at risk of falling and cannot be recommended for use as a falls risk measure in a day hospital environment. Jonsson, Henriksson, & Hirschfeld (2003) reported that performance in the FR test is influenced more by trunk flexibility than displacement of the COP; thus, it may not be a true measure of balance.

Activity Specific Balance Confidence Scale (ABC Scale)

Powell et al. (1995) developed the ABC Scale to measure confidence levels in the performance of activities of daily living in community-dwelling elders. It is an 11-point scale and ratings consist of 0% (no confidence) to 100% (complete confidence) for 16 items. The total score may range from 0 and 1600, which is divided by 16 to get the ABC score. The scale was designed to include a wider continuum of activity difficulty and more detailed item descriptors than the FES. Initial testing involved 60 community seniors (aged 65 – 95) who were self-classified as either high or low in mobility confidence according to their perceived need for a walking aid and personal assistance to ambulate outdoors. The ABC Scale was reported to have internal consistency

(Cronbach's Alpha (α) = 0.96) and test-retest reliability ($r = 0.92$), (Powell et al., 1995). Convergent and discriminative validity of the ABC Scale was found strong in an older population (Myers et al., 1996).

Kressig et al. (2001) examined the prevalence of fear of falling and its association with demographic, functional and behavioural characteristics in older adults aged 70 and older (n = 287, male = 17, female = 270). They found criterion validity of $r = -0.65$, $p < 0.001$ between the FES and the ABC Scale. A significant association was found between depression and fear of falling ($p < 0.001$) with depressed individuals twice more likely to have fear of falling than non-depressed individuals. Also, it was found that non-fearful participants had significantly higher average gait speeds (1.10 ± 0.32 m/s) compared to fearful participants (0.85 ± 0.27 m/s) for the 10 – meter walk with $p < 0.001$. The slow walkers (≤ 0.9 m/s) were 3.8 times (95% CI = 2.3 – 6.3) and participants with impaired gait/balance were 5.4 times (95% CI = 1.5 – 18.9) more likely to be fearful of falling on the ABC scale. They found no significant correlation between age and fear of falling (i.e. fear of falling is common in all older adults transitioning to frailty). Hotchkiss et al. (2004) reported the limitations of the ABC Scale in a study of 118 community-dwelling individuals, aged 60 or over (60 – 99 years) with the mean age of 75.8. They showed that the ABC Scale has little ability to identify individuals who have history of falling and is inadequate to predict individuals who restrict their activities. They concluded that the ABC Scale alone cannot accurately predict who might be at risk for falls and who may need an intervention program.

Table 1: Summary of Clinical and Laboratory Based Balance Assessment Tests

Balance Test	Tasks Conditions	Environmental Conditions	Balance Mechanism
ABC Scale	None, Subjective	-	-
BBS	Self Generated Perturbations	Simple and Stable Some Moving BOS	Predictive and Some Reactive Balance Control
Functional Reach	Self Generated Perturbations	Simple and Stable	Predictive and Some Reactive Balance Control
Gait Velocity	Unperturbed	Simple and Stable Moving BOS	Predictive
LOS test	Self Generated Perturbations	Stable BOS	Predictive
mCTSIB	Unperturbed, Some Perturbations	Simple, Stable and Sensory Manipulation	Predictive and Some Reactive Balance Control
POMA	Self Generated Perturbations	Simple and Stable, Some Moving BOS	Predictive and Some Reactive Balance Control
SMWT	Unperturbed	Simple and Stable	Predictive
SOT	External Perturbations	Complex and Sensory Manipulation	Predictive, Mainly Reactive Balance Control
TUG	Self Generated Perturbations	Simple and Stable	Predictive

STATEMENT OF THE PROBLEM

Falling is the sixth leading cause of death amongst older adults: 33% of older adults fall each year (Campbell, Borrie, & Spears, 1989) and 36% of those who fall are seriously injured (Koski, Luukinen, Laippala, & Kivela, 1998). Balance and ambulatory assessments are typically performed on solid fixed surfaces such as indoor floors. Even though routine clinical assessments incorporate a range of static and dynamic tasks, they are often timed tasks which do not evaluate quality of movements, rely on the subjective evaluation of the administrator, are self-paced and have predictable environments, thus their ability to identify different aspects of balance control and causes of the performance deficit is limited (Refer to Table 1). Other than clinical balance tests, sophisticated instruments for balance assessment such as the Sensory Organization Test (SOT)(Cohen et al., 1996) and the Limits of Stability (LOS) test (Wallmann, 2001) are also available. However, these are expensive commercial products which require special training to administer. Performance in the CTSIB is quantified by recording the amount of time the participant can maintain standing balance, thus it cannot provide quantification of the quality of movement (El Kashlan et al., 1998; Cohen, Blatchly, & Gombash, 1993). Several studies have used a sponge as a compliant surface and biomechanical force plates (underneath the sponge pad) to record COP to quantify the amount of body sway and balance control and advocated the use of sponge as a more comprehensive balance-assessing tool (Creath et al., 2005; El Kashlan et al., 1998; Teasdale et al., 1991a). However, as sponge pad distorts ground reaction forces, it also distorts and damps the COP position signals. COP signals recorded from the bottom of the sponge pad is found to be different and non-linearly related to that of the top of sponge pad (Betker, Moussavi, & Szturm, 2005). In addition, variations in the protocol and analysis used in different studies make it difficult to draw definitive conclusions (Piirtola & Era, 2006). There is a critical need to develop a simple to administer, cost-effective clinical tool, which can assess balance control in community-dwelling older adults in both controlled (predictive) and unpredictive environments.

DESCRIPTION OF THE PAPER

Reduced mobility and falls are common and potentially preventable sources of disability, mortality and morbidity in older adults. Balance control is an important factor when considering mobility and falls in this population. Dynamic balance is required to perform both basic (BADL) and instrumental activities of daily living (IADL). The BADLs include bathing, toileting, preparing food, dressing, and eating. The IADLs include walking a mile, taking public transportation, shopping and crossing streets. Mobility skills are necessary for outdoor walking and functional independence. It is very important to provide effective and simple ways to document changes in balance and mobility skills amongst older individuals. It is also important to have the ability to quantify the cause of balance problem, the level and its association to fall risk. The detection of balance impairments is likely to reduce future probability of falls, if combined with appropriate interventions. So far, the clinical tests developed to quantify balance performance as an outcome measure do not focus on all aspects of balance regulation. Most of these tests are self-paced and performed on stable or predictable surfaces. Tests like the BBS and Tinetti's POMA assess balance in broad categories and are ineffective in detecting borderline balance deficits. Other tests, which are more dynamic (e.g. moving platforms, the SOT), challenge more than one physiological mechanism of balance control but they are costly and difficult to administer; which make them inappropriate for a routine clinical environments.

The goal of this study was to work towards development of a balance assessment tool to assess balance control in community-dwelling older adults. Based on the previous findings and methodologies used, a new balance assessment tool – the Dynamic Balance

Assessment (DBA) test was developed to assess balance in community-dwelling older adults. It is a modification of the foam and dome test. In addition, the DBA test incorporates salient features of the SOT test i.e. elimination or distortion of sensory information, and thus evaluates the contribution of sensory interactions to balance control. It also includes motor tasks which closely simulate activities of daily living e.g. trunk rotation, head turning and trunk bending. In the DBA test, six graded balance tasks are introduced first on a normal fixed floor surface and progression is made by using a sponge as a compliant surface. The DBA test assesses both feedforward and feedback mechanisms of the balance control. The following paper describes the ability of the DBA test to identify community-dwelling older adults with a history of one or more falls in the last one year. The paper describes the features, strength and limitations of the DBA test.

METHODOLOGY SUPPLEMENT

The following section provides detailed descriptions of accelerometers and composite motor co-ordination index, which is not included in the manuscript. It also contains a detailed description of composite score for COP measurements, which is briefly outlined in the manuscript.

Accelerometers

Changes in COP movements are not always accompanied by similar changes in the position of the trunk, suggesting a change in balance strategy rather than balance deficits (Panzer, Bandinelli, & Hallett, 1995). Information about the co-ordination between upper (trunk) and lower segments (legs) is therefore also important while assessing balance control. An accelerometer is a portable, low-cost and sensitive alternative to detect body sway. The transducer is small, lightweight, and can be easily applied. The technique is non-invasive, does not restrict natural movement and is sensitive to subtle changes in motion. The reliability and validity of using accelerometers for balance assessment has been demonstrated previously (Ladin, Flowers, & Messner, 1989; Kamen, Patten, Du, & Sison, 1998). In the current study, two miniaturized tri-axial accelerometers (Nextgen, 2x1x1 cm; 30 grams) were used to measure body sway. One accelerometer was fixed to the lower leg at the tibial tuberosity and the second on the T2 spinous process. The accelerometer signals were recorded at 200 Hz (National Instruments Data Acquisition system, USA).

Composite Score for COP measurements

A balance index was created to quantify performance on the DBA test and allow statistical comparisons. Peak-to- peak COP excursions and swaypathlength were computed for each successful task on the DBA test from the pressure map recordings. A *Composite score* for swaypathlength and COP excursions for AP and ML directions were then calculated for each participant to index balance performance in the DBA test by the following method: For each COP dependent variable, the maximum value over the twelve conditions was identified. This maximum value was then taken as 100%. Based on that, the remaining values were converted into percentile format. The percentile data was transformed to an ordinal scale ranging from 0-5 to make the results of different test conditions comparable and to make residual variances uniform. The conditions that the participant was unable to complete were scored as zero.

Therefore, 0 = unable to complete the test condition
1 = greater than 80% and less than or equal to 100%
2 = greater than 60% and less than or equal to 80%
3 = greater than 40% and less than or equal to 60%
4 = greater than 20% and less than or equal to 40%
5 = greater than 0% and less than or equal to 20%

Thus, the maximum score possible for the DBA test for each COP variable could vary from 0 to 30 for each surface and composite score could vary from 0 to 60 where the higher score indicates better performance. Table 2 illustrates an example of the Composite score calculation.

Table 2: Example of Composite Score for COP measurements

Condition	Subject Performance COP Swaypathlength (cm)	Percentile	Composite Score
1	20	10	5
2	40	20	5
3	100	50	3
4	150	75	2
5	100	50	3
6	150	75	2
7	150	75	2
8	UC	0	0
9	150	75	2
10	UC	0	0
11	200	100	1
12	UC	0	0
Composite Score for COP Swaypathlength			25/60
Normal Surface Score (Condition 1 to 6)			20/30
Sponge Surface Score (Condition 7 to 12)			05/30

UC: Unable to Complete

Composite Motor Coordination Index

The correlation coefficient between the trunk and ankle segments for anteroposterior and mediolateral acceleration signals were computed for each task using Matlab scripts. The test in which participants could not able to complete was recorded as 0. If both segments (trunk and ankle) are moving in harmony, then the correlations can be expected to be higher. A score of 1 indicates good coordination between trunk and ankle and 0 indicates no coordination. The Composite Motor Coordination Index was then computed by summing the correlation coefficient (r) value of Head Rotation, Shoulder Flexion, Trunk Rotation and Trunk Flexion tasks for both surfaces; i.e. 4 correlation coefficients x 2 surfaces. Thus, the composite motor coordination index score could vary from 0 to 8 where higher score indicates better motor coordination.

RESULTS SUPPLEMENT

The following result section is not included in the manuscript. It describes the ability of the DBA test to identify community-dwelling older adults at risk of falling. It also examines the differences between non-fallers and fallers on motor coordination index.

1. The objective was to explore whether the DBA and clinical tests can identify those community-dwelling older adults who are at risk of falling, and to determine which parameter is most beneficial in identifying fallers. Based on performance on the DBA test, participants were separated into groups relating to their risk of falling (or losing their balance). The independent variable was loss of balance in the DBA test, which had three levels –

Low Risk:	Participants were able to complete tasks on the normal surface as well as simple tasks on the sponge surface however they started losing balance in complex tasks on the sponge surface e.g. sponge eye closed, trunk forward bending and/or trunk rotation (n = 32 participants)
Moderate Risk :	Participants were able to complete tasks on the normal surface however they started losing balance in simple tasks performed on the sponge surface e.g. sponge eyes open, sponge head rotation and/or sponge arm movement (n = 28 participants)

High Risk: Participants started losing balance in tasks performed on the normal surface (n = 12 participants)

Means and standard deviations were calculated for the normally distributed variables (scores on the BBS, six-minute walk test, and experimental COP variables for normal surface). Median and Inter Quartile Range (IQR) were computed for non-normally distributed variables (prescribed medication, home care/assistance, the TUG and gait velocity). Independent t test for normally distributed and Mann – Whitney U test for non – normally distributed variables were used to study inter group differences ($p < 0.05$).

The findings are illustrated in Table 3. None of the clinical tests were able to differentiate between the Low and Moderate Risk groups. For the normal surface, scores of swaypathlength and COP ML excursions were able to detect the difference between the Low Risk and Moderate Risk groups. For the comparison between the Low and Moderate Risk groups – only the experimental variables on the normal surface used since both groups would have obvious difference between the experimental variables on the sponge surface.

All clinical tests were able to detect difference between the Low and High Risk groups, while the TUG, gait velocity and BBS were able to differentiate between the Moderate and High Risk groups.

The clinical balance assessment tests were not able to predict fall risk until the participants had a LOB on the normal surface. None of the clinical balance assessment tests were able to differentiate between the Low and Moderate Risk groups who had no incidence of a LOB on the normal surface in the DBA test. However, clinical balance assessment tests were able to differentiate between the Low vs. High and Moderate vs. High-risk groups as high-risk group participants had experienced LOBs on the normal surface in the DBA test. All clinical balance tests failed to differentiate between the Low and Moderate risk group, which suggest that clinical balance tests cannot assess the effect of unpredictable environment on balance control. The results of this study suggest that community-dwelling older adults who are at a risk of fall can be subdivided into three categories – high, moderate and low risk.

Table 3: Group based on LOB in the DBA test

Variables	Low Risk (n = 32) Mean (SD)/Median (IQR)	Moderate Risk (n = 28) Mean (SD)/Median (IQR)	High Risk (n = 12) Mean (SD)/Median (IQR)
Age	81.1 (6)	79.9 (6.5)	82 (7.7)
Prescribed Medication* (number)	7.5(3)	8 (3)	9 (6)
Home Care Assistance* (days)	3(6.5)	1 (6.5)	3.8 (3.5)
Gait Velocity* (meter/second)	0.74 (0.30)	0.81 (0.25)	0.55 (0.25)$^{\$\P}$
Six Minute Walk Test (meters)	247.5 (93)	208.8 (83)	157.9 (64.6)$^{\$}$
TUG* (seconds)	14 (5)	17 (9.5)	34.5 (13)$^{\$\P}$
Berg Balance Scale	45 (6.2)	43 (5.9)	36(7.7)$^{\$\P}$
AP COP Excursion (Normal surface)	23.7 (3.1)	21.9(3.1)	14.1 (3.5)$^{\$\P}$
ML COP Excursion (Normal surface)	24.9 (3.6)	21.9 (3.9)§	16.6 (4.4)$^{\$\P}$
SWAYPATHLENGTH (Normal surface)	25.3 (2.7)	21.1 (3.7)§	15 (4.8)$^{\$\P}$

*: Median (IQR)

$: Low vs. High Risk groups significant at $p < 0.01$

§: Low vs. Moderate Risk groups significant at $p < 0.01$

¶: Moderate vs. High Risk groups significant at $p < 0.01$

2. The second objective was is to investigate if acceleration measurements of trunk and ankle segments during differently graded sensory-motor tasks of the DBA test indicate changes in motor co-ordination. A Shapiro-Wilks test indicated that the Composite Motor Coordination Index scores (ML and AP) were not normally distributed. Mann – Whitney U test was used to determine difference ($p < 0.05$) between fallers and non-fallers groups (Table 4). The non – fallers showed higher motor co-ordination indices as compared to fallers for both AP and ML directions.

Table 4: Composite Motor Coordination Index

Past History of Falls (Experimental Variables)	**Non-fallers Median (IQR)**	**Fallers Median (IQR)**	**p Value (2 – tailed)**
Composite Motor Coordination Index (AP)	3.43 (1.71)	2.44(1.31)	0.008
Composite Motor Coordination Index (ML)	2.59 (1.09)	2.03 (1.45)	0.03

MANUSCRIPT: "A RELATIONSHIP OF POSTURAL SWAY AND FUNCTIONAL PERFORMANCE IN COMMUNITY-DWELLING SENIORS"

INTRODUCTION

Declines in self-efficacy, increased susceptibility to falls and reduced mobility are serious problems facing many older adults. Balance impairment and fear of falling can occur following singular events (Guccione et al., 1994; Moore, Rosenberg, & Fitzgibbon, 1999) or can have an insidious onset, with the problem/source found in multiple predisposing factors such as, the decline of musculo-skeletal, cardiovascular, respiratory or neural fitness (Tinetti, Williams, & Mayewski, 1986; Gijsen et al., 2001).

Maintenance and restoration of balance depends on the integration of multiple sources of spatial information within the central nervous system, which receives input from both internal and external frames of reference, especially visual, vestibular, proprioceptive and cutaneous sensations (Creath et al., 2002; Peterka, 2002; Szturm et al., 1998; van der et al., 2001). Feed-forward predictive control is required for preparatory postural adjustments which helps in avoiding potential future disturbances or obstacles. Feedback control is essential for responding in a timely fashion to unexpected disturbances or for correcting movement errors. Sensing the "state" of balance or threat to balance, and timely selection of feed-forward and feedback motor actions are determined by both the goal of the task (degrees of freedom and difficulty) and the demands of the environment in which it is being performed (Horak et al., 1990). Individuals manage reasonably well in their home where they may control tasks, arrange environmental elements and use assistive devices that compensate for either perceived or real instability.

However, it is not always possible to predict the surface characteristics of outdoor terrains (uneven, compliant, and slippery) and to be prepared for other disruptive environmental conditions. Many older adults experience a substantial decrease in physical activity and a greater fear of falling, particularly when walking outdoors in the winter. Careful consideration therefore needs to be given to the impact of "uncertainty" on stability during standing and walking (Brooke-Wavell et al., 2002; Hay et al., 1996; Teasdale et al., 1991a; Redfern et al., 1997).

The detection of changes in balance and mobility is a critical part of evidence-based practice in rehabilitation. Screening tools for early detection of physical decrements can allow for immediate implementation of preventive measures. These tools also minimize the development of secondary problems such as reduced confidence, physical dependence and decreased quality of life. Valid outcome measures are also required for evaluation of treatment efficacy, both in the short and long terms.

Measurement of physical performance in selected tasks has been reported to predict declines in physical function or dependence (Topper, Maki, & Holliday, 1993). Low scores on the Berg Balance Scale (BBS) (Berg et al., 1992b; Shumway-Cook et al., 1997), higher scores in the Timed up and Go (TUG) test (Podsiadlo et al., 1991; Gunter et al., 2000; Shumway-Cook et al., 2000) and slower self-selected gait speed (Maki, 1997; Woo, Ho, Lau, Chan, & Yuen, 1995) can indicate someone's likelihood of falling. However, the clinical balance test that is most accurate in predicting fallers in community-dwelling seniors with varying levels of physical function and co-morbidities has not been clearly identified (Bogle Thorbahn et al., 1996; Brauer, Burns, & Galley, 2000). These clinical tests incorporate a range of static and dynamic tasks. However, most of these tests are self-paced and conducted in a predictable environment. Therefore, their ability to evaluate balance control and causes of the performance deficit are limited. Tests such as the Sensory Organization Test (SOT) and the Limits of Stability (LOS) provide objective information on biomechanical changes relevant to balance control (Cohen et al., 1996; Melzer et al., 2004; Simmons et al., 1997; Wallmann, 2001; Whipple et al., 1993). However, they are expensive commercial products and require special training to administer.

Shumway-Cook et al. (1986) developed a less expensive test based on the same principles as the SOT, known as the Clinical Test of Sensory Interaction and Balance (CTSIB). The CTSIB uses a compliant sponge as an unstable support surface to emulate the SOT in terms of somatosensory distortion, with an added advantage that it is not limited to pitch plane; i.e. the disturbance could be multi- directional (Allum et al., 2002). The use of a compliant surface can modify the ground reaction forces under the feet (i.e. the compliant surface cannot completely reciprocate the normal body forces beneath the feet as the centre of body mass moves). This can increase the magnitude and frequency of unpredictable body sway. To prevent a fall, the individual must be able to sense and respond to this sway. This increased demand on whole body balance reactions and continuous automatic postural adjustments are required to maintain stability. Performance on the CTSIB is quantified by recording the amount of time the participant can maintain standing balance. However, peak excursions or amount of body sway is not recorded, thus it cannot provide quantification of the quality of movement (El Kashlan et al., 1998; Cohen et al., 1993).

Several studies have used a sponge as a compliant surface and biomechanical force plates (underneath the sponge pad) to record centre of foot pressure (COP) to quantify the amount of body sway and balance control as a more comprehensive balance-assessing tool (Creath et al., 2005; El Kashlan et al., 1998; Teasdale et al., 1991a). However, as the sponge pad distorts ground reaction forces, it also distorts and damps the COP position signals. COP signals recorded from the bottom of the sponge pad is found to be different and non-linearly related to that of the top of sponge pad (Betker et al., 2005). In addition, variations in the protocol and analysis used in different studies make it difficult to draw definitive conclusions (Piirtola et al., 2006).

Although performance-based clinical balance tests are able to provide an indication of balance abilities, they cannot detect subtle changes in postural stability. Laboratory-based assessments can provide information regarding control processes and physiological changes relevant to balance, however high costs limit their use in the clinical environment. There is a need for further development of a clinically based balance assessment, which incorporates dynamic balance assessment under both self-generated and unexpected or externally- generated perturbations. It is also important to recognize factors influencing balance (i.e. environmental interactions) and to quantify the cause of the balance problem, its level and its association to fall risk. In the present study, a new balance assessment tool - the Dynamic Balance Assessment (DBA) test - was used to evaluate balance in community-dwelling older adults. The test incorporates features of the modified CTSIB (mCTSIB) test (Boulgarides, McGinty, Willett, & Barnes, 2003). In addition to standing with eyes open and closed, the DBA test includes four additional tasks: head rotation (large gaze shifts), lifting arms, trunk rotation and forward trunk bending. Execution of these voluntary movements displaces the body centre of mass (COM), which requires preparatory postural adjustments to maintain balance. It uses a flexible pressure mapping system to record COP signals. Use of a sponge as a compliant surface and a flexible pressure mapping mat to record COP signal enhances the system's portability and yet allows an objective measure of balance control (Betker et al., 2005). The first objective of this study was to determine if COP measurements (excursions and swaypathlength) on the DBA test could differentiate fallers from non-fallers in community-dwelling seniors aged 65 or over, based on a history of falls. Studies have shown that the displacement of COP is an indicator of instability (Cohen et al., 1996; Whipple et al., 1993; Wallmann, 2001; Simmons et al., 1997) and an increase in COP displacement is directly related to the amount of muscle activity during a disturbance (Nakamura, Tsuchida, & Mano, 2001). Swaypathlength is a widely-used linear parameter that quantifies the amount of COP movement and consequently body sway over time (Melzer et al., 2004). It is one of the most valuable clinical parameters in the analysis of human balance control under a variety of conditions (Baratto, Morasso, Re, & Spada, 2002).

The second objective of this study was to determine the relationship between functional-based performance tests (BBS, TUG, SMWT and gait velocity) and the DBA test. In this study, we investigated the pattern of association between COP parameters and performance on functional balance tests.

METHODS

Participants

The study included community-dwelling seniors age 65 or older who attended Riverview Health Centre Day Hospital for treatment of balance and mobility impairments. The inclusion criteria were a) 65 years or older, b) a mini-Mental State Examination Score (MMSE) > 24, c) ability to speak English, d) ability to understand the nature of the study and provide informed consent e) ability to stand for 2 minutes without any gait aids and f) ability to walk 10 feet with or without gait aids. Participants who had any medical condition or disability which could prevent them from participating in routine clinical balance tests (e.g. BBS, TUG) were excluded. For example, a medical history including current treatment for terminal cancer, recent fracture, seizure disorder, cardiovascular-related problems that restrict exercise, fainting or dizzy spells, and legal blindness were grounds for exclusion.

The nurse or occupational therapist contacted outpatient clients who were attending Riverview Day Hospital for physiotherapy treatment and completed a preliminary assessment to determine their eligibility for the study. The nurse and occupational therapists were fully informed of the study. Once the participant expressed willingness to take part in the study, the investigator obtained consent and recruited the participant. For this study, the intention was to include older adults with a range of neurological and/or musculo-skeletal conditions. Ethical approval was obtained from the Research Ethics Board (University of Manitoba) and Riverview Health Centre.

Test Protocol

Each participant completed four clinical tests [the Berg Balance Scale (BBS) (Berg et al., 1992b), the Time Up and Go test (TUG) (Podsiadlo et al., 1991), the Six Minute Walk test (SMWT) (Guyatt et al., 1985; Cho et al., 2004) and Gait Velocity (GV) (Hageman et al., 1986; Ostrosky et al., 1994)] in the first session. The BBS consists of 14 common movement tasks, which are graded on a 5-point ordinal scale (0 to 4), where a score of 4 indicates that the patient performs the task independently, needs no cues and meets time or distance criteria; a score of 0 indicates an inability to perform the task. The total score ranges from 0 to 56. The authors support a cut-off score of 45 of 56 for independent safe ambulation (Berg et al., 1992b). The TUG measures the time to complete a 3-meter walk. The test requires the participant to get up from a regular armchair, walk for three meters, turn, walk back to the chair and sit down. A cut-off time of 13 seconds is suggested to separate fallers from non-fallers amongst community-dwelling older adults (Shumway-Cook et al., 2000). The SMWT is used to measure the maximum distance that a person can walk in 6 minutes. GV is customarily measured in the clinical environment to assess mobility. A time of 1.2–1.4 meters/second is desirable for healthy older adults (Hageman et al., 1986; Ostrosky et al., 1994). For this study, average gait velocity over a 25-meter walk distance was recorded for each participant.

The DBA test was performed on a separate visit within one week of the clinical tests. The DBA test conditions are as follows:

1 Quiet standing on a firm surface with eyes open

2 Quiet standing on a firm surface with eyes closed

3 Standing on a firm surface and performing rhythmic head rotation to left and right to visual targets placed 120 degrees apart

4 Standing while performing a rhythmical arm lifting and lowering task while holding onto a 50 cm lightweight wooden pole, 1.91 cm in diameter, with both hands kept shoulder width apart and elbows extended. The pole was raised to shoulder level and then lowered to the legs

5 Standing while performing rhythmic horizontal trunk rotations to 45 degrees in each direction

6 Standing while performing rhythmic forward trunk bending and extension to return to the upright (erect) standing position. The amplitude of the trunk bending was about 30 degrees

After a rest period of 2 – 3 minutes, the six tasks were repeated while standing on a 50.8 cm x 50.8 cm x 10.16 cm sponge pad. A 25.4 cm x 40.64 cm x 1.91 cm wooden board was placed on top of the sponge to distribute the forces equally, thus minimizing the compression of the sponge. A pressure mapping mat was placed on the top of the wooden board for direct recording of COP. Two grades of sponge were used to counterbalance the effect of differences in body weight in compressing the sponge pads (Betker et al., 2005). A low support: (50.8 cm x 61 cm x 10.16 cm) sponge, with a density of 16.016 kg/m^3 and a 25% *indentation force deflection* (IFD) of 6.82 kg. was used for people who weighed less than 120 lbs. A medium support (50.8 cm x 61 cm x 10.16 cm) sponge, with a density of 22.66 kg/m^3 and a 25% IFD of 13.64 kg. was used for people who weighed more than 120 lbs. The compliant surface distorts the spatial information provided by the cutaneous sensors of the feet.

All of the DBA test tasks were performed with the FSA (Verg Inc., Winnipeg, MB) pressure mapping mat directly underneath the feet. The thin flexible pressure mapping mat has dimensions of 53 cm x 53 cm x 0.036 cm and contains a 16 x 16 grid of piezo resistive sensors spaced 2.8575 cm apart. The FSA mat used for this experiment was connected to the interface module through a serial interface cable. FSA 3.1.x version software was used to read the signals. The sampling frequency was 15 HZ.

Each task was performed for 20 seconds. All tasks were performed with a high table (chest height) in front of the participant and a physiotherapist positioned immediately behind the participant to offer assistance if required. The metronome was set at 0.5 Hz to pace all rhythmical movements (tasks 3 to 6). If a participant was unable to complete the task in the DBA test, the task was stopped. The trial was recorded as a loss of balance (LOB) and the participant advanced to the next task. Here, the LOB is defined as the participant's inability to complete the task due to loss of balance and the need for external support to prevent a fall.

The following information was also obtained from each participant or retrieved from his/her medical chart: age, sex, residential status, medical history, self-reported history of falls, use of assistive device for ambulation, whether walking outdoors for half a mile regularly (2 – 3 times/week), and amount of home care assistance (frequency of days per week), and current number of prescription medications (numbers). This information was used to characterize the demographics and general health status of participants in the study.

DATA ANALYSIS

General characteristics

Peak-to- peak COP excursions and swaypathlength were computed for each successful task from the pressure mat recordings. **Composite scores** for COP swaypathlength and COP excursions for ML and AP directions were then computed to index balance performance in the DBA test.

For each participant, the composite score was calculated by the following method. For each COP dependent variable, the participant maximum value over the twelve conditions was identified. This maximum value was then taken as 100% and based on that, the remaining values were converted into a percentile format. The percentile data was transformed to an ordinal scale ranging from 0-5 to make the results of different test conditions comparable and to make residual variances uniform. Conditions that the participant was unable to complete were scored as zero.

Therefore, 0 = unable to complete the test condition

1 = greater than 80% and less than or equal to 100%

2 = greater than 60% and less than or equal to 80%

3 = greater than 40% and less than or equal to 60%

4 = greater than 20% and less than or equal to 40%

5 = greater than 0% and less than or equal to 20%

Thus, the maximum score possible for the DBA test for each COP variable could vary from 0 to 30 for each surface and the composite score could vary from 0 to 60 where the higher score indicates better performance.

Statistical Analysis

Seventy-eight participants took part in this study. Six participants were excluded due to missing clinical or experimental data. The McNemar test was used to determine the effect of surface on LOB. Cochrane's Q test for the normal and compliant surface was computed to determine the effect of tasks on LOB. Analysis of variance (ANOVA) was used to determine the effect of tasks on COP parameters (normal surface only) as there was large number of LOB on the compliant surface. The Mann-Whitney U test was used to determine the difference between non-fallers and fallers for normal surface quiet standing tasks.

A Shapiro-Wilks test was used to determine a normal distribution of outcome measures. To address the first objective of this study a Mann – Whitney U test was used for non-normally distributed variables (TUG, BBS, prescribed medication, home care/assistance) and an independent t-test was used for the normally distributed variables (Age, GV, SMWT, experimental COP variables). Means and standard deviations were calculated for the normally distributed variables. Median and Inter Quartile Range (IQR) were computed for non-normally distributed variables. A Chi square was computed for the following binomial variables: sex, walking aids and the activity of walking half a mile. To address the second objective of this study and to determine the strength of the association between the composite score of the DBA test and clinical tests, Spearman correlation coefficients were computed. The Spearman correlation coefficient can be used with continuous or ordinal variables. In addition, the use of Spearman correlations allowed the results to be presented in a consistent format. All statistical analyses were performed using the SPSS statistical package for Windows, release 10.0.

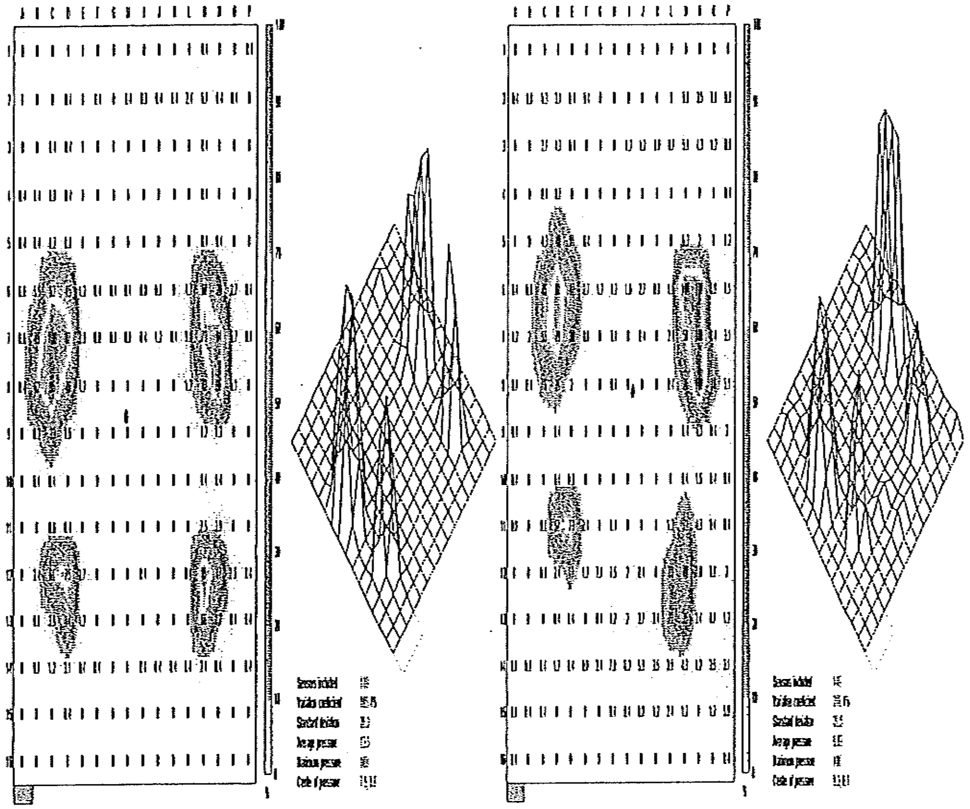
RESULTS

Figure 1 shows the comparison of FSA recordings for eyes open task on the normal and sponge surface where black dots represents COP. Figure 2 and 3 show COP excursions for both AP and ML directions for eyes closed and trunk flexion task on the normal and sponge surfaces. In both tasks, the COP excursions were higher for both AP and ML direction on the sponge surface than on the normal surface. Figure 4 shows the effect of surface and task on balance control. The number of LOB older adults experienced on compliant surface tasks was significantly higher than on normal surface tasks (McNemar test, $p < 0.0001$). There was a total of 16 LOB on the normal surface and

205 LOB on the compliant surface. The LOB in the normal surface tasks were not significantly different (Cochrane's Q test, p = 0.14). A significant effect of tasks on LOB was noted for compliant surface tasks (Cochrane's Q test, p < 0.0001). A high incidence of LOB was noted for large COM movements as well as for the eyes closed condition on the compliant surface. Fifty-three out of 72 participants had a LOB on the sponge during eyes closed condition, 47 had a LOB on the compliant surface trunk flexion condition and 41 had LOB on compliant surface trunk rotation condition.

Group means and standard errors of means (SEM) for the peak COP excursion in the AP and ML direction are presented in Figures 5 and 6. Except for trunk flexion tasks, peak excursions were approximately two times greater on compliant surface tasks than on the normal surface. Group means (SEM) of COP swaypathlength is presented in Figure 7. Swaypathlength was three times greater on the compliant surface than on the normal surface except for trunk rotation and flexion tasks, which were approximately twice on the compliant surface than on the normal surface. Analysis of variance for the effect of tasks on COP parameters (normal surface only) showed significant tasks effect for AP COP excursions (F = 45.2243, df= 5, p = 0.0001), ML COP excursions (F =48.36, df = 5, p = 0.0001) and swaypathlength (F = 58.56, df = 5, p = 0.0001). Analysis of variance for the compliant surface was not calculated due to the large number of LOB, which reduced the sample size.

Figure 1: Comparison of FSA Recordings

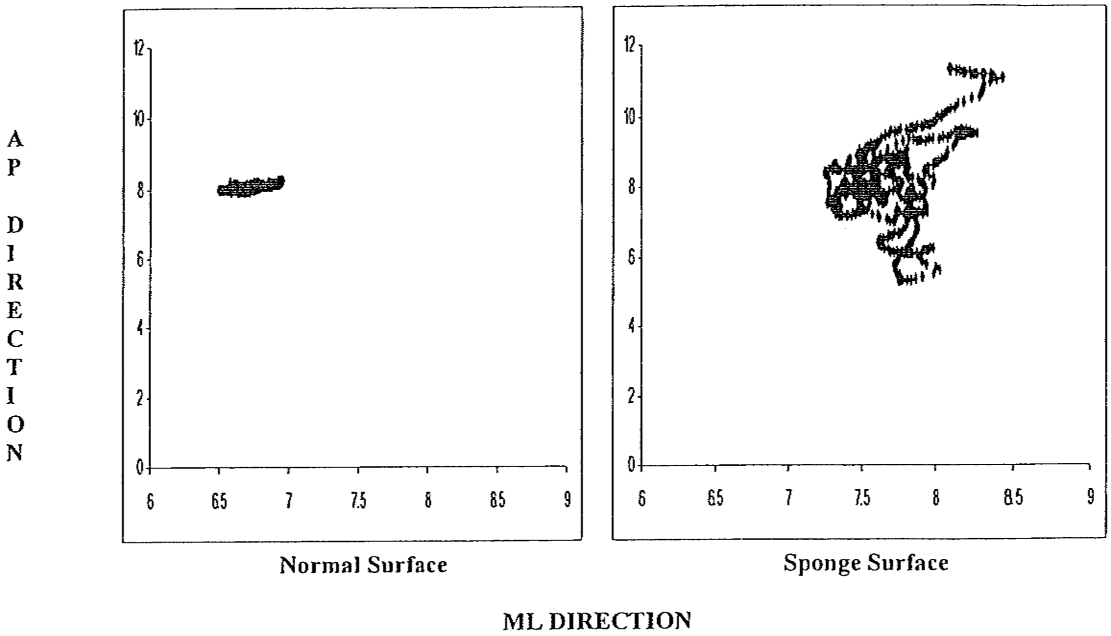


Normal Surface Eyes Open

Sponge Surface Eyes Open

The figure shows comparison of FSA recording for eyes open task on the normal and sponge surface. The black point represents Centre of foot Pressure.

Figure 2: Effect of Surface on COP Excursion for Eyes Closed Condition

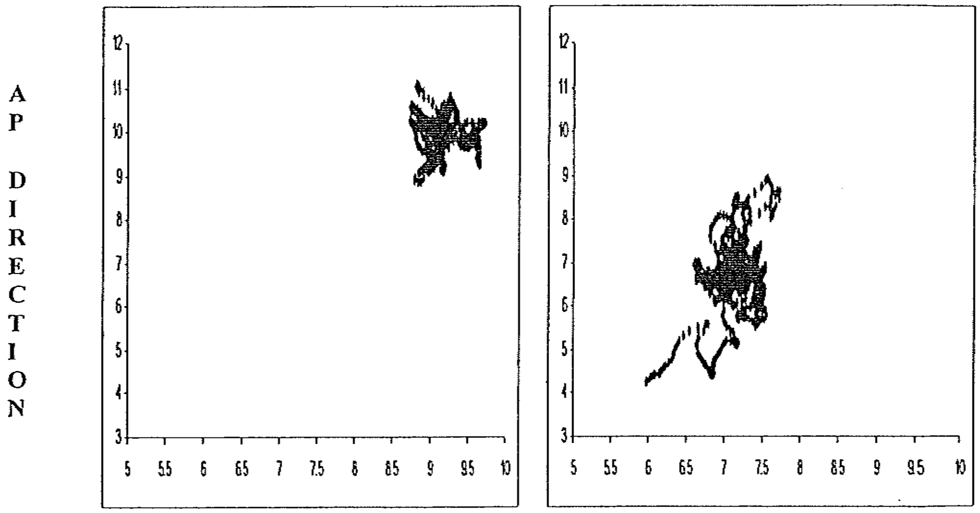


Normal Surface

Sponge Surface

The graphs show raw COP signals for 20 seconds for eyes closed condition on the normal and sponge surface. The X axis represents COP movement in ML direction and Y axis represents COP movement in AP direction. The COP excursions were higher on the sponge surface than on the normal surface for both AP and ML directions.

Figure 3: Effect of Surface on COP Excursion for Trunk Flexion Condition

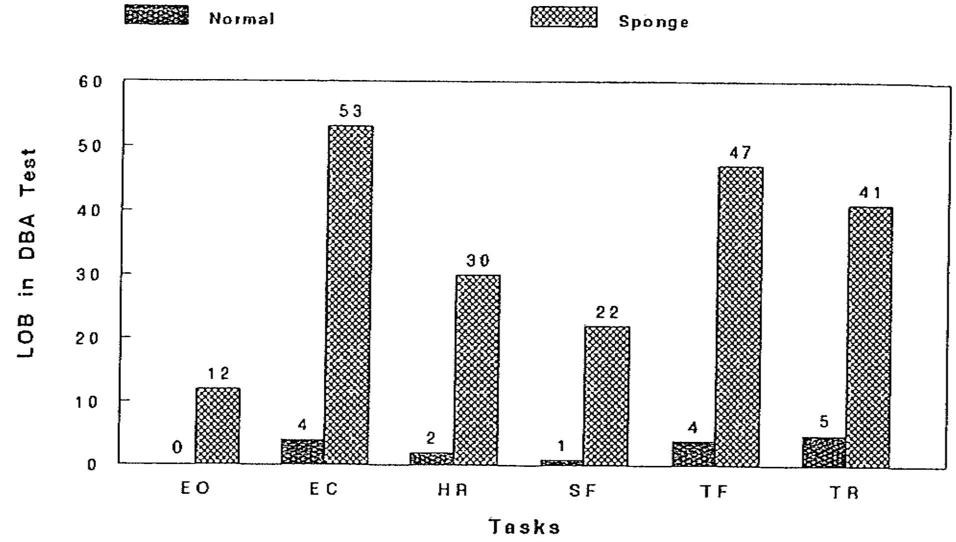


Normal Surface

Sponge Surface

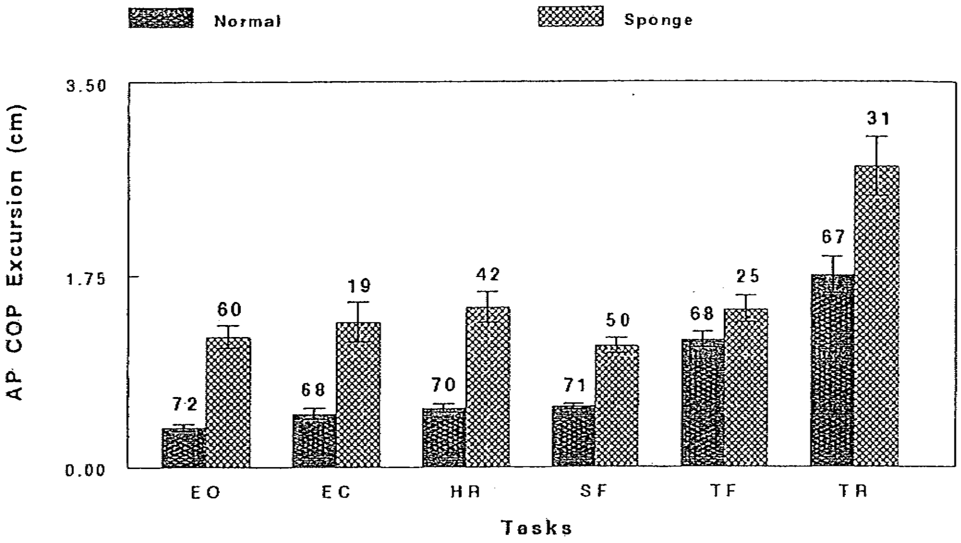
The graphs show raw COP signals for 20 seconds for trunk flexion condition on the normal and sponge surface. The X axis represents COP movement in ML direction and Y axis represents COP movement in AP direction. The COP excursions were higher on the sponge surface than on the normal surface for both AP and ML directions.

Figure 4: LOB in the DBA Test



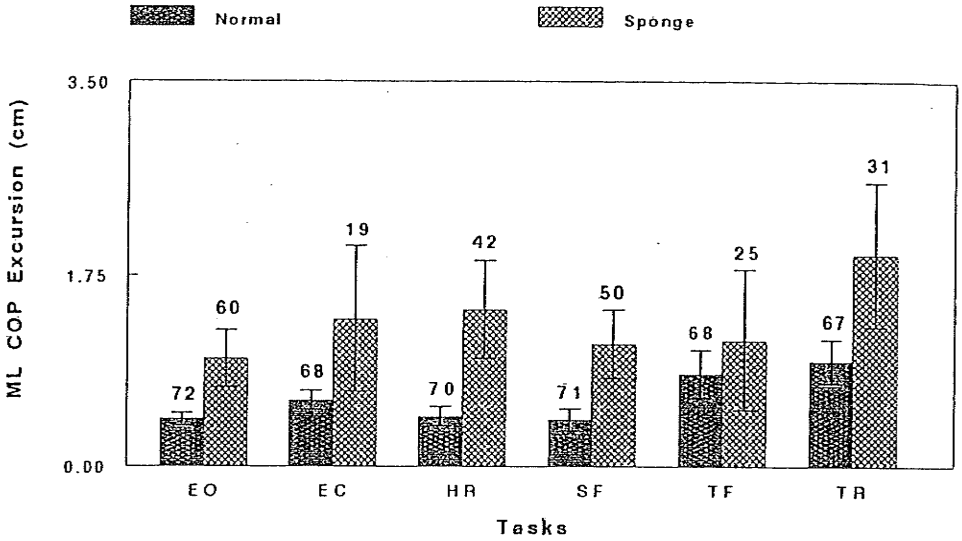
EO: Eyes Open, EC: Eyes Close, HR: Head Rotation, SF: Shoulder Flexion, TF: Trunk Flexion, TR: Trunk Rotation. The number on the top of the bar indicates number of LOB in a particular test.

Figure 5: Effect of surface and task on AP COP Excursion



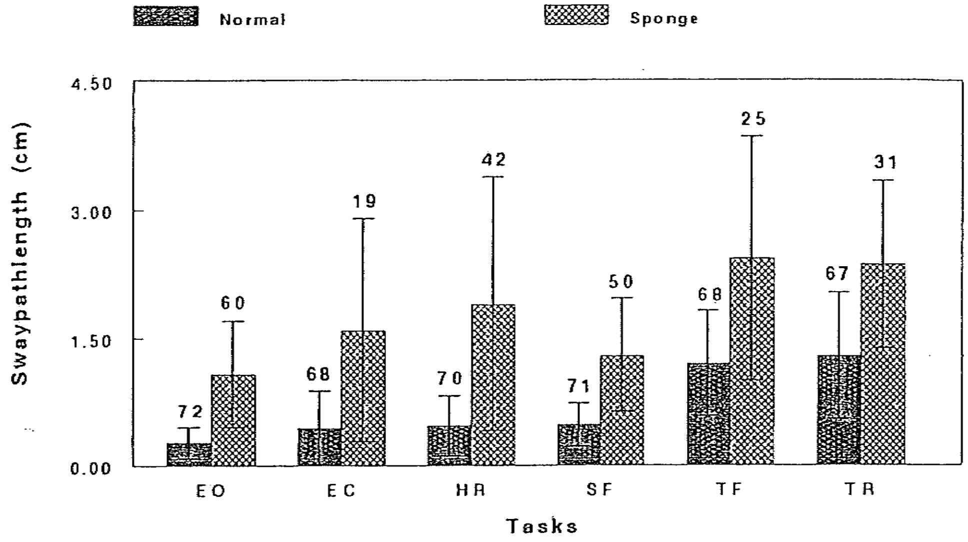
Effect of surface (normal/sponge) and task (EO: Eyes Open, EC: Eyes Close, HR: Head Rotation, SF: Shoulder Flexion, TF: Trunk Flexion, TR: Trunk Rotation) on AP COP excursion. Mean Scores and associated standard error of means are shown for continuous data. The numbers on the top of the bars indicate the number of participants who completed the task.

Figure 6: Effect of surface and task on ML COP Excursion



Effect of surface (normal/sponge) and task (EO: Eyes Open, EC: Eyes Close, HR: Head Rotation, SF: Shoulder Flexion, TF: Trunk Flexion, TR: Trunk Rotation) on ML COP Excursion. Mean Scores and associated standard error of means are shown for continuous data. The numbers on the top of the bars indicate the number of participants who completed the task.

Figure 7: Effect of surface and task on COP Swaypathlength



Effect of surface (normal/sponge) and task (EO: Eyes Open, EC: Eyes Close, HR: Head Rotation, SF: Shoulder Flexion, TF: Trunk Flexion, TR: Trunk Rotation) on Swaypathlength. Mean Scores and associated standard error of means are shown for continuous data. The numbers on the top of the bars indicate the number of participants who completed the task.

Participants were classified as fallers or non-fallers based on their history of falling. The criterion for inclusion in the faller category was a self-report of one or more falls within the year prior to the study. A fall was defined as any event that led to an unplanned, unexpected loss of balance and contact with a supporting surface. Twenty-five older adults were classified as non-fallers and 47 were classified as fallers. Table 5 summarizes sex, use of assistive device, amount of home care (assistance), number of medication and ability to walk half a mile for fallers and non-fallers. No statistical difference was found between non-faller and faller subgroups for any of the variables in Table 5. Clinical performance-based test scores and the DBA test scores for non-faller and faller subgroups are presented in Table 6. No significant difference was found between non-fallers and fallers for all clinical tests except the TUG. However, there was a greater trend toward decreased scores on the BBS, GV and SMWT for the faller subgroup than among the non-fallers. The results of the statistical analysis revealed that composite scores for COP excursions and swaypathlength, compliant surface score for COP excursions and swaypathlength, LOB frequency and normal surface score for ML COP excursion were able to distinguish non-fallers from faller subgroups. No significant difference was noted for COP parameters for normal surface eyes open and closed tasks (Table 7).

Spearman correlation analysis (Table 8) revealed moderate to high (0.58 – 0.83) correlations among clinical performance-based test scores (BBS, SMWT, TUG, GV). High to moderate (0.79 – 0.92) correlations were also found among composite scores based on the COP position and LOB. Low correlations (0.25 – 0.31) were found between clinical tests and composite scores based on the COP position and LOB.

Table 5: Demographic Data

	Non – fallers (n = 25) Mean (SD) Or Median (IQR)*	**Fallers (n = 47) Mean (SD) Or Median (IQR)***
Age (years)	79.4 (5.48)	81.5 (6.87)
Sex	Male = 8 Female = 17	Male = 23 Female = 24
Assistive Device		
• None	28 %	26 %
• Cane/Walker	72 %	74 %
Prescribed Medication* (number)	8 (3.5)	8 (4)
Home Care/Assistance* (days)	2 (6.5)	2 (7)
Walk half a mile (regularly)		
• Yes	28%	40 %
• No	72%	60 %

Median (IQR)*: Inter quartile range

Table 6: Independent t test and Mann – Whitney U test for Faller and Non - faller subgroups for Clinical and Experimental Variables (DBA test)

Past History of Falls	Non-fallers Mean (SD) Or Median (IQR)*	Fallers Mean (SD) Or Median (IQR)*	p Value (2 – tailed)
Gait Velocity (meter/second)	0.75 (0.26)	0.72 (0.27)	0.73
Six Minute Walk Test (meters)	220.36 (90.26)	215.97 (81.11)	0.85
Timed Up & Go Test* (seconds)	**13 (7.50)**	**17 (10)**	**0.03**
Berg Balance Scale*	47 (12)	44 (8.5)	0.28
AP COP (Normal surface)	22.40 (4.65)	20.81 (4.93)	0.19
ML COP (Normal surface)	**24.12 (4.29)**	**21.38 (4.81)**	**0.02**
Swaypathlength (Normal surface)	23.72 (3.85)	21.53 (5.42)	0.08
AP COP (Sponge surface)	**11.44 (6.21)**	**6.75 (4.95)**	**0.001**
ML COP (Sponge surface)	**9.12 (5.6)**	**5.8 (4.58)**	**0.009**
Swaypathlength (Sponge surface)	**9.96 (5.60)**	**6.70 (5.13)**	**0.01**
AP COP (Composite)	**33.84 (9.77)**	**27.55 (8.78)**	**0.007**
ML COP (Composite)	**33.24 (9.28)**	**27.21 (8.19)**	**0.006**
Swaypathlength (Composite)	**33.68 (8.95)**	**28.23 (9.47)**	**0.02**
LOB in DBA test (number)	**2.36 (1.84)**	**3.45 (2.09)**	**0.04**

Median (IQR)*: Inter quartile range

Table 7: Mann – Whitney U test for Normal Surface Quiet Standing Tasks

Past History of Falls	Non-fallers Median (IQR)	Fallers Median (IQR)	p Value (2 – tailed)
NEO COP AP Excursion	0.36 (0.26)	0.23 (0.42)	0.41
NEO COP ML Excursion	0.39 (0.30)	0.39 (0.38)	0.89
NEO Swaypathlength	0.22 (0.14)	0.20 (0.19)	0.77
NEC COP AP Excursion	1.06 (0.77)	1.17 (0.86)	0.44
NEC COP ML Excursion	1.42 (1.35)	1.65 (1.23)	0.19
NEC Swaypathlength	1.06 (0.67)	1.24 (0.75)	0.40

NEO: Normal surface eyes open
NEC: Normal surface eyes closed

Table 8: Spearman's correlation between Experimental Variables (DBA test) and Clinical Balance Assessment Tests

Variables	GV	SMWT	TUG	BBS	CAPE	CMLE	CSPL	LOB
GV	1.00	0.83**	-0.69**	0.58**	0.28*	0.14	0.14	0.19
SMWT		1.00	-0.72**	0.59**	0.28*	0.05	0.13	-0.15
TUG			1.00	-0.62**	-0.37**	-0.20	-0.26*	0.25*
BBS				1.00	0.42**	0.28*	0.31**	-0.29*
CAPE					1.00	0.79**	0.85**	-0.85**
CMLE						1.00	0.88**	-0.89**
CSPL							1.00	-0.92**
LOB								1.00

**Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

GV = Gait Velocity, SMWT = Six Minute Walk Test, TUG = Timed up & Go Test, BBS = Berg Balance Scale, CAPE = composite AP COP excursion, CMLE = Composite ML COP Excursion CSPL = Composite Swaypathlength, LOB: Loss of Balance in DBA test

DISCUSSION

The primary aim of this study was to evaluate whether composite COP scores obtained from a set of selected tasks performed on both a fixed and compliant support surface could differentiate between fallers and non – fallers in a sample of community-dwelling older adults. The secondary aim was to determine the strength of association between the composite COP performance test scores and performance-based clinical outcome measures of balance and walking functions.

The main findings of this study revealed that the composite scores derived from COP position data could discriminate between fallers and non-fallers, whereas amongst the performance-based clinical tests, only the TUG was able to differentiate fallers from non-fallers. The results also show a poor association between the composite COP scores and performance-based clinical test scores.

A number of studies have used performance-based clinical assessments to examine fall risk in community-dwelling older adults. Some studies reported that clinical test such as the BBS and Functional Reach did not differentiate fallers from non-fallers (Brauer et al., 2000; Boulgarides et al., 2003) while other studies observed that tests scores in such as the BBS (Chiu, Au-Yeung, & Lo, 2003; Shumway-Cook et al., 1997) and GV (Maki, 1997) did distinguish fallers from non-fallers. The fallers in this study showed lower BBS scores (mean = 42.46 ± 1.01, median = 43) than non-fallers (mean = 43.8 ± 1.45, median = 47). However, this was considerably different from those mentioned by Brauer et al. (2000) for fallers with an average of 53.4 ± 0.9 and for non-fallers with an average of 53.9 ± 0.6. Boulgarides et al. (2003) reported a mean score of 53.18 (range 46 – 56) for fallers and 53.15 for non – fallers (range 34 – 56). One of the limitations of the BBS test is that it assesses only static balance control (standing, sitting unsupported) and dynamic balance control (standing on one leg, turning 360°, stepping on stool). However, it is very limited in evaluating reactive balance control as all tasks are performed on solid surfaces. BBS scores offers only limited guidance for clinical intervention. With a score above 45, one can say that a person has a low risk of fall, however the cause for a low score (i.e. motor problems, sensory problems, environmental effects) cannot be identified; furthermore, a score below 45 does not inform where the deficiency lies. Therefore, the BBS is not very useful in designing a client-tailored exercise program.

No significant differences were noted between the groups for GV and the SMWT. The faller subgroup in the present study showed an average GV of 0.72 ± 0.27 m/s. This was similar to that reported by Maki (1997) for fearful fallers (0.66 ± 0.19 m/s), but higher than that reported by VanSwearingen, Paschal, Bonino, & Chen (1998) for frail community-dwelling older adults with history of two or more falls in the previous year (0.50 ± 0.24 m/s). The fallers in this study showed average walking distances of 215 ± 81 meters for the SMWT, which was considerably lower than the walking distance reported by Cho et al. (2004) for community-dwelling older adults with balance impairments (333 ± 110 meters). Gait velocity and SMWT are simple timed tasks that look at only one aspect of self-paced walking function on a predictable solid indoor surface. There is also a need to evaluate other aspects of gait requirements such as stability and adaptability over different support surfaces and environmental conditions, which could lead to stumbles.

The participants included in this study were relatively frail and their performance on clinical tests was comparatively lower than those mentioned by Boulgarides et al. (2003) and Brauer et al. (2000). The possible differences might be explained by the following factors. The participants in this study were relatively older (non – fallers 79.4 ± 5.4, fallers 81.5 ± 5.87) than those in Boulgarides et al. (2003) (74.02 ± 5.64) and Brauer et al. (2000) (non – fallers 72.03 ± 0.6, fallers 74.1 ± 1.1). In addition, the participants in this study were taking greater number of prescribed medications than those in above-mentioned studies. The participants of Boulgarides et al. (2003) were recruited from retirement communities, seniors' centres, 50-Plus Wellness program and general community, whereas Brauer et al. (2000) recruited community-dwelling volunteers. In contrast, the participants included in this study were visiting the Day Hospital specifically for balance and mobility impairments.

There were no differences noted in demographic variables between faller and non - faller groups in this study. Many combinations of demographic and health covariates have been examined to predict fall risk. Although, general trends have been established with factors such as age, walking distance, number of medications and social support, their predictive capacity are relatively low and these variables provide little information about the reasons for the falls or balance difficulties and limitations in mobility (Hoeymans, Feskens, Kromhout, & van den Bos, 1997; Boulgarides et al., 2003; Brauer et al., 2000, Thomas et al., 2005). An attempt was also made to combine performance-based clinical tests and demographic information to predict the fall risk in community-dwelling older adults (Boulgarides et al., 2003; Brauer et al., 2000). Boulgarides et al. (2003) combined five balance tests (BBS, TUG, Dynamic Gait Index, mCTSIB, 100% Limits of Balance Tests) with health and demographic factors to predict falls in active and independent community-dwelling older adults. Brauer et al. (2000) used four balance tests (BBS, Functional Reach test, Step up Test and Lateral Reach test) to predict falls in relatively active community-dwelling older people. Both studies concluded that performance-based clinical tests were not able to predict falls in community- dwelling older adults. The participants included in these two studies were physically active. This indicates that these tests are not suitable for higher- functioning older adults due to the potential ceiling effect in this population. The participants included in this study were relatively frail and their performance on clinical tests was comparatively lower than those mentioned by Boulgarides et al. (2003) and Brauer et al. (2000). In contrast to clinical balance assessment tests, all COP measurements on the sponge surface and the composite score of the DBA test as well as LOB in the DBA test were able to differentiate fallers and non – fallers. This indicates that borderline differences in balance deficit may exist in frail community older adults and clinical balance assessment tests fails to identify the same.

Previous studies have found that the TUG can discriminate between fallers and non-fallers (Chiu et al., 2003; Shumway-Cook et al., 2000). Shumway-Cook et al. (2000) reported a cutoff score of 13 seconds to differentiate independently living community-dwelling seniors who had either no falls or more than two falls in the previous six months, whereas Chiu et al. (2003) reported a cut off score of 20 seconds to separate one-time fallers from non-fallers. The difference between these two studies might by explained by the age difference between the groups, the participants in the Shumway-Cook et al. (2000) study were older than those in Chiu et al. (2003). In this study, the

TUG was able to differentiate between fallers (median = 17 seconds) and non-fallers (median = 13 seconds). Further analysis of data revealed that ten participants (3 non-fallers and 7 fallers) took at least 30 seconds to complete the TUG; 9 of the 10 were using gait aids. The current study could not establish the relationship between use of walking aid and falls, however, the use of walking aids could have affected TUG scores.
In contrast to this study finding, Thomas et al. (2005) found no significant differences between fallers and non-fallers in the TUG test scores in frail older adults.

The fallers in this study had higher (low composite score) COP excursions and swaypathlength than the non – fallers. Increased COP velocity, swaypathlength and amplitude have been interpreted as decreased stability or reduced dynamic balance (Melzer et al., 2004; Amiridis et al., 2003; Brooke-Wavell et al., 2002; Lord et al., 1991; Lord et al., 1994; Lord & Ward, 1994; Nakamura et al., 2001). On a normal fixed surface, only ML COP excursions were able to differentiate between fallers and non – fallers. The fallers showed higher ML COP excursions than non-fallers. Several studies have shown that older adults with increased medio-lateral sway have a high risk of falling (Melzer et al., 2004; Laufer, Barak, & Chemel, 2006; Maki, Holliday, & Topper, 1994). In a prospective study of fall risk assessment in one hundred community-dwelling older adults, Maki et al. (1994) found more medio-lateral sway in fallers than in non-fallers and suggested that control of ML sway is an important area for fall-prevention in this population.

The DBA test incorporates dynamic functional tasks, since quiet standing alone provides limited evidence of balance instability. This study showed that quiet standing with eyes open or closed on normal surface did not result in significant increases in LOB or magnitude of COP displacements (See Table 7). The findings are in agreement with other studies (Panzer et al., 1995; Laughton et al., 2003; Boulgarides et al., 2003).

The participants had difficulty in maintaining standing balance when two sources of external spatial information were either eliminated or distorted. Seventy-three percent of the participants experienced LOB on the compliant surface eyes closed condition, compared to only 16% on the compliant surface eyes open condition. In addition, when vision was eliminated and cutaneous information was distorted on the compliant surface, there was a substantial increase in body sway parameters (both peak excursion and pathlength) for participants who were able to complete the tasks without losing balance. The findings of this study demonstrate that elimination or distortion of one sensory input such as surface or vision independently, is not sufficient to bring out differences in balance performance. Other studies have also found that exclusion or disruption of only one sensory input only is not sufficient to elicit balance reactions in normal participants (Fransson, Gomez, Patel, & Johansson, 2007) and older adults (Redfern et al., 1997; Brooke-Wavell et al., 2002). However, significant increases in body sway and LOB were evident when two sources of external spatial information (vision and support surface) were either eliminated or distorted. A number of studies have examined the maintenance of standing balance in different sensory conditions and shown that when there is an elimination or distortion of two sensory input such as using a sponge surface and eyes closed condition (Teasdale et al., 1991a; Cohen et al., 1993) or conditions 5 and 6 on the SOT (Whipple et al., 1993; Simmons et al., 1997; Wallmann, 2001), there is a significant decrease in balance performance and substantial increase in LOB.

Ability to detect and correct for balance disturbances, while performing activities such as turning the head or bending and lifting, is essential for independent living. The DBA test incorporates both simple standing tasks (eyes open, eyes closed) and graded movement tasks (head rotation, arm raising, trunk rotation, trunk bending). It also incorporates different sensory components including large gaze movement for the head rotation condition, elimination of vision in the eyes closed condition and distortion of cutaneous information by using a compliant surface. Thus, the task protocol in the DBA test assesses both feedforward and feedback aspects of balance control. This test has similarities to the SOT, which uses visual and support surface sway-referenced conditions to assess the effect of sensory conflicts or elimination of vision on standing balance control. Performance on the SOT has been demonstrated to deteriorate with increasing age which is reflected by an increase in body sway and loss of balance in response to sensory disturbances (Cohen et al., 1996; Whipple et al., 1993). Performance on the SOT has been demonstrated to distinguish between fallers and non-fallers in community-dwelling older adults (Melzer et al., 2004; Wallmann, 2001). Similar to the SOT, the participants in this study also showed increased loss of balance and a decrease in the composite balance index for COP excursions and swaypathlength when somatosensory inputs were altered and/or vision was eliminated. In addition, three tasks used in the DBA test included cyclic movements of the arms and trunk. These body movements produce rhythmical horizontal trunk rotation, forward and backward arms lifting and trunk bending. These movements are similar to the laboratory studies which employed predictive sinusoidal platform motion paradigms to assess the feed forward mechanism of balance control (Dietz et al., 1993; Corna et al., 1999). These studies demonstrated that after one or two cycles the participant could predict the forward/backward movements of the platform and prepare the necessary balance adjustments in advance of the platform turning points. A similar mechanism is required to ensure stability while performing voluntary movements on the normal surface. However, this predictive process of preparatory balance adjustments is more difficult when performing the task on a compliant surface. Planning errors can occur on the compliant surface which can cause a sudden loss of balance. Quick detection of disturbances and corrections are therefore required to maintain the balance. This multidimensional approach is very important when assessing functional ability during basic and instrumental activities of daily living both indoors and outdoors.

The correlation analysis revealed weak associations (Spearman $r < 0.5$) between the DBA test scores (Composite score and LOB) and performance-based clinical tests (SMWT, TUG, GV and BBS). This is consistent with the findings of Hughes, Duncan, Rose, Chandler, & Studenski (1996) where no significant correlation was noted between body sway (computed from COP pathlength, excursions and ellipse during quiet stance on a fixed surface with eyes open and closed tasks) and functional measures of balance (Functional Reach, SMWT, 10 Meter Walk and Chair Raise, Falls Efficacy Scale). The present findings demonstrate that there is a large effect of surface properties and task dynamics on body sway parameters and LOB. Moderate to strong associations (Spearman $r \geq 0.5$) were noted between performance-based clinical tests. This was expected since all performance-based clinical tests measure the same predictive aspects of balance and mobility function. The findings in the current study reinforce that measurement of body sway and performance-based clinical tests evaluate different components of balance control.

The main limitation of this study is that fall history relied on participant recall. We attempted to control for recall bias by having another family member present for confirmation. Also, the clinical information (medical, balance, mobility and cognitive status) collected at the time of study may have been different than that at the time of fall. The fallers in this group reported being more physically active (walking ½ mile) than the non-fallers. However, we are not sure if the perception of half mile is consistently correct among the all participants. Further, we did not collect information about participants' perception on their balance. Test such as the ABC would have established the participants' perceived level of balance confidence. The scoring system used for the DBA test is novel, however it is very similar to the scoring system of the SOT which computes a weighted score of the peak to peak COP excursion in the AP direction to index balance performance (Rosengren et al., 2007). The composite score of the DBA test uses COP position data for both AP and ML directions and pathlength to index balance performance. The DBA test examines participants' ability to maintain balance while performing graded motor tasks with alteration of sensory inputs. Measures of body sway for the tasks in which participants maintain their balance provide further insight into performance abilities of individuals compared to simply recording the frequency of LOB.

Reduced mobility and falls are common and potentially preventable sources of disability, mortality and morbidity in older adults. Dynamic balance control is required to perform both basic and instrumental activities of daily living. Mobility skills are necessary for outdoor walking and functional independence. Therefore, it is very important to provide effective and simple ways to document changes in balance and mobility skills amongst older individuals. The findings of this study demonstrate that most performance-based clinical assessment tests fail to detect subtle changes in balance control in community-dwelling older adults who were partially dependent on others to perform their activities of daily living. The findings of this study provide evidence that the DBA test can identify community-dwelling older adults who are at risk of falls. In addition, early detection of balance impairment over compliant surfaces is likely to reduce the future probability of falls in this population, if it is combined with appropriate interventions. Further research is needed to investigate the ability of DBA test to predict future falls.

CLINICAL SIGNIFICANCE

The DBA test was designed to assess dynamic balance control while performing standing activities in community-dwelling older adults. The use of a normal and compliant sponge surface has been part of other assessment systems notably the CTSIB. The DBA test also incorporates important features of the SOT and moving platform paradigms. The test is designed to evaluate both feedforward and feedback mechanisms of the balance control. The tasks included in the DBA test are of increasing difficulty and assess both motor and sensory aspects of balance control. The DBA test uses similar method of analysis as the SOT i.e. COP measurement to quantify balance control. However, tests like the SOT and the LOS require expensive set-up and are not portable, thus they are unavailable to clinicians who need screening tools for objective outcome measures in daily practice. The CTSIB is economic and easy to use but it only records time in seconds to quantify balance control in simple standing tasks. The DBA test extends the idea of the SOT and CTSIB. The DBA test is portable and less expensive (approximately CAD $ 10,000). Balance performance in the DBA test is quantified by COP signal which is a valid objective outcome measure. The use of a foam surface has been proven to be an effective way to make balance control more difficult, as the foam induced sway in both the anteroposterior and mediolateral directions. Since majority of the clinical balance assessment tests are timed tests and do not look at the quality and compensatory mechanisms used, they do not assess the effect of unpredictable environmental conditions and compensatory balance corrections. The ability to quantify changes in balance control with a relatively high degree of precision during standing activities is a critical part of evidence-based practice in rehabilitation and provides the basis and direction for treatment. Screening tools that can detect early physical decrements would allow earlier implementation of preventive measures. This study was the first step towards the development of the DBA test for assessment of balance control during standing activities in community-dwelling older adults. The FSA mat and modified DBA test protocol were used to assess short-duration sitting balance control in spinal cord and brain injured patients (Manuscript in Publication: Szturm, Desai, Betker, Kapadia, Nett, 2007). The tasks of the DBA test could be further developed to assess functional activities which require a moving BOS such as walking and stepping.

LIMITATIONS AND FUTURE IMPLICATIONS

1. A sample of convenience consisting of 72 older adults, who were specifically attending the geriatric day hospital for treatment of balance and mobility restrictions, was recruited in this study. Inclusion of a sample from a different seniors environments such Day Hospitals, Personal Care Homes and Senior's Residential Apartments would be required to extend the result to the wider population of older adults with different activities levels and health status.
2. Location of fall was not recorded or determined. The numbers of participants reported walking ½ mile regularly were higher in the fallers than non-fallers subgroup. By recording the location of falls, one could determine the relationship between outdoor/indoor falls vs. activity level. It is possible that individuals, who view their health more positively and are physically active, are more likely to fall outdoors.

3. Home Care/Assistance measurement in this study simply described number of days per week. Recording the type of assistance (bathing, laundry, housekeeping) and duration (in hours) would have provided further insight on functional capabilities of the participants.
4. An automated program to quantify the DBA test scores is required for ease of application in clinical environment.
5. Test – retest reliability of the DBA test needs to be established.
6. A prospective study is required to determine the sensitivity and specificity of the DBA and CTSIB test to predict the fall risk in fit (independent) and frail (partially dependent) community-dwelling older adults.
7. Further studies should include the ABC or the FES tests to measure the perceived balance control in this population.
8. Even though 2/3 of the study population could not complete the complex sponge tasks (trunk rotation, trunk flexion, eyes closed), these tasks still need to be included in the test as all of these tasks assess different aspects of balance control. For example, trunk flexion and rotation are motor tasks that assess AP and ML balance control respectively, while the eyes closed task assesses balance when vision is eliminated and cutaneous sensations are distorted. Assessment of balance during these perturbations will help in early detection of balance deterioration in independently residing community-dwelling older adults with fewer co-morbidities which will assist in generalizing the applicability of the test to wider population.

REFERENCES

Allum, J. H. & Honegger, F. (1998). Interactions between vestibular and proprioceptive inputs triggering and modulating human balance-correcting responses differ across muscles. *Exp.Brain Res., 121,* 478-494.

Allum, J. H. & Shepard, N. T. (1999). An overview of the clinical use of dynamic posturography in the differential diagnosis of balance disorders. *J.Vestib.Res., 9,* 223-252.

Allum, J. H., Zamani, F., Adkin, A. L., & Ernst, A. (2002). Differences between trunk sway characteristics on a foam support surface and on the Equitest ankle-sway-referenced support surface. *Gait.Posture., 16,* 264-270.

Amiridis, I. G., Hatzitaki, V., & Arabatzi, F. (2003). Age-induced modifications of static postural control in humans. *Neurosci.Lett., 350,* 137-140.

Baratto, L., Morasso, P. G., Re, C., & Spada, G. (2002). A new look at posturographic analysis in the clinical context: sway-density versus other parameterization techniques. *Motor Control, 6,* 246-270.

Berg, K. & Norman, K. E. (1996). Functional assessment of balance and gait. *Clin.Geriatr.Med., 12,* 705-723.

Berg, K. O., Maki, B. E., Williams, J. I., Holliday, P. J., & Wood-Dauphinee, S. L. (1992a). Clinical and laboratory measures of postural balance in an elderly population. *Arch.Phys.Med.Rehabil., 73,* 1073-1080.

Berg, K. O., Wood-Dauphinee, S. L., Williams, J. I., & Maki, B. (1992b). Measuring balance in the elderly: validation of an instrument. *Can.J.Public Health, 83 Suppl 2,* S7-11.

Betker, A. L., Moussavi, Z. M., & Szturm, T. (2005). On modeling center of foot pressure distortion through a medium. *IEEE Trans.Biomed.Eng, 52,* 345-352.

Black, F. O., Shupert, C. L., Horak, F. B., & Nashner, L. M. (1988). Abnormal postural control associated with peripheral vestibular disorders. *Prog.Brain Res., 76,* 263-275.

Bogle Thorbahn, L. D. & Newton, R. A. (1996). Use of the Berg Balance Test to predict falls in elderly persons. *Phys.Ther., 76,* 576-583.

Bohannon, R. W. (1997). Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants. *Age Ageing, 26,* 15-19.

Boulgarides, L. K., McGinty, S. M., Willett, J. A., & Barnes, C. W. (2003). Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Phys.Ther., 83,* 328-339.

Brauer, S. G., Burns, Y. R., & Galley, P. (2000). A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. *J.Gerontol.A Biol.Sci.Med.Sci., 55,* M469-M476.

Brooke-Wavell, K., Perrett, L. K., Howarth, P. A., & Haslam, R. A. (2002). Influence of the visual environment on the postural stability in healthy older women. *Gerontology, 48,* 293-297.

Buchner, D. M., Larson, E. B., Wagner, E. H., Koepsell, T. D., & de Lateur, B. J. (1996). Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing, 25,* 386-391.

Butland, R. J., Pang, J., Gross, E. R., Woodcock, A. A., & Geddes, D. M. (1982). Two-, six-, and 12-minute walking tests in respiratory disease. *Br.Med.J.(Clin.Res.Ed), 284,* 1607-1608.

Cahalin, L., Pappagianopoulos, P., Prevost, S., Wain, J., & Ginns, L. (1995). The relationship of the 6-min walk test to maximal oxygen consumption in transplant candidates with end-stage lung disease. *Chest, 108,* 452-459.

Cahalin, L. P., Mathier, M. A., Semigran, M. J., Dec, G. W., & DiSalvo, T. G. (1996). The six-minute walk test predicts peak oxygen uptake and survival in patients with advanced heart failure. *Chest, 110,* 325-332.

Campbell, A. J., Borrie, M. J., & Spears, G. F. (1989). Risk factors for falls in a community-based prospective study of people 70 years and older. *J.Gerontol., 44,* M112-M117.

Carpenter, M. G., Allum, J. H., & Honegger, F. (1999). Directional sensitivity of stretch reflexes and balance corrections for normal subjects in the roll and pitch planes. *Exp.Brain Res., 129,* 93-113.

Chiu, A. Y., Au-Yeung, S. S., & Lo, S. K. (2003). A comparison of four functional tests in discriminating fallers from non-fallers in older people. *Disabil.Rehabil., 25,* 45-50.

Cho, B. L., Scarpace, D., & Alexander, N. B. (2004). Tests of stepping as indicators of mobility, balance, and fall risk in balance-impaired older adults. *J.Am.Geriatr.Soc., 52,* 1168-1173.

Cipriany-Dacko, L. M., Innerst, D., Johannsen, J., & Rude, V. (1997). Interrater reliability of the Tinetti Balance Scores in novice and experienced physical therapy clinicians. *Arch.Phys.Med.Rehabil., 78,* 1160-1164.

Cohen, H., Blatchly, C. A., & Gombash, L. L. (1993). A study of the clinical test of sensory interaction and balance. *Phys.Ther., 73,* 346-351.

Cohen, H., Heaton, L. G., Congdon, S. L., & Jenkins, H. A. (1996). Changes in sensory organization test scores with age. *Age Ageing, 25,* 39-44.

Corna, S., Tarantola, J., Nardone, A., Giordano, A., & Schieppati, M. (1999). Standing on a continuously moving platform: is body inertia counteracted or exploited? *Exp.Brain Res., 124,* 331-341.

Creath, R., Kiemel, T., Horak, F., & Jeka, J. J. (2002). Limited control strategies with the loss of vestibular function. *Exp.Brain Res., 145,* 323-333.

Creath, R., Kiemel, T., Horak, F., Peterka, R., & Jeka, J. (2005). A unified view of quiet and perturbed stance: simultaneous co-existing excitable modes. *Neurosci.Lett., 377,* 75-80.

Di Nardo, W., Ghirlanda, G., Cercone, S., Pitocco, D., Soponara, C., Cosenza, A. et al. (1999). The use of dynamic posturography to detect neurosensorial disorder in IDDM without clinical neuropathy. *J.Diabetes Complications, 13,* 79-85.

Dietz, V., Trippel, M., Ibrahim, I. K., & Berger, W. (1993). Human stance on a sinusoidally translating platform: balance control by feedforward and feedback mechanisms. *Exp.Brain Res., 93,* 352-362.

Duncan, P. W., Chandler, J., Studenski, S., Hughes, M., & Prescott, B. (1993). How do physiological components of balance affect mobility in elderly men? *Arch.Phys.Med.Rehabil., 74,* 1343-1349.

Duncan, P. W., Studenski, S., Chandler, J., & Prescott, B. (1992). Functional reach: predictive validity in a sample of elderly male veterans. *J.Gerontol., 47,* M93-M98.

Duncan, P. W., Weiner, D. K., Chandler, J., & Studenski, S. (1990). Functional reach: a new clinical measure of balance. *J.Gerontol., 45,* M192-M197.

El Kashlan, H. K., Shepard, N. T., Asher, A. M., Smith-Wheelock, M., & Telian, S. A. (1998). Evaluation of clinical measures of equilibrium. *Laryngoscope, 108,* 311-319.

Fitzpatrick, R. & McCloskey, D. I. (1994). Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. *J.Physiol, 478 (Pt 1),* 173-186.

Fransson, P. A., Gomez, S., Patel, M., & Johansson, L. (2007). Changes in multi-segmented body movements and EMG activity while standing on firm and foam support surfaces. *Eur.J.Appl.Physiol.*

Fujisawa, N., Masuda, T., Inaoka, Y., Fukuoka, H., Ishida, A., & Minamitani, H. (2005). Human standing posture control system depending on adopted strategies. *Med.Biol.Eng Comput., 43,* 107-114.

Galindo-Ciocon, D. J., Ciocon, J. O., & Galindo, D. J. (1995). Gait training and falls in the elderly. *J.Gerontol.Nurs., 21,* 10-17.

Gijsen, R., Hoeymans, N., Schellevis, F. G., Ruwaard, D., Satariano, W. A., & van den Bos, G. A. (2001). Causes and consequences of comorbidity: a review. *J.Clin.Epidemiol., 54,* 661-674.

Gill, J., Allum, J. H., Carpenter, M. G., Held-Ziolkowska, M., Adkin, A. L., Honegger, F. et al. (2001). Trunk sway measures of postural stability during clinical balance tests: effects of age. *J.Gerontol.A Biol.Sci.Med.Sci., 56,* M438-M447.

Goldie, P. A., Bach, T. M., & Evans, O. M. (1989). Force platform measures for evaluating postural control: reliability and validity. *Arch.Phys.Med.Rehabil., 70,* 510-517.

Grace, E. M., Gerecz, E. M., Kassam, Y. B., Buchanan, H. M., Buchanan, W. W., & Tugwell, P. S. (1988). 50-foot walking time: a critical assessment of an outcome measure in clinical therapeutic trials of antirheumatic drugs. *Br.J.Rheumatol., 27,* 372-374.

Grisso, J. A., Kelsey, J. L., Strom, B. L., Chiu, G. Y., Maislin, G., O'Brien, L. A. et al. (1991). Risk factors for falls as a cause of hip fracture in women. The Northeast Hip Fracture Study Group. *N.Engl.J.Med., 324,* 1326-1331.

Guccione, A. A., Felson, D. T., Anderson, J. J., Anthony, J. M., Zhang, Y., Wilson, P. W. et al. (1994). The effects of specific medical conditions on the functional limitations of elders in the Framingham Study. *Am.J.Public Health, 84,* 351-358.

Gunter, K. B., White, K. N., Hayes, W. C., & Snow, C. M. (2000). Functional mobility discriminates nonfallers from one-time and frequent fallers. *J.Gerontol.A Biol.Sci.Med.Sci., 55,* M672-M676.

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N.Engl.J.Med., 332,* 556-561.

Guyatt, G. H., Sullivan, M. J., Thompson, P. J., Fallen, E. L., Pugsley, S. O., Taylor, D. W. et al. (1985). The 6-minute walk: a new measure of exercise capacity in patients with chronic heart failure. *Can.Med.Assoc.J., 132,* 919-923.

Hageman, P. A. & Blanke, D. J. (1986). Comparison of gait of young women and elderly women. *Phys.Ther., 66,* 1382-1387.

Hakkinen, K., Kraemer, W. J., Kallinen, M., Linnamo, V., Pastinen, U. M., & Newton, R. U. (1996). Bilateral and unilateral neuromuscular function and muscle cross-sectional area in middle-aged and elderly men and women. *J.Gerontol.A Biol.Sci.Med.Sci., 51,* B21-B29.

Harada, N. D., Chiu, V., & Stewart, A. L. (1999). Mobility-related function in older adults: assessment with a 6-minute walk test. *Arch.Phys.Med.Rehabil., 80,* 837-841.

Hay, L., Bard, C., Fleury, M., & Teasdale, N. (1996). Availability of visual and proprioceptive afferent messages and postural control in elderly adults. *Exp.Brain Res., 108,* 129-139.

Hoeymans, N., Feskens, E. J., Kromhout, D., & van den Bos, G. A. (1997). Ageing and the relationship between functional status and self-rated health in elderly men. Soc.Sci.Med., 45, 1527-1536.

Horak, F. B. (1987). Clinical measurement of postural control in adults. *Phys.Ther., 67,* 1881-1885.

Horak, F. B. & Nashner, L. M. (1986). Central programming of postural movements: adaptation to altered support-surface configurations. *J.Neurophysiol., 55,* 1369-1381.

Horak, F. B., Nashner, L. M., & Diener, H. C. (1990). Postural strategies associated with somatosensory and vestibular loss. *Exp.Brain Res., 82,* 167-177.

Horak, F. B., Nutt, J. G., & Nashner, L. M. (1992). Postural inflexibility in parkinsonian subjects. *J.Neurol.Sci., 111,* 46-58.

Hotchkiss, A., Fisher, A., Robertson, R., Ruttencutter, A., Schuffert, J., & Barker, D. B. (2004). Convergent and predictive validity of three scales related to falls in the elderly. *Am.J.Occup.Ther., 58,* 100-103.

Hughes, M. A., Duncan, P. W., Rose, D. K., Chandler, J. M., & Studenski, S. A. (1996). The relationship of postural sway to sensorimotor function, functional performance, and disability in the elderly. *Arch.Phys.Med.Rehabil., 77,* 567-572.

Johansson, R. & Magnusson, M. (1991). Human postural dynamics. *Crit Rev.Biomed.Eng, 18,* 413-437.

Jonsson, E., Henriksson, M., & Hirschfeld, H. (2003). Does the functional reach test reflect stability limits in elderly people? *J.Rehabil.Med., 35,* 26-30.

Judge, J. O., Ounpuu, S., & Davis, R. B., III (1996). Effects of age on the biomechanics and physiology of gait. *Clin.Geriatr.Med., 12,* 659-678.

Kadikar, A., Maurer, J., & Kesten, S. (1997). The six-minute walk test: a guide to assessment for lung transplantation. *J.Heart Lung Transplant., 16,* 313-319.

Kamen, G., Patten, C., Du, C. D., & Sison, S. (1998). An accelerometry-based system for the assessment of balance and postural sway. *Gerontology, 44,* 40-45.

Kandel ER, Schwartz JH and Jessel. T. M. (2000). *Principles of neural science.* New York: McGraw-Hill.

Kennedy, D., Stratford, P. W., Pagura, S. M., Walsh, M., & Woodhouse, L. J. (2002). Comparison of gender and group differences in self-report and physical performance measures in total hip and knee arthroplasty candidates. *J.Arthroplasty, 17,* 70-77.

Kenshalo, D. R., Sr. (1986). Somesthetic sensitivity in young and elderly humans. *J.Gerontol., 41,* 732-742.

Kornetti, D. L., Fritz, S. L., Chiu, Y. P., Light, K. E., & Velozo, C. A. (2004). Rating scale analysis of the Berg Balance Scale. *Arch.Phys.Med.Rehabil., 85,* 1128-1135.

Koski, K., Luukinen, H., Laippala, P., & Kivela, S. L. (1998). Risk factors for major injurious falls among the home-dwelling elderly by functional abilities. A prospective population-based study. *Gerontology, 44,* 232-238.

Kressig, R. W., Gregor, R. J., Oliver, A., Waddell, D., Smith, W., O'Grady, M. et al. (2004). Temporal and spatial features of gait in older adults transitioning to frailty. *Gait.Posture., 20,* 30-35.

Kressig, R. W., Wolf, S. L., Sattin, R. W., O'Grady, M., Greenspan, A., Curns, A. et al. (2001). Associations of demographic, functional, and behavioral characteristics with activity-related fear of falling among older adults transitioning to frailty. *J.Am.Geriatr.Soc., 49,* 1456-1462.

Ladin, Z., Flowers, W. C., & Messner, W. (1989). A quantitative comparison of a position measurement system and accelerometry. *J.Biomech., 22,* 295-308.

Lamb, S. E., Guralnik, J. M., Buchner, D. M., Ferrucci, L. M., Hochberg, M. C., Simonsick, E. M. et al. (2000). Factors that modify the association between knee pain and mobility limitation in older women: the Women's Health and Aging Study. *Ann.Rheum.Dis., 59,* 331-337.

Laufer, Y., Barak, Y., & Chemel, I. (2006). Age-related differences in the effect of a perceived threat to stability on postural control. *J.Gerontol.A Biol.Sci.Med.Sci., 61,* 500-504.

Laughton, C. A., Slavin, M., Katdare, K., Nolan, L., Bean, J. F., Kerrigan, D. C. et al. (2003). Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait.Posture., 18,* 101-108.

Levangie P. K. and Norkin C.C. (2001). *Joint structure and function: a comprehensive analysis.* India: Jaypee Brothers.

Lord, S. R., Clark, R. D., & Webster, I. W. (1991). Postural stability and associated physiological factors in a population of aged persons. *J.Gerontol., 46,* M69-M76.

Lord, S. R., Lloyd, D. G., & Li, S. K. (1996). Sensori-motor function, gait patterns and falls in community-dwelling women. *Age Ageing, 25,* 292-299.

Lord, S. R. & Menz, H. B. (2002). Physiologic, psychologic, and health predictors of 6-minute walk performance in older people. *Arch.Phys.Med.Rehabil., 83,* 907-911.

Lord, S. R., Sambrook, P. N., Gilbert, C., Kelly, P. J., Nguyen, T., Webster, I. W. et al. (1994). Postural stability, falls and fractures in the elderly: results from the Dubbo Osteoporosis Epidemiology Study. *Med.J.Aust., 160,* 684-691.

Lord, S. R. & Ward, J. A. (1994). Age-associated differences in sensori-motor function and balance in community-dwelling women. *Age Ageing, 23,* 452-460.

Luchies, C. W., Alexander, N. B., Schultz, A. B., & Ashton-Miller, J. (1994). Stepping responses of young and old adults to postural disturbances: kinematics. *J.Am.Geriatr.Soc., 42,* 506-512.

Maki, B. E. (1997). Gait changes in older adults: predictors of falls or indicators of fear. *J.Am.Geriatr.Soc., 45,* 313-320.

Maki, B. E., Holliday, P. J., & Topper, A. K. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *J.Gerontol., 49,* M72-M84.

Maki, B. E. & McIlroy, W. E. (1996). Postural control in the older adult. *Clin.Geriatr.Med., 12,* 635-658.

Maki, B. E. & McIlroy, W. E. (1997). The role of limb movements in maintaining upright stance: the "change-in-support" strategy. *Phys.Ther., 77,* 488-507.

Marks, R. (1994). Reliability and validity of self-paced walking time measures for knee osteoarthritis. *Arthritis Care Res., 7,* 50-53.

Mathias, S., Nayak, U. S., & Isaacs, B. (1986). Balance in elderly patients: the "get-up and go" test. *Arch.Phys.Med.Rehabil., 67,* 387-389.

Means, K. M., Rodell, D. E., O'Sullivan, P. S., & Winger, R. M. (1998). Comparison of a functional obstacle course with an index of clinical gait and balance and postural sway. *J.Gerontol.A Biol.Sci.Med.Sci., 53,* M331-M335.

Mecagni, C., Smith, J. P., Roberts, K. E., & O'Sullivan, S. B. (2000). Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: a correlational study. *Phys.Ther., 80,* 1004-1011.

Melzer, I., Benjuya, N., & Kaplanski, J. (2004). Postural stability in the elderly: a comparison between fallers and non-fallers. *Age Ageing, 33,* 602-607.

Montgomery, P. S. & Gardner, A. W. (1998). The clinical utility of a six-minute walk test in peripheral arterial occlusive disease patients. *J.Am.Geriatr.Soc., 46,* 706-711.

Moore, E. G., Rosenberg, M. W., & Fitzgibbon, S. H. (1999). Activity limitation and chronic conditions in Canada's elderly, 1986-2011. *Disabil.Rehabil., 21,* 196-210.

Myers, A. H., Young, Y., & Langlois, J. A. (1996). Prevention of falls in the elderly. *Bone, 18,* 87S-101S.

Myers, A. M., Powell, L. E., Maki, B. E., Holliday, P. J., Brawley, L. R., & Sherk, W. (1996). Psychological indicators of balance confidence: relationship to actual and perceived abilities. *J.Gerontol.A Biol.Sci.Med.Sci., 51,* M37-M43.

Nakamura, H., Tsuchida, T., & Mano, Y. (2001). The assessment of posture control in the elderly using the displacement of the center of pressure after forward platform translation. *J.Electromyogr.Kinesiol.*, *11*, 395-403.

Nashner, L. M. (1971). A model describing vestibular detection of body sway motion. *Acta Otolaryngol.*, *72*, 429-436.

Nashner, L. M., Black, F. O., & Wall, C., III (1982). Adaptation to altered support and visual conditions during stance: patients with vestibular deficits. *J.Neurosci.*, *2*, 536-544.

Ostchega, Y., Harris, T. B., Hirsch, R., Parsons, V. L., Kington, R., & Katzoff, M. (2000). Reliability and prevalence of physical performance examination assessing mobility and balance in older persons in the US: data from the Third National Health and Nutrition Examination Survey. *J.Am.Geriatr.Soc.*, *48*, 1136-1141.

Ostrosky, K. M., VanSwearingen, J. M., Burdett, R. G., & Gee, Z. (1994). A comparison of gait characteristics in young and old subjects. *Phys.Ther.*, *74*, 637-644.

Paige, G. D. (1991). The aging vestibulo-ocular reflex (VOR) and adaptive plasticity. *Acta Otolaryngol.Suppl*, *481*, 297-300.

Panzer, V. P., Bandinelli, S., & Hallett, M. (1995). Biomechanical assessment of quiet standing and changes associated with aging. *Arch.Phys.Med.Rehabil.*, *76*, 151-157.

Pavol, M. J. & Pai, Y. C. (2002). Feedforward adaptations are used to compensate for a potential loss of balance. *Exp.Brain Res.*, *145*, 528-538.

Peterka, R. J. (2002). Sensorimotor integration in human postural control. *J.Neurophysiol., 88,* 1097-1118.

Piirtola, M. & Era, P. (2006). Force platform measurements as predictors of falls among older people - a review. *Gerontology, 52,* 1-16.

Podsiadlo, D. & Richardson, S. (1991). The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *J.Am.Geriatr.Soc., 39,* 142-148.

Potter, J. M., Evans, A. L., & Duncan, G. (1995). Gait speed and activities of daily living function in geriatric patients. *Arch.Phys.Med.Rehabil., 76,* 997-999.

Powell, L. E. & Myers, A. M. (1995). The Activities-specific Balance Confidence (ABC) Scale. *J.Gerontol.A Biol.Sci.Med.Sci., 50A,* M28-M34.

Redfern, M. S., Moore, P. L., & Yarsky, C. M. (1997). The influence of flooring on standing balance among older persons. *Hum.Factors, 39,* 445-455.

Reuben, D. B. & Siu, A. L. (1990). An objective measure of physical function of elderly outpatients. The Physical Performance Test. *J.Am.Geriatr.Soc., 38,* 1105-1112.

Riddle, D. L. & Stratford, P. W. (1999). Interpreting validity indexes for diagnostic tests: an illustration using the Berg balance test. *Phys.Ther., 79,* 939-948.

Rogers, M. W., Wardman, D. L., Lord, S. R., & Fitzpatrick, R. C. (2001). Passive tactile sensory input improves stability during standing. *Exp.Brain Res., 136,* 514-522.

Rosengren, K. S., Rajendran, K., Contakos, J., Chuang, L. L., Peterson, M., Doyle, R. et al. (2007). Changing control strategies during standard assessment using computerized dynamic posturography with older women. *Gait.Posture., 25,* 215-221.

Rubenstein, L. Z. & Josephson, K. R. (2002). The epidemiology of falls and syncope. *Clin.Geriatr.Med., 18,* 141-158.

Runge, C. F., Shupert, C. L., Horak, F. B., & Zajac, F. E. (1999). Ankle and hip postural strategies defined by joint torques. *Gait.Posture., 10,* 161-170.

Scheibel, A. B. (1985). Falls, motor dysfunction, and correlative neurohistologic changes in the elderly. *Clin.Geriatr.Med., 1,* 671-677.

Schieppati, M., Giordano, A., & Nardone, A. (2002). Variability in a dynamic postural task attests ample flexibility in balance control mechanisms. *Exp.Brain Res., 144,* 200-210.

Schwartz, A. V., Villa, M. L., Prill, M., Kelsey, J. A., Galinus, J. A., Delay, R. R. et al. (1999). Falls in older Mexican-American women. *J.Am.Geriatr.Soc., 47,* 1371-1378.

Sekuler, R. & Hutman, L. P. (1980). Spatial vision and aging. I: Contrast sensitivity. *J.Gerontol., 35,* 692-699.

Shumway-Cook, A., Baldwin, M., Polissar, N. L., & Gruber, W. (1997). Predicting the probability for falls in community-dwelling older adults. *Phys.Ther., 77,* 812-819.

Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Phys.Ther., 80,* 896-903.

Shumway-Cook, A. & Horak, F. B. (1986). Assessing the influence of sensory interaction of balance. Suggestion from the field. *Phys.Ther., 66,* 1548-1550.

Simmons, R. W., Richardson, C., & Pozos, R. (1997). Postural stability of diabetic patients with and without cutaneous sensory deficit in the foot. *Diabetes Res.Clin.Pract., 36,* 153-160.

Skinner, H. B., Barrack, R. L., & Cook, S. D. (1984). Age-related decline in proprioception. *Clin.Orthop.Relat Res.,* 208-211.

Spiegel, J. S., Paulus, H. E., Ward, N. B., Spiegel, T. M., Leake, B., & Kane, R. L. (1987). What are we measuring? An examination of walk time and grip strength. *J.Rheumatol., 14,* 80-86.

Steffen, T. M., Hacker, T. A., & Mollinger, L. (2002). Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. *Phys.Ther., 82,* 128-137.

Stelmach, G. E. & Worringham, C. J. (1985). Sensorimotor deficits related to postural stability. Implications for falling in the elderly. *Clin.Geriatr.Med., 1,* 679-694.

Szturm, T. & Fallang, B. (1998). Effects of varying acceleration of platform translation and toes-up rotations on the pattern and magnitude of balance reactions in humans. *J.Vestib.Res., 8,* 381-397.

Szturm, T, Desai, A., Betker, A. L., Kapadia, N, and Nett, C. (2007). Game-Based Exercises for Dynamic Short-sitting Balance Rehabilitation of Subjects with Chronic Spinal Cord and Traumatic Brain Injuries. *Phys.Ther.,* Ref Type: Generic (Manuscript in Publication)

Tait, H. (1993). Injuries and seniors: The Canadian Context. Ottawa: The Product Safety Bureau (Health Canada).

Teasdale, N., Stelmach, G. E., & Breunig, A. (1991a). Postural sway characteristics of the elderly under normal and altered visual and support surface conditions. *J.Gerontol., 46,* B238-B244.

Teasdale, N., Stelmach, G. E., Breunig, A., & Meeuwsen, H. J. (1991b). Age differences in visual sensory integration. *Exp.Brain Res., 85,* 691-696.

Thomas, J. I. & Lane, J. V. (2005). A pilot study to explore the predictive validity of 4 measures of falls risk in frail elderly patients. *Arch.Phys.Med.Rehabil., 86,* 1636-1640.

Tinetti, M. E. (1986). Performance-oriented assessment of mobility problems in elderly patients. *J.Am.Geriatr.Soc., 34,* 119-126.

Tinetti, M. E. (1989). Instability and falling in elderly patients. *Semin.Neurol., 9,* 39-45.

Tinetti, M. E., Richman, D., & Powell, L. (1990). Falls efficacy as a measure of fear of falling. *J.Gerontol., 45,* 239-243.

Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. *N.Engl.J.Med., 319,* 1701-1707.

Tinetti, M. E., Williams, T. F., & Mayewski, R. (1986). Fall risk index for elderly patients based on number of chronic disabilities. *Am.J.Med., 80,* 429-434.

Topper, A. K., Maki, B. E., & Holliday, P. J. (1993). Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/or type of fall? *J.Am.Geriatr.Soc., 41,* 479-487.

van der, K. H., Jacobs, R., Koopman, B., & van der, H. F. (2001). An adaptive model of sensory integration in a dynamic environment applied to human stance control. *Biol.Cybern., 84,* 103-115.

VanSwearingen, J. M. & Brach, J. S. (2001). Making geriatric assessment work: selecting useful measures. *Phys.Ther., 81,* 1233-1252.

VanSwearingen, J. M., Paschal, K. A., Bonino, P., & Chen, T. W. (1998). Assessing recurrent fall risk of community-dwelling, frail older veterans using specific tests of mobility and the physical performance test of function. *J.Gerontol.A Biol.Sci.Med.Sci., 53,* M457-M464.

Wallmann, H. W. (2001). Comparison of elderly nonfallers and fallers on performance measures of functional reach, sensory organization, and limits of stability. *J.Gerontol.A Biol.Sci.Med.Sci., 56,* M580-M583.

Waters, R. L., Lunsford, B. R., Perry, J., & Byrd, R. (1988). Energy-speed relationship of walking: standard tables. *J.Orthop.Res., 6,* 215-222.

Whipple, R., Wolfson, L., Derby, C., Singh, D., & Tobin, J. (1993). Altered sensory function and balance in older persons. *J.Gerontol., 48 Spec No,* 71-76.

Winter, D. A. & Eng, P. (1995). Kinetics: our window into the goals and strategies of the central nervous system. *Behav.Brain Res., 67,* 111-120.

Woo, J., Ho, S. C., Lau, J., Chan, S. G., & Yuen, Y. K. (1995). Age-associated gait changes in the elderly: pathological or physiological? *Neuroepidemiology, 14,* 65-71.

Woollacott, M. H., Shumway-Cook, A., & Nashner, L. M. (1986). Aging and posture control: changes in sensory organization and muscular coordination. *Int.J.Aging Hum.Dev., 23,* 97-114.

Zupan, L. H., Peterka, R. J., & Merfeld, D. M. (2000). Neural processing of gravito-inertial cues in humans. I. Influence of the semicircular canals following post-rotatory tilt. *J.Neurophysiol., 84,* 2001-2015.