

## AN ABSTRACT OF THE THESIS OF

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Abstract approved: \_\_\_\_\_

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Activity-based balance and mobility tests indicate fall risk and functional decline (disability) in older adults, thereby identifying a need for therapeutic intervention. However, these types of tests do not provide guidance to practitioners about the specific impairments to be treated. The purposes of this study were to determine whether postural control system impairments are related to reduced performance on activity-based balance and mobility tests, and identify which impairments are associated with difficulty performing particular activities.

Ninety-six older adults (65 women, 31 men) from 65 to 94 years of age (mean  $70 \pm 7$ ) were recruited from local nursing homes, retirement communities, and neighborhoods. By self-report, 40 subjects had never fallen, 35 had fallen once, and 21 had fallen two or more times. All subjects signed an informed consent form prior to participation in this study.

Each older adult completed the 14-item Berg Balance Scale (BBS), the Timed Get-Up-and-Go Test (TGUGT), and 12 impairment tests: bilateral lower extremity (BLE) range of motion, BLE strength, (KinCom®), BLE proprioception and vibration, depth perception (Frisby Stereotest®) and contrast sensitivity (Pelli-Robson®), smooth pursuit and motion- provoked dizziness, simple reaction time, postural response latency (Motor Control Test/EquiTest®), center of gravity (COG) position perception (Sensory Organization Test/EquiTest®), and COG excursion (Limits of Stability test/PRO

Balance Master®). Proprioception and vibration scores were combined to form a “somatosensory” score. Depth perception and contrast sensitivity scores were converted to standardized units and then combined to form a “vision” score. Smooth pursuit and motion-provoked dizziness scores were converted to standardized units and then combined to form a “vestibular” score.

Canonical correlation was used to examine the relationship between the two sets of variables (13 activity and nine impairment scores). The overall multivariate relationship was significant, Wilk’s Lambda = .07,  $F(117, 567) = 2.14$ ,  $p \leq .001$ . The first correlation between the two sets of variables was  $R_c = .86$ , with 74% overlapping variance. Spearman’s rho was employed to discern which impairments were associated with difficulty performing specific activities. Significant associations ( $p \leq .05$ ) were found for each of the impairments with one or more of the activities. Correlations were low ( $r = .20$  to  $.43$ ) for the easier activity items and low to moderate ( $r = .22$  to  $.59$ ) for the more difficult activity items. Multiple regression was used post hoc to indicate which impairments contributed most to reduced performance on specific activity items. The total BBS score was most significantly influenced by impairments of COG excursion, COG perception, BLE strength, and BLE range of motion. Impairments of COG excursion, BLE strength, BLE somatosensation, and BLE range of motion most significantly influenced the TGUGT score.

Postural control system impairments are related to disabilities, as evidenced by reduced performance on the BBS and TGUGT. Low scores on particular activities signal the presence of specific impairments. This knowledge increases the value of the BBS and TGUGT, which may now be used to guide clinical decisions regarding further assessment and potential treatment.

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**Relationships Between Postural Control System Impairments and Disabilities**

by

**Leslie K. Allison**

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Leslie K. Allison, Author

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For first demonstrating that physical therapists could acquire advanced degrees, and inspiring me to get one of my own, I thank my undergraduate faculty at Penn. For their belief in my abilities, encouragement to begin, coaxing to proceed, and patience until completion, I thank my wonderful professional colleagues, who will now ask me when I plan to start a doctoral program. To Dr. Maureen Weiss, who offered early advice for analysis methods, Sean Clark, Ben Young and Star Sutton, who assisted in data collection for this study, and Dr. Terry Wood, who provided guidance for measurement, analysis, and interpretation of data, I extend my sincere appreciation.

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## **DEDICATION**

This thesis is dedicated to three women: my grandmothers, Hellen Allison and Lillian Shoemaker, who had the ability, but not the opportunity, to attend college; and my mother, Susan Allison, who believed she had to choose between graduate school and marriage. She chose the latter and later raised a daughter who lives, happily, in a time where women with aptitude have access to, and support for, higher education. I hope I may honor them through this accomplishment.

# **RELATIONSHIPS BETWEEN POSTURAL CONTROL SYSTEM IMPAIRMENTS AND DISABILITIES**

## **INTRODUCTION**

Falls have long been identified as a major source of injury and accidental death in the elderly. Falls are the leading cause of injury in older adults and the leading cause of accidental death in those over age 85 (Coogler, 1992; Pocinki, 1990). Hip fractures are the most common major injury. An additional 10% of all fallers will sustain other serious injuries requiring medical care, such as joint dislocations, sprains, and hematomas. Recent efforts to control rising health care costs have drawn attention to the enormous cost of care for elderly fallers. Research to identify which older people are likely to fall, and which intervention strategies are most successful at reducing the risk and number of falls, is now occurring (Rose & Clark, 1995; Shumway-Cook, Gruber & Baldwin, 1995; Tinetti et al., 1994).

Falls are prevalent, dangerous, and costly. Every year, one-third to one-half of the population age 65 years and over experience falls (Coogler, 1992). Half of the elderly people who fall do so repeatedly (Tinetti & Speechley, 1989). Five percent of falls lead to a fracture. Falls cause more than 200,000 hip fractures annually: one in ten of these patients will die of complications, and one in four survivors will never regain their previous mobility (Coogler, 1992; Tinetti & Speechley, 1989). The cost of direct care for hip fracture patients alone is over 7 billion dollars a year; 100,000 become long-term disability cases. Even falls that do not result in injury can have serious consequences. Psychological trauma and fear-of-falling produce a downward spiral of self-imposed activity reduction which leads to loss of strength, flexibility, and mobility, thereby

increasing the risk of future falls (Tinetti & Speechley, 1989). Falls and instability contribute to 40% of nursing home admissions (Pocinki, 1990).

Falls are not a normal part of aging. Elderly fallers are different than their healthy, age-matched counterparts (Horak, Shupert & Mirka, 1989; Lizardi, Wolfson & Whipple, 1989; Whipple & Wolfson, 1989). Some fallers have a medical diagnosis such as diabetes or Parkinson's disease that contributes to the increased likelihood of falling, but over 50% have no diagnosis at all that would explain their falls (Fife & Baloh, 1993). This is because they do not have one large problem within a single system that would be classified by a medical diagnosis. Instead, they often have many small problems across systems, which interact to produce instability (Horak et al., 1989). Each of these problems is a risk factor for falls. The more risk factors an individual has the greater the likelihood that he or she will fall (Tinetti & Speechley, 1989). The elimination or minimization of even one or two of several risk factors can reduce an individual's risk of falling significantly (Tinetti et al., 1994).

Practitioners involved in the rehabilitation of individuals with imbalance are being asked to assess the risk for falls in elderly patients and predict the eventual functional ability levels of these patients after a single visit. Further, they are under pressure to produce meaningful improvements in functional ability levels with the least possible amount of intervention. The demand for more efficient, informative assessment methods, and more effective interventions, is high.

In response to these demands, several fast, low-cost screening tests for the elderly have been developed to predict risk for falls (Berg, Wood-Dauphinee, Williams & Gayton, 1989; Hogue, Studenski & Duncan, 1990; Lusardi, 1995; Mathias, Nayak, & Isaacs, 1986; Tinetti, 1986). All share some common characteristics. Each consists of a list of balance and mobility activities to be performed in a specified manner, such as rising from a chair, standing with eyes closed, stepping over an obstacle, and reaching a maximum distance. Each item is scored using an ordinal rating scale. Then, item scores

are summed, and the total score indicates relative risk for falls. These screening tests vary in their degree of reliability, sensitivity, and ease of use. They all indicate whether or not risk exists, and highlight the need for intervention. However, they do not identify the specific problems that might cause a decline in balance and mobility performance, and therefore do not provide information critical to the formulation of an intervention program.

According to the terminology of the World Health Organization's International Classification of Impairment, Disability, and Handicap (I.C.I.D.H.) framework, problems within the cognitive, sensory and motor systems, which together produce postural dyscontrol, are termed "impairments". An impairment is "any loss or abnormality of an anatomical, physiological or psychological structure or function" (p. 36, National Institutes of Health, 1993). Examples of impairments that might impact balance control include sensory loss, muscle weakness, and delayed reaction time. If impairments are numerous or severe, the ability to perform certain balance and mobility activities may become compromised. The inability to perform an activity in a normal manner, or within the normal range, is termed a "disability" according to the I.C.I.D.H. framework. Examples of disabilities might include the inability to rise from a chair, climb stairs, dress, or drive a car. A "handicap", according to this model, is a change in the life-role of an individual. A person whose role as the family "breadwinner" can no longer be fulfilled due to their disability would be experiencing a handicap.

Traditionally, a causal relationship between impairments and disabilities was assumed but not documented. For example, if a patient has leg weakness and cannot rise to standing from a chair, then strengthening exercises for the leg muscles are prescribed with the idea that increased strength will lead to independence in rising to stand. Until recently, rehabilitation research questions were heavily focused on the impairment side of this assumed equation. To continue with the above example, researchers who focus on the impairment only might consider what frequency, intensity and duration of exercise is

necessary to produce a doubling of strength, but would not explore the relationship of amount of strength to ability to rise to stand.

Currently, there is a shift in the focus of rehabilitation research and intervention. Increasing attention is being given to "functional outcomes", or changes in the level of disability which result from an intervention (Jette, 1995). Researchers are beginning to systematically explore relationships between impairments and disabilities to determine which impairments, if minimized or eliminated, are most likely to reduce disabilities and improve functional outcomes (Duncan, Chandler, Studenski, Hughes & Prescott, 1993; Lord, Clark & Webster, 1991; MacRae, Lacourse & Moldavon, 1992).

Buchner and deLateur (1991) demonstrated a strong relationship between muscle strength and functional performance. They chose two functional tasks, sit-to-stand and stair climbing, and measured the ability to perform those tasks in a group of subjects with varied levels of lower extremity strength. A significant curvilinear relationship of muscle strength to functional performance was documented. Below a certain level of strength, a task could not be accomplished at all, while above a certain level of strength, no improvements in performance were seen. These authors made clear the important concept of "threshold" for a given task. Strength could be insufficient, adequate, or greater than necessary. Just how much strength would be "adequate" depended on the task; strength levels within a defined range are sufficient to rise from a chair but insufficient to climb stairs.

Improvements in strength have also been shown to be associated with improvements in functional performance of specific daily tasks. Hunter et al. (1995) measured the effects of a strength training program on the ability of 14 older women to rise from a chair, walk, and carry groceries while walking. Significant increases in strength ( $p < 0.01$ ) were accompanied by improvements in three functional performance measures - rising from a chair, walking velocity, and ability to walk while carrying a bag of groceries. In an earlier study, Finlay (1993) demonstrated that increased walking

velocities in elderly women contributed to the successful, safe negotiation of pedestrian crosswalks, a functional activity required for independence in community ambulation.

Gibbs, Hughes, Dunlop, Singer & Chang (1996) found that both quadriceps weakness and joint impairment were related to and predictive of a loss of walking velocity in older adults over a 4-year period. Walking velocity is a known indicator of disability as well as risk-for-falls in the elderly. A total of 282 subjects over age 60 years completed tests of joint impairment, strength, reflexes, comorbidity (concurrent medical diagnosis), anxiety, depression, and pain three times over the course of a 4-year interval. Bilateral hip flexor and knee extensor strength were measured using manual muscle testing. Joint impairment included pain, deformity, or loss of motion; the feet, ankles, knees, hips, and lower spine were tested. Other tests were also performed, but were not found to contribute to the prediction of reduced walking velocity below a minimum threshold. The authors documented two motor effector impairments (loss of strength and joint flexibility) that were associated with change in walking velocity, a measure indicative of disability level. The findings of this study support the relationship between two specific impairments (decreased strength and joint range-of-motion) and one specific disability (excessively slow walking velocity). Because walking velocity is known to be indicative of disability level and risk for falls, the results also suggest a relationship between those impairments and problems with the performance of other activities as well, though no other activities were actually tested.

Joint contractures were also seen to be associated with loss of function in patients with Alzheimer's disease (AD). Souren, Franssen and Reisberg (1995) defined contracture as a 50% or greater loss of normal passive joint range of motion. They investigated cognitive levels in 161 subjects using the Mini Mental State Exam (Folstein, Folstein and McHugh, 1975) and functional levels using the Functional Assessment Staging Scale, a functional scale commonly used with AD patients (Reisberg, 1988). Degree of functional decline was strongly correlated with the occurrence of contractures

in one or both upper or lower extremities ( $r = .70, p < .001$ ). Contractures were found in only 11% of ambulatory subjects, while more than 75% of non-ambulatory subjects had contractures. The authors note that contractures are “a fundamental outcome of AD, and not an independent concurrent condition” (p. 653). Taken together, the work of Gibbs et al. (1996) and Souren et al. indicate the loss of joint range of motion may be both a contributor to, and a consequence of, immobility.

Impairments in the feet that cause foot pain were found to be associated with a higher incidence of disability by Benvenuti, Ferrucci, Guralnik, Gangemi & Baroni (1995). A total of 459 elderly (65 years and older) subjects were objectively tested for foot problems/pain, and completed a subjective report of problems performing both basic and instrumental activities of daily living. (Basic activities of daily living [BADL] would include simple tasks like rolling in bed, coming to sit, transferring on and off a toilet, etc., while instrumental activities of daily living [IADL] include more difficult tasks such as stair climbing, street crossing, etc. According to the WHO ICIDH framework, problems performing any of these functional activities would be termed “disabilities”.) Foot pain caused by a variety of problems (e.g., old fractures, corns, calluses, deformities, etc.) was prevalent, and significantly associated with abnormal gait characteristics (including reduced walking velocity) and greater disability for instrumental activities of daily living tasks, especially those involving standing and ambulation.

In 1993, Duncan et al. investigated the association between impairments in multiple physiological components of balance and mobility levels in elderly men. The physiological components measured included four sensory inputs (vision, vestibular, proprioception and vibration), two motor effectors (strength and range-of-motion of the lower extremities), and one central processing indicator (response time to surface perturbations). Mobility was assessed using the Duke Mobility Skills Test (Hogue, Studenski and Duncan, 1990), the Functional Reach test (Duncan, Weiner, Chandler & Studenski, 1990), and two gait parameters (distance and speed). Based on the results of

the mobility tests, subjects were categorized as high, intermediate, or low functioning. The number of impairments per individual subject was significantly different between groups, with 56% of the low function group having two or more impairments while only 20% of the intermediate function and 7% of the high function groups had two or more impairments. Duncan et al. concluded that the accumulation of multiple impairments (versus any single specific impairment) might best explain declines in functional performance.

Schultz et al. (1995) also investigated the relationship between “physical capacities” and mobility in older adults. Multiple lower extremity strength measures and ankle proprioception sense were evaluated in a group of 85 older subjects with varied functional ability levels. Numerous balance and mobility tasks (seven ambulation, six chair-rise, and six balance tasks) of graded difficulty levels were also tested. The authors demonstrated a significant association ( $p < 0.001$ ) between mobility task performance and a composite measure of lower extremity strength. The authors also stated that proprioceptive sense thresholds were “strongly associated with performance success”, however, the actual correlation values were not presented.

In a pilot study to determine if poor balance is associated with decreased mobility and physical function, King et al. (1995) selected subjects over the age of 70 years known to have difficulty performing at least one of several functional activities, e.g., walking, climbing stairs, etc., or slow walking velocities (less than one meter per second). Subjects completed multiple balance tests: Functional Base of Support (FBOS), which measures the maximum center-of-gravity (COG) excursion in all directions over a fixed base of support, single leg stance time, and frequency of balance loss during the Sensory Organization Test (SOT). In addition, ankle dorsiflexion strength and gait velocity were measured. Results from this “disabled” group of subjects were compared to results from a group of healthy elderly subjects. Compared to their healthy counterparts, older adults with mobility problems exhibited significantly slower gait velocities, less ankle strength,

and lower FBOS scores, the latter indicating an impairment in the ability to control the COG excursion over the base of support.

Though the number of studies documenting the relationship between impairments and disabilities is small, the existence of such relationships is consistently evident. Many more studies need to be done, however, to clarify precisely which impairments (or clusters of impairments) are associated with specific functional losses, and which impairments are causal in nature. Only then will clinicians charged with producing improved “functional outcomes” for their patient populations have sufficient information to guide the development of optimal intervention programs designed to ameliorate disability. When multiple impairments exist within the same individual, as they do in most elderly fallers, it is not practical to address each and every problem given current constraints on the delivery of rehabilitation services. Efficient improvement of specific functional abilities cannot occur unless clinicians target the most influential impairments first and foremost. To do this, they need [studies that yield] information about what impairments to address, and the extent to which those impairments must improve before functional performance changes can be expected.

Efforts to reduce the risk of falls and increase mobility through improved balance control in the unstable elderly are hampered by insufficient information. Clinicians commonly administer activity-based screening tests to determine whether or not an elderly individual has balance problems and is at risk for falls. Once at-risk individuals have been identified, intervention to reduce the risk of falls and increase mobility is required. Yet not all fallers fall for the same reasons; one may have weakness and somatosensory loss while another may suffer vestibular dysfunction and joint restrictions. Treatment, therefore, should not be the same for all fallers, but should be individualized, based upon the particular impairments causing disability for each person (Shepard & Telian, 1993). Unfortunately, activity-based screening tests do not identify the specific

impairments affecting each individual. The clinician must perform further testing to discern them prior to the development of an individualized treatment program.

Limited by time, clinicians cannot possibly perform all the tests necessary to rule out every potential impairment, and must decide which additional tests to perform. What information is needed to support such decisions? If clinicians knew that certain postural control impairments were associated with the inability to perform particular activities, then screening test results could signal the potential presence of specific impairments, and thus indicate which additional tests ought to be administered. This information is not currently available to clinicians because the relationship between impairments within the postural control system and the inability to perform functional activities that demand balance has not been adequately explored.

### Statement of the Problem

The primary purpose of this study was to examine the relationship between impairments in the systems controlling balance (e.g., sensory, processing, musculoskeletal) and the ability to perform activities that demand balance skills. Since multiple systems contribute to postural control, multiple impairment tests were employed to identify the presence or absence of impairments. The impact of an impairment on the ability to perform a specific balance activity is considered to be threshold-sensitive, thus several balance activities of increasing difficulty levels were used. Unlike previous studies, this investigation did not narrowly focus on the effect of one or two impairments on one or two functional activities. Nor did it consider the summed, or total score of the disability test to be of primary importance, since this score alone cannot guide treatment. Rather, it explored the associations between impairments and each individual balance activity item within a chosen disability test battery.

## Research Questions

Three questions of interest were addressed in this exploratory study. First, is there a substantial relationship between postural control system impairments and balance-related disability? Second, are specific impairments associated with the ability to perform certain balance and mobility tasks? For example, is lower extremity weakness associated with an inability to rise to standing? Is vestibular dysfunction associated with problems in head or full body turns? No previous study has specifically identified which postural control impairments may be associated with each activity item on a widely accepted and used clinical balance test. If specific impairments are associated with particular balance and mobility tasks, then - in addition to the usefulness of a total disability test score in predicting risk for falls - results from individual items (or clusters of items) on the disability tests would help guide further evaluation decisions. If test items such as rising from a chair, curb toe touches, and single-leg-stance-time abilities are all associated with lower extremity strength scores, and an individual scores poorly on these three items, then a detailed strength assessment is indicated and justified. If forward reaching and object retrieval abilities are associated with center-of-gravity control scores, then a thorough limits-of-stability assessment should be considered.

Third, are there impairments that are known risk factors for falls that are not associated with any of the activity items on the selected disability tests? In other words, would acceptable performance of the screening tests fail to reflect the presence of certain problems predisposing an individual to falls? For example, no unpredictable perturbations or sensory conflict situations are presented in the chosen disability test, yet the literature suggests that problems responding to these demands are characteristic of elderly fallers (Parry, 1994; Whipple, in press). If this is so, therapists should be made aware of these test limitations, and test for those impairments separately. Or, perhaps

disability test items that are associated with these impairments could be developed and added to the disability test battery.

Through investigation of the relationships between impairments in the postural control system and the ability to perform functional activities, this study sought to provide answers to these questions and contribute to improved clinical decision-making processes regarding screening and evaluation procedures in elderly patients.

### Delimitations

This study included 96 men and women aged 65 years or older, of varied functional ability levels. Subjects were volunteers from the community surrounding Oregon State University and from senior residential centers in Corvallis and Albany, Oregon. All subjects performed a multiple item disability test battery, and the following tests to detect the presence or absence of postural control system impairments: (a) vibration and proprioception, (b) visual depth perception and contrast sensitivity, (c) motion-provoked vestibular symptoms and smooth pursuit, (d) Sensory Organization Test, (e) Motor Control Test, (f) simple reaction time, (g) Limits-of-Stability, (h) lower extremity strength (bilateral knee, ankle), (i) lower extremity joint range-of-motion (bilateral hip, knee, ankle).

### Limitations

1. The tests selected for use were limited to tests that can be performed by frail elderly subjects, and may not be the most appropriate tests for the identification of impairments or balance deficits.

2. Confirmation of test validity and reliability in previous investigations was not available for all tests, therefore, certain widely accepted and commonly used tests were performed in the absence of such confirmation.

3. All tests for any individual subject were performed within one week, hence data collection was not longitudinal or prospective. Thus, the causal role of postural control system impairments may not be inferred.

4. Subjects were not randomly chosen, therefore effects cannot be generalized to the population at large of older adults.

#### Assumptions

1. All subjects performed each test to the best of their abilities.
2. All equipment was properly calibrated.
3. The test administrators were properly trained.

#### Terminology

Activities of daily living (ADL) - Tasks that are commonly performed in everyday life, such as rolling in bed, getting into and out of bed, rising from a chair, walking, stair climbing, etc.

**Amplitude** - indicates the intensity of the balance response (foot pressure on forceplate) to a surface perturbation in the Motor Control Test; the size of the response should ideally be matched to the size of the stimulus (perturbation).

**Ankle strategy** - an automatic postural response to a balance perturbation wherein the body sways from the ankle joint, with the head and hips moving in synchrony (as an inverted pendulum).

**Balance** - the ability to control the center-of-gravity in relation to the base of support in a given environment.

**Balance Master®** - a computerized static forceplate system for balance assessment and retraining.

**Body-scaled** - the expression of a measure as a ratio with a particular characteristic of the subject, (e.g., muscle strength in relation to body weight).

**Center-of-gravity** - the point at which the sum of all the forces acting on a body equal zero; center-of-mass.

**Center-of-pressure** - the point representing the sum of all the forces distributed onto surface.

**Contrast sensitivity** - the visual ability to distinguish edges.

**Depth perception** - the visual ability to judge distance.

Disability - the inability to perform an activity in a normal manner or within the normal range.

Equitest® - a computerized dynamic forceplate system for the assessment of balance.

Fall - unintentionally coming to rest on the ground.

Faller - a person who has experienced two or more falls within the past year.

Functional limitation - inability to perform the tasks that constitute usual activities for an individual, such as driving a car or preparing a meal.

Handicap – restrictions attributable to social policy or barriers (structural or attitudinal) which limit fulfillment of life roles or deny access to services and opportunities associated with full participation in society.

Hip strategy - an automatic postural response to a balance perturbation wherein the body sways from the hips, with the head and hips moving out-of-phase with each other.

Impairment - any loss or abnormality of an anatomical, physiological or psychological structure or function.

Instrumental activities of daily living [IADL] - higher level functional activities such as crossing a street or shopping.

**Latency** - a measure of the time which elapses between the presentation of a stimulus and the initiation of a response (e.g., foot pressure response against the forceplate following a surface perturbation stimulus).

**Limit-of-stability** - the furthest distance a person can lean in any direction without changing the original base of support or falling.

**Limit-of-Stability test** - a standardized test that measures the excursion of the vertical component of the center-of-gravity when a subject attempts to lean to eight consecutive targets placed at a given distance away from the subject's midline position. Target distance is body-scaled to subject height. (NeuroCom International, Inc.)

**Motion-provoked** - symptoms which occur only when the head or body is actually moving, and dissipate when the head or body is at rest.

**Motor Control Test** - a standardized test that measures the amplitude and latency of responses to surface perturbations (translations) that disturb the subjects' balance by suddenly altering the alignment of the center-of-gravity over the base of support. Perturbation size is body-scaled to subject height. (NeuroCom International, Inc.)

**Perturbation** - an intentionally, externally produced disturbance of balance.

**Postural control** – the ability to align limb and body segments to optimize forces counteracting the pull of gravity.

PRO Balance Master® - a computerized dynamic forceplate system for balance assessment and retraining.

Proprioception - the sensory ability to detect joint position.

Range-of-motion - the amount of passive joint movement, measured in degrees.

Reaction time - the interval of time between the presentation of a stimulus (e.g., visual, auditory), and the initiation of a response.

Sensory Organization Test - a standardized test that measures the use of somatosensory, visual, and vestibular inputs for postural stability in upright stance.  
(NeuroCom International, Inc.)

Smooth pursuit - the ability to track a moving object with the eyes while the head remains stationary.

Somatosensory - a group of sensory abilities to detect joint position, joint movement, muscle length, muscle tension, light touch, vibration, pain and temperature.

Stepping strategy - an automatic postural response to a balance perturbation wherein the center-of-gravity (COG) passes beyond the limit of stability boundary, and a step must be taken in order to re-establish a new base-of-support underneath the COG to prevent a fall.

**Strength** - the amount of force that a group of muscles can generate, measured isokinetically in foot-pounds.

**Supervision** - a degree of assistance provided to an unstable individual to “guard” the person; no physical contact is made unless necessary to prevent a fall.

**Vestibular** - the sensory ability to detect head position in relation to gravity, as well as angular and linear acceleration and deceleration of the head.

**Vibration sense** - the sensory ability to detect vibration; sensory afferent information is carried along the same spinal cord tracts (medial-lemniscal) as proprioception.

## REVIEW OF LITERATURE

### Introduction

Early geriatric balance research suffered from failure to distinguish healthy versus impaired elderly subjects. The inclusion of both fit and frail older adults in a single group led to the conclusion that declines in balance are largely age-related, and therefore inescapable (Horak, Shupert & Mirka, 1989). More recent studies have taken care to separate healthy elderly subjects from those with known disease processes such as stroke or Parkinson's disease, as well as from a third group of aged individuals without medical diagnoses but with positive neurological findings on careful clinical examination. Results from these studies indicate that age alone does not cause imbalance and falls (Gabell & Nayak, 1984). Healthy older adults do exhibit mild declines in balance abilities compared to young adults; however, the differences are relatively small and do not cause functional dependence or falls (Lizardi, Wolfson & Whipple, 1989; Whipple & Wolfson, 1989). Significant loss of balance control appears to be associated with the presence of certain impairments affecting only a portion of the elderly population (Chandler & Duncan, 1993; Horak et al., 1989).

Current research is intensely focused on falls in the elderly, a widespread, dangerous, and costly problem. Identification of the risk factors associated with falling, and the efficacy of interventions to reduce the number of risk factors to consequently reduce the number of falls, are of particular interest to investigators (Province et al., 1995).

The traditional medical model, which is diagnostically driven, is an inadequate model for understanding the problems of a majority of the unstable elderly who have no diagnosis, but who do have balance problems and perhaps fall repeatedly (Guccione,

1993). A more appropriate framework from which to understand geriatric balance deficits is the World Health Organization (WHO) International Classification of Impairment, Disability, and Handicap (ICIDH) framework. This model includes the medical diagnosis and adds three additional levels - impairment, disability, and handicap (World Health Organization, 1990). Diagnosis refers to the injury or disease that is causing the observable problem(s). An impairment is a loss or abnormality in any physiological, psychological, or anatomical structure or function. The term disability indicates a limitation in the ability to perform activities in the normal manner or within a normal range. A handicap is a restriction in the fulfillment of life roles. For example, an older adult may have a diagnosis of Parkinson's Disease, which produces several impairments such as flexed posture, bradykinesia, and resting tremor. The combined effect of these impairments may cause disability (i.e., difficulties in performing activities of daily living such as walking, bathing, dressing). If these difficulties resulted in an inability to live alone, and precipitated a move to institutional living, then a handicap would be experienced. Assumptions of practitioners providing rehabilitation interventions include the belief that the diagnosis produces the impairments, which cause the disabilities, which result in the handicaps (National Institutes of Health, 1993). Efforts to minimize disability therefore have focused on the remediation of the impairments assumed to be producing the disabilities (Schenkman & Butler, 1989).

Rehabilitation research is now investigating these assumptions, especially the link between impairments and disabilities (Guccione, 1993; Jette, 1993). Several studies indicate that such relationships exist. Buchner and deLateuer (1991) demonstrated the relationship between lower extremity strength and the ability to rise from sitting to standing, and to climb stairs. Hunter et al. (1995) found that an improvement in lower extremity strength was associated with improvements in rising from a chair, walking velocity, and carrying a bag of groceries while walking. Both lower extremity weakness and joint impairment were shown to be predictive of declines in walking velocity by

Gibbs, Hughes, Dunlop, Singer & Chang (1996). Problems performing instrumental activities of daily living and walking were found by Benvenuti, Ferucci, Guralnik, Gangemi & Baroni (1995) to be associated with impairments of the feet. In 1993, Duncan, Chandler, Studenski, Hughes and Prescott demonstrated that physiological factors were related to the ability to perform mobility and gait tasks.

The term “balance” has not fit neatly into the ICDH framework, however. Imbalance is not an isolated impairment, but rather an observable result of one or more impairments within the postural control system. Neither is it a disability, but rather a cause of disability. This intermediate position between pure impairment and disability has led to apparent confusion in the literature concerning imbalance in the elderly. Various studies have examined relationships between a) impairments and disabilities, b) impairments and balance, c) balance and disabilities, d) impairments and falls, e) balance and falls, and f) disabilities and falls.

Several authors have written about the relationship between impairments and disabilities in the elderly. Strength has frequently been studied. For example, Buchner and deLateur (1991) examined one impairment (strength) and two functional activities (rise from sit-to-stand; climb stairs). They demonstrated a strong relationship between strength and task performance. Hunter et al. (1995) investigated the effects of a strength training program (impairment remediation) on the ability to perform three functional activities: rise from a chair, walk rapidly, and carry a bag of groceries while walking. Their findings indicated that as strength increases, so does level and perceived ease of functional performance. A 1996 study by Gibbs et al. described a significant association between two impairments (strength and joint flexibility) and one functional measure, walking velocity. [Sufficient walking speed is necessary for the safe negotiation of pedestrian crosswalks (Finlay, 1993)]. Souren, Franssen and Reisberg (1995) also related impaired joint flexibility to diminished functional performance in a study. Impairments of the feet were correlated with reduced performance of instrumental activities of daily

living (IADL) by Benvenuti et al. in 1995. The presence of multiple impairments in the postural control system was shown to be related to the degree of mobility and gait restriction by Duncan et al. in 1993. Similarly, Schultz et al. (1995) found a significant association between two impairment measures (strength and proprioception) and difficulty with mobility and gait tasks. King et al. (1995) found older subjects with known disabilities to have impaired ankle strength and center of gravity control.

Relationships between impairments and balance in older adults have also been reported. Lord and colleagues (Lord, Clark & Webster, 1991; Lord, Ward, Williams & Anstey, 1994) have investigated the associations between selected physiological variables (e.g., proprioception, vision, strength, reaction time) and measures of postural stability (both forceplate and clinical measures). They found significant ( $p < .05$ ) and specific associations between the postural stability measures and physiologic impairments. Visual acuity and contrast sensitivity were positively associated with forceplate measures of standing sway. Proprioception, touch, vibration, knee and ankle strength, and reaction time were positively associated with both forceplate and clinical balance measures. In addition, they found that all the above impairments, with the exception of touch, were also correlated with a history of multiple falls in elderly individuals. A 1995 study by Era et al. also demonstrated positive correlations between selected impairment measures (visual acuity, vibration sense, reaction time, and strength) and excessive postural sway. Two additional studies (Gehlsen & Whaley, 1990; Prieto, Myklebust & Myklebust, 1992) demonstrated significant associations between two impairments, leg strength and joint flexibility, and balance tests including eyes open and closed in double stance, tandem stance, and backwards walking. Loss of strength was again shown to be a consequential impairment by Iverson, Gossman, Shaddeau & Turner (1990) and MacRae, Lacourse & Moldavon (1992). Both groups found that reduced lower extremity strength was significantly related to poor performance on clinical measures of balance (one-legged stance test [OLST], Sharpened Romberg [SR], and sit-to-stand test [STS]). Furthermore,

Maylor and Wing (1996) and Shumway-Cook, Woollacott and Baldwin (1995) and have reported associations between a cognitive impairment (ability to allocate attentional resources) and increased postural sway measures.

Other investigators have discussed the relationship between imbalance and disabilities. Iverson et al. (1990) found correlations between scores on two tests of balance (single-leg stance time and eyes closed stance time) and self-reported activity performance abilities in older men. Standing balance, walking pace, and sit-to-stand performance were predictive of subsequent disability (restricted performance of ADLs) four years later (Guralnik, Ferrucci, Simonsick, Salive and Wallace, 1995).

Associations between impairments and falls, balance and falls, and disabilities and falls have been frequently documented. The ability of certain physical measures (strength and reaction time) to predict faller versus non-faller status was documented by MacRae et al. (1992). Supporting the relationship between loss of strength and faller status were two additional studies (Lipsitz et al., 1994; Whipple, Wolfson & Amerman, 1987). Gehlsen and Whaley (1990) found that there were significant group differences between fallers and non-fallers on two tests of balance (single-leg stance time with eyes open and closed). Vandervoort, Hill, Sandrin & Vyse (1990) reported significant correlations between mobility loss and falls in elderly subjects.

Numerous clinical “balance” tests, which often include both balance and disability measures, are predictive of faller versus non-faller status in the elderly. The balance tasks usually include reducing the size of the base of support (i.e. standing with feet together, tandem stance, etc.) and reducing the use of visual input by performance of standing tasks with eyes closed. Common functional activities include sit-to-stand/stand-to-sit tasks, picking up an object from the floor, turning around, and walking. Clinical tests that have been shown to adequately discriminate fallers from non-fallers are the Performance Oriented Mobility Assessment (POMA; Tinetti, 1986), the Functional Reach Test (Duncan, Studenski, Chandler & Prescott, 1992), the Berg Balance Scale

(Thorbahn & Newton, 1996), the Postural Stress Test (Whipple & Wolfson, 1989), and the Modified Gait Assessment Rating Scale (M-GARS; Paschal & VanSwearingen, 1994; Van Swearingen, Paschal, Bonino & Yang, 1996). Laboratory measures of “balance”, using a forceplate to measure sway, also discriminate fallers from non-fallers (Maki, Holliday & Topper, 1992; Parry, 1994; Thapa, Gideon, Fought, Kormicki & Ray, 1994; Topper, Maki & Holliday, 1993; Williams, McClenaghan & Dickerson, 1997). Clinical measures of walking speed (Obuchi, Shibata, Yasamura & Suzuki, 1994; Whipple & Wolfson, 1989) or challenged walking through an obstacle course (Means, Rodell & O’Sullivan, 1996) have also been reported to distinguish between fallers and non-fallers. Kinematic gait variables alone do not appear to identify those at risk for falls, however (Feltner, MacRae & McNitt-Gray, 1994).

A small but growing number of studies describe the positive effects of exercise on strength and balance with concurrent increases in functional abilities and reduction in falls. They lend further support to the assumption that the remediation of (ostensibly causative) impairments will reduce the risk for and frequency of falls, as well as the extent of disability. Fiatarone (1994) demonstrated that a doubling of strength post resistance training was accompanied by improved gait speed (11.8%) and stair-climbing ability (28%) in frail nursing home residents. Gains in strength in older women who were already physically independent, however, were not associated with much functional change (Skelton, Young, Grieg & Malbut, 1995). Improved stair-climbing ability (11%) and one-legged stance time (a balance measure) (26%) occurred following lower extremity strength increases in community-dwelling older adults (Nichols, Hitzelberger, Sherman & Patterson, 1995). In addition to strength, improvements in balance are also followed by improvements in functional ability. A 1995 study of community dwelling elderly by Rose, Clark & Hobbel described large increases in multiple dynamic balance measures, with concurrent improvements in the performance of walking, stepping over obstacles, sit-to-stand, and stair-climbing tasks. Positive changes in balance were also

accompanied by functional improvements in older adults living in residential care facilities, according to Harada et al., 1995. They found significant improvements on the Berg Balance Scale (Berg, 1989) and the Tinetti POMA (Tinetti, 1986); 90% of subjects improved significantly in walking, 88% in transfers, and 12% in stair climbing and street-crossing. Exercise programs targeting balance and strength have achieved moderate success in reducing falls. Tinetti et al. (1994) used a multifactorial intervention with 301 community dwelling older adults; post-hoc analysis showed that balance/strength exercise and reduced medication use were the two factors responsible for the significant difference between the number of post-intervention falls experienced by the experimental group (35%) versus the control group (47%). Balance and strength improvements were also demonstrated by Lord and colleagues (Lord, Ward, Williams & Strudwick, 1995) following a 12-month training program. They demonstrated that compliant exercisers (those who attended 75% or more of the exercise sessions) experienced half the number of multiple falls as non-exercising control subjects. The total fall rate in the compliant exercise subjects was 45.8 per 100 versus 66.6 per 100 in the non-compliant subjects who exercised but attended less than 75% of the sessions. A 1995 study of multiple fallers by Shumway-Cook, Gruber and Baldwin also found significant differences in fall risk between compliant and non-compliant exercisers, and controls. Balance, strength and mobility exercises were offered for 12 weeks. Compliant exercisers reduced their fall risk by 33%, non-compliant exercisers by 11%, while control subjects' fall risk actually increased by 8%. Tai Chi Quan exercises were used as a balance exercise intervention by Wolf and associates (Wolf, Barnhart, Ellison & Coogler, 1996). They found a 47.5% delay in the onset of first or multiple falls in older subjects practicing these exercises compared to control subjects.

Balance is an interim process between the impairment and disability levels. The impairments that exist in components of postural control impact the balance process. If the outcome of the process is successful, falls do not occur and the ability to perform

functional activities is preserved (disability is avoided). If the outcome of the process is unsuccessful, falls may occur and functional activities cannot be performed (disability results). Greater clarity regarding the significance and direction of relationships between impairments, balance, disabilities and falls in the elderly would be achieved if future studies included all four levels concurrently. Currently, however, readers of the literature must consider existing studies collectively to infer support for the assumption that causal relationships between impairments, balance, disabilities and falls actually exist.

### The Systems Model of Postural Control

Balance is a complex sensorimotor process that achieves the goal of controlled movements in upright postures. It has been defined as the ability to control the center of gravity (COG) over the base of support in any given sensory environment (Nashner, 1989). The COG is an imaginary point in space, calculated biomechanically from forces and moments, where the sum total of all the forces equals zero. The position of the COG in space changes constantly with body movement. The base of support is the body surface that experiences pressure as the result of body weight and gravity. In the case of upright standing, the feet and the area between them constitute the base of support. The size of the base of support will affect the difficulty level of the task of balancing: the larger the base of support, the easier the task, while a small base of support challenges balance. With any given base of support, there is a limit to the distance a body can move without either falling (as the COG exceeds the base of support), or creating a new base of support by stepping or reaching. This boundary is referred to as the limit of stability (Horak et al., 1989). It is the furthest distance a person can lean in any direction without altering the base of support. The position of the COG in relation to the base of support may be altered either volitionally, as in reaching to remove an object from a shelf, or

involuntarily, as when a bus suddenly brakes unexpectedly and riders must react to the disturbance.

The biomechanical task of maintaining the COG over the base of support must be accomplished within an environmental context. Knowledge about the environmental conditions is acquired through the sensory systems. Peripheral sensory receptors detect information about the environment, the body in relation to the environment, and the body segments in relation to each other. Central sensory structures process this information to determine the opportunities and risks present in the environment. They perceive the meaning in the sensory signals collected by the peripheral receptors. Gravity is a constant environmental condition. The support surface conditions may be stable or unstable (paved versus gravel driveway) as may the visual conditions (fixed reference points versus moving crowds). Stable environments with adequate, accurate sensory cues place a lower demand on the individual, while unstable conditions with insufficient or inaccurate sensory cues increase the difficulty of perceiving position in space. Variations in the balance responses required to control the COG position result from the interaction of the individual (with normal or abnormal abilities), the task that the individual is choosing to perform, and the environment in which the task must be accomplished. Any of these three variables may change, creating the need for an adaptive change in balance response.

The components of the postural control system have been described by Nashner (1989). (The methods section will describe how these components will be measured.) Three primary peripheral sensory inputs contribute to postural control. These are the bilateral receptors of the somatosensory, visual and vestibular systems. Somatosensory receptors located in the joints, ligaments, muscles and skin provide information about muscle length, stretch, tension, and contraction, as well as pain, temperature, pressure, touch and joint position (Simoneau, Ulbrecht, Derr & Cavanaugh, 1995). Visual receptors in the eyes allow environmental orientation for navigation (focal vision) and

permit detection of motion, including head movement (ambient vision). Vestibular receptors in the inner ears provide information about head position in relation to gravity, and linear and angular accelerations of the head during movement. Vision is the only sense contributing to feedforward, or anticipatory, postural control, while all three senses provide feedback and contribute to reactive postural control. Changes in these peripheral receptors due to aging, disease, or injury will reduce the amount and/or accuracy of information transmitted to the brain for use in postural control.

Sensory organization is the central perceptual process by which the incoming sensory inputs from the periphery are recognized, compared, selected (based on usefulness for the task or environment at hand), and combined. If all three senses are available and accurate, and the two sides (right and left) and three systems all “agree” about the conditions of the environment and the body within it, then the processing task is (relatively) easy. However, if sensory information is not available (i.e., visual cues not available in darkness), is inaccurate (i.e. the sand on the beach is compliant under the feet), or if the two sides or three senses do not “agree” about the environmental conditions (i.e. air travel at night), then the perceptual processing problems are difficult and resolution is complex. Changes in the brain due to aging, disease, or injury can reduce the ability of the central nervous system to perceive environmental conditions and body position, and to resolve sensory conflicts when they occur.

The central nervous system is also critical for the motor control of balance. Movement is largely goal-directed, thus intention to act precedes action itself. Motor planning involves the formation of a solution to the motor problem at hand, and the timing, sequencing, and force modulation of movements. The brain compares this intended plan of action to the actual motions that occur, making adjustments to correct movement errors and refine motor skills. Changes in the brain due to aging, disease, or injury can impede motor problem solving, planning, coordination and learning.

The motor plan is transmitted to the peripheral musculoskeletal system, where the muscles and joints execute it. The joints must have adequate excursion to allow motions to occur; the muscles must be able to recruit fibers quickly and produce sufficient force to initiate and control limb movements. For many actions, muscle endurance is also required. Changes in muscles and/or joints due to aging, disease or injury diminish the ability to move through normal ranges of motion with the speed and force necessary to accomplish purposeful tasks.

At the most basic level of postural control are involuntary reflexes and righting reactions. The vestibulo-ocular reflex (VOR) allows the coordination of eye and head movements: stabilizing visual gaze when the head is moving. Visual tracking when the head is fixed or moving (smooth pursuit) is supported by visuo-ocular responses that work concurrently with the VOR. The vestibulo-spinal reflex (VSR) allows the coordination of the trunk relative to the extremities and stabilizes the body when the head is moving. Righting reactions orient the head on the trunk and the position of the head in relation to the ground.

At a subconscious level, automatic and anticipatory postural responses operate to maintain the COG over the base of support. Automatic postural responses provide “feedback” control when an unexpected perturbation occurs (suddenly altering the position of the COG within the limits of stability). Stereotypical movement strategies emerge, termed “ankle”, “hip” and “stepping” strategies. These are matched to the perturbation in amplitude (equal) and direction (opposite). They occur in less than 250 milliseconds, hence are not under volitional, conscious control. Anticipatory postural responses are similar to automatic postural responses, however, they occur before a predicted disturbance of the COG position. They provide feedforward control by “setting” the postural musculature prior to expected or self-initiated movement.

At the conscious level, volitional postural movements are controlled. Leaning to reach for the telephone or to put the laundry in the dryer, for example, are

voluntary actions requiring dynamic COG control through the limits of stability. These actions can range from the simple to the complex, with new or more complex actions requiring greater conscious attention and effort to accomplish.

If the components of the postural control system described earlier do not function normally, disturbances of balance can be seen at one or more of the levels of postural control: reflexes, righting reactions, automatic postural responses, anticipatory postural responses, and volitional movements. A major problem in the measurement of balance is that no single test adequately reflects all levels of control. Multiple tests are thus necessary to confidently identify (1) which levels of postural control are affected, and (2) the specific components involved.

### The Aging Postural Control System

Several excellent reviews of postural control system changes in older adults have been published (Alexander, 1994, 1996; Horak et al., 1989; Woollacott, 1990). It should be noted that these and other authors agree that healthy elderly individuals have fewer, and less severely, involved components, compared to the unstable elderly or those older individuals experiencing falls. Certain researchers have focused on the relative degree of risk posed by some impairments versus others (Patla, Winter, Frank, Walt & Prasad, 1990; Tinetti & Speechly, 1989); all appear to concur that a greater number of impairments (and their interactive effects) directly increase the risk of falls. Chandler and Duncan (1993) have described the concept of “functional reserve” and a critical threshold for functional loss and falls. In other words, one-plus-one equals more than two: the presence of multiple impairments (versus which particular impairments) may be the critical factor. The following summary of postural control changes in the elderly is based largely on thorough reviews by Horak et al. (1989) and Alexander (1994, 1996).

Loss of peripheral sensation in the elderly is frequently reported (Anacker & DiFabio, 1992; Manchester, Woollacott, Zederbauer-Hilton & Marin, 1989; Tobis et al., 1990; Whipple, Wolfson, Derby, Singh & Tobin, 1993). Somatosensory loss for both vibration sense and position sense at the ankle is prevalent, affecting 30% to 50% of the older adult population (Skinner, Barrack & Cook, 1984). Visual loss is also widespread, including reduced acuity, contrast sensitivity, depth perception, and motion sensitivity (Amerson, Mershon & Gilliom, 1990; Sundermeir, Woollacott, Jensen & Moore, 1996). Vestibular degeneration occurs, with hair cell, ganglion cell, and nerve fiber loss (Weindruch, Korporek & Hadley, 1989). Smooth pursuit eye movements, which rely on both visual and vestibular interactions, are also reported to be impaired in the elderly. Common pathologies that may produce peripheral sensory loss in the elderly include cervical spondylosis, diabetes, vascular compromise, cataracts, glaucoma, and macular degeneration.

Central sensory organization and perception of stability limits are also diminished in the aged. When presented with conflicting sensory input, young subjects sway significantly more, but do not fall, while older subjects often lose balance (Wolfson et al., 1992). The ability to select and prioritize sensory inputs adaptively appears to be slowed in almost all older adults, and significantly reduced or absent in elderly fallers (Camicioli, Panzer & Kaye, 1994, 1997; Parry, 1994; Panzer, Kaye, Edner & Holme, 1992). Inaccurate perception of the limits of stability has been documented in older adults; the limits are perceived to be smaller than they actually are, and the older adult will not lean very far away from midline for fear of exceeding the (perceived) stability boundary (Blaszczyk, Lowe & Hansen, 1994; Hudgins et al., 1995; Light, Rose & Purser, 1997). While older adults may not be able to lean as far forward as young adults, elderly fallers lean significantly less than age matched non-fallers (Duncan, Studenski & Chandler, 1992). It is unclear at this time whether this finding reflects an inability (due to perceptual

problems) and/or an unwillingness (due to fear) to move the COG away from the midline position.

Central motor planning and adaptation abilities in older adults are similar to those of young adults in conditions where speed is not a factor and tasks are simple and predictable. However, when rapid responses are required and/or the tasks are complex or unpredictable, older subjects perform more poorly than their young counterparts. Elderly individuals who are unstable and/or experiencing falls display a loss of movement timing, sequencing and interlimb coordination compared to age-matched controls (Light, 1990). When perturbed, older adults tend to co-activate all muscles surrounding the joints to be controlled, antagonists as well as agonists, which produces stiffness instead of the normal automatic postural response strategies. They take slightly longer to begin a perturbation-induced postural response, and significantly longer to complete a successful postural response, than do younger adults (Nardone, Siliotto, Grasso & Schiepetti, 1995; Schleenbaker, Giersh, Sivaramakrishnan, Fisher & Bruce, 1993)). Problems are also seen in the scaling of responses to perturbations, with over or under reactions that are not well matched to the size of the stimulus. Anticipatory postural responses prior to self-initiated movements are also diminished in older adults. This anticipatory ability is critical for upper body control during walking (Prince, Winter, Stergiou & Walt, 1995; Woollacott & Tang, 1997). Slower voluntary reaction times are well documented in the elderly. Problems with central sensory and/or central motor processing may be due to slowed nerve conduction velocities, deficits in stimulus encoding, reduced neural transduction, cerebellar degeneration, and reduced neurotransmitter production or reception.

Musculoskeletal impairments are also prevalent in the elderly (Kauffman, 1990). Flexed posture is common, which shifts the head anteriorly and the COG position posteriorly in the limits of stability. Muscle weakness, particularly in the ankle dorsiflexors, is prominent, as is an increase in the amount of time required to reach maximum muscle contraction force. Other sites of weakness include neck, trunk, hip and

knee extensors, and hip abductors. Loss of strength in the extensor muscles of the neck, trunk and legs negatively affects the ability to control the large mass of the head, arms and trunk (Patla, Frank & Winter, 1990). Loss of joint flexibility is prevalent, with loss of spinal and hip extension, and ankle dorsiflexion most often documented. Flexed posture in the elderly may be due to sub-clinical damage to the extra-pyramidal system.

Weakness in older adults is thought to be caused by a loss of fast-twitch muscle fibers and by disuse. Joint contractures may result from contractile tissue changes, diseases such as arthritis, and disuse.

Older adults frequently experience impairments in at least one and occasionally all of the components of the postural control system. If numerous impairments are present, or if impairments are severe, instability and falls will occur (Studenski, Duncan & Chandler, 1994; Studenski, Duncan, Weiner & Chandler, 1989). Each of these impairments associated with balance loss is a risk factor for falls. Current rehabilitation efforts to reduce the risk for falls in elderly individuals involve attempts to reduce or eliminate these impairments. Therefore, the identification of postural control system impairments becomes critical in the planning of treatment programs for elderly fallers.

### Assessment of Postural Control System Components

The presence or absence of impairments within the postural control system was determined through the performance of a comprehensive test battery that included measures of both peripheral and central sensory and motor components. Within the traditional medical model, various specialists would separately evaluate these components. For example, a neurologist, an ophthalmologist and an otolaryngologist might individually test somatosensory, vision, and vestibular sensory systems,

respectively. The combination of these tests into a multifactorial assessment battery is just beginning to gain acceptance in those clinicians working with elderly fallers.

Whenever possible, objective measures with documented reliability and validity were used. However, many clinical measures, frequently adopted due to their low cost and ease of administration, lack supportive documentation regarding measurement quality. Computerized measurement was available for the reaction time, limits of stability, sensory organization, motor control, and strength tests.

The three peripheral sensory inputs for postural control, somatosensory, vision, and vestibular, were tested using accepted clinical measures. Proprioception and vibration of the ankles and great toes were tested according to Nolan (1996). No publications on the reliability of these methods were found, however, they are the dominant clinical methods currently used for testing proprioception and vibration. Visual acuity was not tested, as the literature offers conflicting evidence regarding its contribution to risk for falls in the elderly (Means, 1995). Impairments of depth perception and contrast sensitivity, however, are widely accepted as risk factors and were both tested. Depth perception was tested using the Frisby Stereotest (Wright & Wormwald, 1992), as this was the only clinical test of stereopsis reported for use with older adults and which had documented validity (Manny, Martinez, & Fern, 1991; Rosner, 1984). Test-retest reliability for the Frisby Stereotest was not reported. Contrast sensitivity was measured using the Pelli-Robson contrast sensitivity chart (Elliott, Sanderson & Conkey, 1990; Pelli, Robson & Wilkins, 1988). Test-retest reliability in both young and older adults was demonstrated with a coefficient of repeatability of  $\pm 0.15$  log units with reported mean scores of 1.88 log units for young adults (mean age 22.5  $\pm$  4.3 years) and 1.75 log units for older adults (mean age 70.2  $\pm$  6.7 years). Vestibular impairments were identified using a clinical test of smooth pursuit, and the University of Michigan Motion Provoked Dizziness Test. The smooth pursuit test, as described by Herdman (1995) and commonly performed, has no quantifiable score, so reliability has not been documented. Within a

physiologic range of tracking speeds, normal subjects demonstrate no saccades: the presence of saccades while tracking a target at reasonable speeds (1.5 to 3.5 oscillations per second) is abnormal. The University of Michigan Motion Provoked Dizziness Test (Smith-Wheelock, Shepard & Telian, 1991) does allow a score to be assigned, however, no test-retest reliability data has been published.

Central sensory organization was tested using the Sensory Organization Test (SOT) on the EquiTest computerized dynamic posturography system (Nashner, 1990; Wolfson et al., 1992). Parry (1994) reported that the average equilibrium score from this test was able to discriminate fallers from non-fallers. Reliability for the SOT has been reported to be moderate (Intraclass coefficient (ICC) = .68) (Ford-Smith, Wyman, Elswick & Newton, 1995). Volitional limits of stability were investigated using the Limit of Stability test (LOS) on the Pro Balance Master computerized forceplate system (Allison, 1995). Reliability for the maximum excursion measure on the 100% LOS test has been reported by Clark, Rose and Fujimoto (1997) to be high ( $G = .84$  to  $.91$ ; Day 1 through Day 3). A computerized simple reaction time test was used as an indicator of central processing speed. Automatic postural responses were tested using the Motor Control Test on the EquiTest computerized dynamic posturography system. (Nashner, 1990; Wolfson et al., 1992). Reliability for this test has not been reported.

Musculoskeletal measures of strength and joint range of motion were performed. Isokinetic dynamometry (KinCom) was used to test lower extremity strength. Test-retest reliability for this instrument has not been reported. Joint range of motion was measured using a goniometer, according to the clinical method described by Norkin and White (1995). This method of testing has high intrarater reliability (knee ICC = .98; ankle ICC = .92) to within five degrees of motion (Clapper & Wolf, 1988; Watkins, 1991).

### Assessment of Disability

The Berg Balance Scale (BBS) is one of the most carefully developed and widely accepted clinical tests of balance and mobility (Berg et al., 1989; Berg, Wood-Dauphinee & Williams, 1995). This test is reliable in older adult populations (ICC = 0.98) and has been shown to be sensitive and specific for older adults who are mobility impaired and fallers versus non-fallers (Harada et al., 1995; Shumway-Cook, Baldwin, Polissar & Gruber, 1997). One limitation of this test, however, is that it contains no measure of walking performance, so the Timed Get-Up-and-Go Test (TGUGT) was used in addition to the BBS, as it includes a timed gait measure. The TGUGT is a valid indicator of functional ability in older adult populations (Podsiadlo and Richardson, 1991) and demonstrates good test-retest reliability (ICC = 0.84).

## METHODS AND PROCEDURES

### Introduction

The purpose of this study was to explore the relationship(s) between impairments within the systems contributing to postural control and disabilities as reflected by diminished performance of activities requiring balance skills. Components of the postural control system that were investigated included three peripheral sensory systems (somatosensory, vision, and vestibular), central sensory processing (sensory organization), central motor control (processing speed, volitional center-of-gravity control, and reactive postural responses), and two peripheral motor, or biomechanical, factors (strength and joint range-of-motion). Impairments within these systems were identified using multiple tests specific to each component. Disabilities were identified using the Berg Balance Scale (BSS), a 14-item rating scale frequently used in clinical practice, and the Timed Get-Up-and-Go test.

### Subjects

A total of 103 subject were recruited for this study. Four subjects were too frail to complete all the testing; one dropped out due to an unrelated medical problem, and two subjects were excluded due to lost data. Ninety-six (31 male and 65 female) volunteers who completed all tests served as subjects for this study. Volunteers were recruited from

the Benton County community and from senior residential living centers in Corvallis and Albany, OR. Subjects ranged in age from 65 to 94 years of age, with a mean age of 79 years. All subjects were mentally capable of understanding the purpose of the study, and had the apparent (though not tested) cognitive and physical abilities to safely perform all of the testing procedures. A broad range of functional ability levels was represented. Subjects included healthy elders with few, mild impairments as well as frail elders with numerous or more severe impairments. Subjects were asked to indicate whether or not they had experienced any unexplained falls (unintentionally coming to rest on the ground with no apparent precipitating cause). By self-report, 40 of the subjects had no falls, 35 had experienced one fall, and 19 had fallen two or more times (two subjects did not answer this question). Of the 88 subjects who reported their medication status, 17 took no prescription drugs, 53 took one to three drugs, and 26 took four or more drugs. All subjects gave their informed consent prior to inclusion in this study (see Appendix 1).

### Procedures

Multiple tests were performed, each involving separate equipment and procedures. Testing was performed in either one or occasionally two sessions (when necessary to minimize potential subject fatigue). Frail subjects for whom fatigue was a concern attended each session (one at the Motor Behavior Laboratory on the OSU campus and one at their place of residence) on two separate days, not more than three days apart. Measurements requiring non-portable equipment, e.g. EquiTest®, PRO

Balance Master®, KinCom® isokinetic dynamometer, and Macintosh computer, were performed in the Motor Behavior Laboratory in a single two-hour session. Tests that could be performed with portable measurement devices (vision chart, goniometer, etc.) were administered either at the campus site or at the subject's residential living center in a second two-hour session. Non-frail subjects generally preferred to complete all tests in a single visit. Tests were not administered in any particular order, but were in effect nearly randomized, as subjects were started at whatever testing "station" was available at the time of their arrival, and afterward proceeded to any available station. To minimize fatigue for frail subjects during the campus session, less strenuous (seated) tests were interspersed with the tests requiring greater effort (standing).

The tests that were conducted for the purpose of identifying impairments within the four components of the postural control system are as follows:

### 1. Peripheral Sensory Systems

Somatosensory: Proprioception and Vibration Sense

Vision: Depth Perception and Contrast Sensitivity

Vestibular: Smooth Pursuit and Motion Sensitivity

### 2. Central Sensory Processing

Sensory Organization Test®

### 3. Central Motor Control

Simple Reaction Time

Motor Control Test®

Limits of Stability Test®

#### 4. Peripheral Motor Systems

Strength (bilateral knee flexion and extension, ankle dorsiflexion and plantarflexion)

Range of Motion (bilateral hip extension, knee extension and ankle dorsiflexion)

The tests used to identify disabilities (problems performing activities) were the Berg Balance Scale (BBS) and the Timed Get-Up-and-Go Test (TGUGT). Descriptions of each test, including the specific equipment and procedures involved with each test, are presented in the next section.

#### Peripheral Sensory System Tests

##### Somatosensory: Proprioception

Proprioception is the ability to detect joint position. The subject lay supine with knees slightly flexed over a support, barefoot, with visual access to the feet obstructed. Instructions were given to the subject to indicate verbally if the toe/ankle moved “up” or “down”. Each of the four joints to be tested (first metatarsal and ankle joints bilaterally) was passively moved a small amount (two to five degrees) away from the neutral position alternately into flexion and extension.

Two practice trials were provided, with exaggerated joint movement to near end ranges, to ensure that the subject understood the test and followed instructions appropriately. Four scored trials per joint (two flexion, two extension) were performed. The great toes were tested first. If the results of these trials indicated no sensory loss at the great toes, the ankle trials were eliminated. (Peripheral sensory loss occurs in a distal to proximal sequence. If the distal joint sensation is intact, the more proximal joints are also assumed to have intact sensation.) If sensory loss was apparent at the toes, the ankle trials were then administered. The right side joints were tested first, followed by the left side joints.

An ordinal rating scale (zero to four) was used to score the degree of proprioceptive impairment. For the purposes of this study, a joint was considered to have normal proprioception sense if the directions of all the movements were correctly identified. A score of four indicated that both toes had normal proprioception. A score of three indicated that one toe was impaired; the other toe and both ankles had normal proprioception. A score of two indicated that either a) both toes were impaired while both ankles had normal proprioception, or b) one toe and ankle were impaired while the opposite side had normal proprioception. A score of one indicated that one ankle had normal proprioception, but the other ankle and both toes had impaired sensation. A score of zero indicates that proprioception was impaired bilaterally at the toes and ankles.

### Somatosensory: Vibration Sense

Vibration sense is the ability to detect vibration, including the discrimination of frequency, onset, and cessation. Two tuning forks, one 30 Hz and one 256 C, were used for this test. The subject lay supine with knees slightly flexed over a support, barefoot, with visual access to the feet obstructed. Instructions were given to verbally indicate immediately whether the contact was vibrating “fast” or “slow”. (Some subjects preferred the terms “high” and “low”). Contact points for the forks were the head of the first metatarsal bone and the medial malleolus bilaterally. Two practice trials, one with each fork placed at the wrist, were provided to ensure that the subject understood the test and followed the instructions appropriately. Four scored trials (two with each fork) were administered to the distal joints, right side preceding left side. If the results of these trials indicated no sensory loss at the great toes, the ankle trials were eliminated. If sensory loss was apparent at the toes, the ankle trials were then administered.

An ordinal rating scale (zero to four) was used to score the degree of vibration sense impairment. For the purposes of this study, a joint was considered to have normal vibration sense if all frequencies were correctly identified. A score of four indicated that both toes had normal vibration sense. A score of three indicated that one toe was impaired; the other toe and both ankles had normal vibration sense. A score of two indicated that either a) both toes were impaired while both ankles had normal vibration sense, or b) one toe and ankle were impaired while the opposite side had normal vibration sense. A score of one indicated that one ankle had normal vibration sense, but the other

ankle and both toes had impaired vibration sense. A score of zero indicated that vibration sense was impaired bilaterally at the toes and ankles.

The proprioception and vibration sense tests as described above are commonly used in clinical practice (Nolan, 1996), but scientific studies documenting their reliability have not been published. The ordinal rating scales as described above were developed for this study. Unfortunately, this method of scoring did not distinguish between joints which had three, two, one or zero of four correct; i.e., it reflected only the presence or absence of impairment, not the degree of impairment, at any one joint

### Vision: Depth Perception

Depth perception (stereopsis) is the binocular visual ability to judge distance. The Frisby Stereotest Screener (Clement Clarke International), a 6 mm. diameter plate with four square visual images covering a stereo-acuity range of 600 to 85 of arc, was employed for this test. One of the four images contained a “circle-in-depth”, that is a circular portion of the display appeared to be raised (or, lowered if the plate was reversed). The plate was placed on a piece of white paper on the table in front of the subject. During the test, the plate and the subject’s head remained still. The subject was asked to view each of the four images and to name or point to the square that contained the offset circle. The subject was given 5 s. to reply. The tester recorded the response as correct or incorrect, with responses taking longer than five seconds classified as incorrect. The subjects were told to close their eyes, and the tester then randomly rotated the plate

to a new position. The subject was told to open their eyes, and the test was repeated. The position of the square image that contained the circle-in-depth changed each trial. A total of one practice trial and 10 scored trials were performed. The number of correct responses out of 10 attempts served as the score for this test.

A literature search revealed no test-retest reliability documentation for this test, however, it is commonly used in clinical visual practice and visual research, and was the only stereopsis test in the literature to have been used with elderly subjects (Wright & Wormald, 1992)

#### Vision: Contrast Sensitivity

Contrast sensitivity is the visual ability to discern foreground from background. The Pelli-Robson Contrast Sensitivity Chart (Clement Clarke, Inc. Columbus, OH) was used to determine contrast sensitivity levels. There were 16 letter triplets on the chart, ranging in contrast from 96% to 1%. The wall chart was mounted at the subject's eye level, in a well-illuminated area without glare. The subject sat 40-in. from the chart, wearing corrective lenses if needed. The subject attempted to name each letter on the chart, beginning in the upper left hand corner and reading horizontally across the line (letters became fainter as the test continued, both across lines and from line to line). Subjects were asked to guess even if they believed the letters to be invisible, per the manufacturer's protocol. The tester scored each letter as read correctly versus incorrectly. Scoring was stopped when a subject incorrectly identified two of three letters in a

“triplet” of letters at a certain contrast level. The subject’s contrast sensitivity score is the contrast level at the last triplet of letters where two of the three letters were correctly identified.

Elliott (1990) has reported normative data and test-retest reliability for this method. The mean Pelli-Robson contrast sensitivity score for young adults (mean age 22.5 +/- 4.3 years) was  $1.88 \pm 0.08$  log units, and for older adults (mean age 70.2 +/- 6.7 years) was  $1.75 \pm 0.12$  log units. Test-retest reliability for the Pelli-Robson contrast sensitivity chart was analyzed using the coefficient of repeatability (Bland & Altman, 1986; Elliott & Sheridan, 1988). This method gives the 95% confidence limits for the amount of difference between two sets of results. It is calculated as 1.96 multiplied by the standard deviation of the mean differences between the two sets of data. The coefficient of repeatability for contrast sensitivity test-retest was plus or minus 0.15 log units.

### Vestibular: Smooth Pursuit

Visual interaction with the vestibular-ocular reflex allows the coordination of eye and head movements, such that the eyes can remain fixed on a target while the head is fixed but the target is moving; this function is termed “smooth pursuit”. Normal subjects can track the moving target with smooth eye movements. Subjects with vestibular-ocular deficits display saccadic eye movements when tracking the target, that is, the eyes do not keep up with the target and must make small corrective “jumps” to catch up to the target. A metronome and a visual target were used during this test. The examiner sat opposite

the subject and held the visual target at the subject's eye level at a distance from the subject equal to the subject's arm length. The metronome was started at a two second pacing. The subject was asked to keep their head fixed resting on their hands, with the eyes fixed upon the target while the examiner moved the target side to side (approximately 35 degrees each way), for 10 s. The metronome pace was increased in increments of one-half seconds until a half-second pacing was reached. The tester observed the eyes of the subject for saccadic eye movements, and recorded the fastest metronome pace at which smooth pursuit could be maintained without visible saccades. This number served as the smooth pursuit score.

This test as described above is commonly used in clinical practice (Herdman, 1995; Shepard & Telian, 1996; Whitney, 1991), but empirical studies documenting its reliability have not been published. The use of the metronome to standardize the pacing, and provide the score, was developed for this study.

### Vestibular: Motion Sensitivity

Head movement (i.e., angular rotation) stimulates the semicircular canals of the vestibular organs; normally, opposite sides produce equal and opposite reactions and no dizziness is experienced. Asymmetrical responses (indicating that one side is hyper or hypo-responsive compared to the other) can evoke sensations of dizziness or vertigo. A stopwatch and the University of Michigan's Motion Sensitivity form (see Appendix 2) were used for this test (Shepard & Telian, 1993; Smith-Wheelock, Shepard & Telian,

1991). The subject performed each of the 16 motions once as described on the form. The subject was instructed to inform the tester of any sensation of dizziness, rating its severity on a scale of one to five (five being the most severe). The tester used a stopwatch to monitor the time in seconds that the sensation of dizziness remained after the provoking motion was stopped. The tester later calculated the “Motion Sensitivity Quotient” (MSQ) per University of Michigan protocol (intensity plus duration totals, divided by the largest possible total). This quotient served as the score for this test. This test as described above is commonly used in clinical practice (Shepard & Telian, 1993), but empirical studies documenting its reliability have not been published.

#### Central Sensory Processing : Sensory Organization Test®

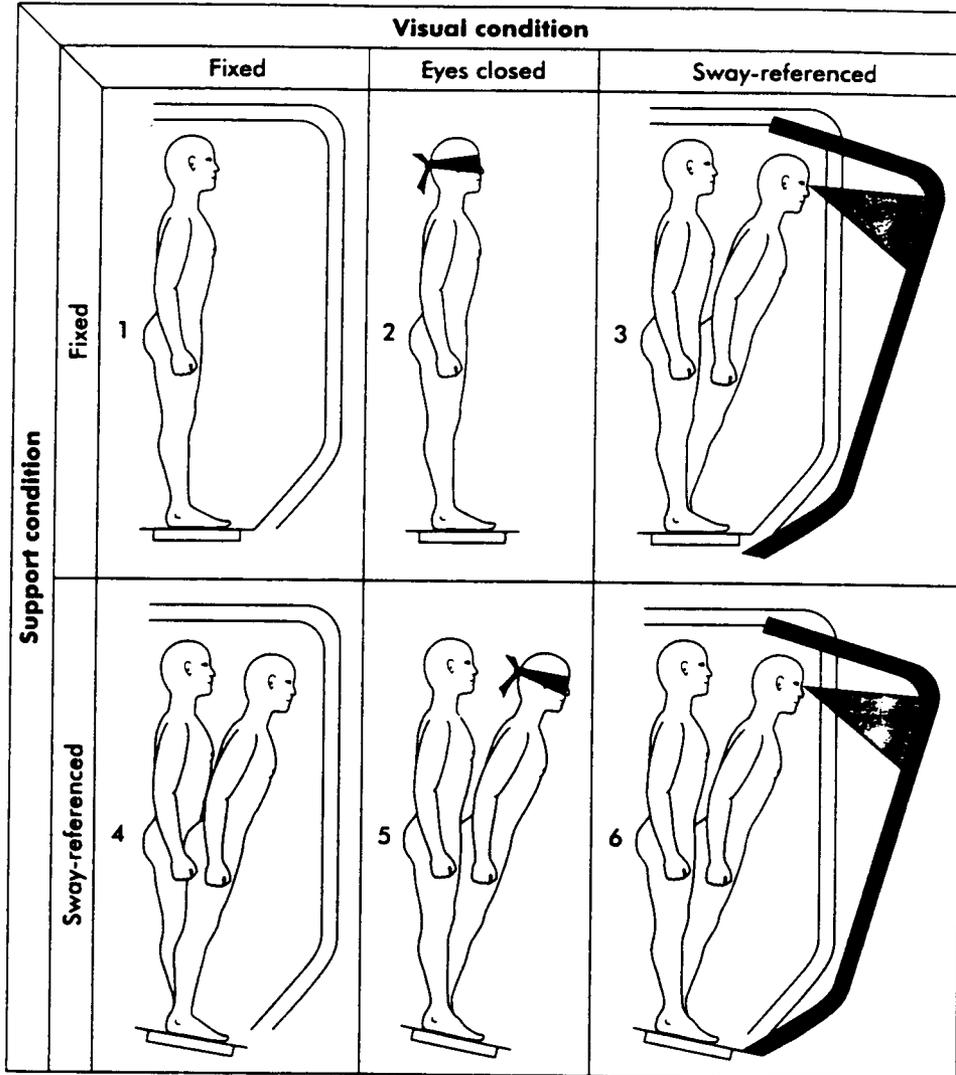
Sensory organization (for postural control) is the ability of the brain to compare, select and combine the accurate and available sensory inputs to achieve a correct perception of spatial position in relationship to self and environment. Normally, three senses (somatosensory, vision, vestibular) provide somewhat redundant information. In the (artificially produced) absence of available or accurate information from any sensory system(s), the ability to make use of the remaining sense(s) is considered normal. Inability to maintain postural control (reflected by increased sway) when sensory inputs are removed or altered indicates an inability to use the remaining sensory inputs. The EquiTest® computerized dynamic posturography system (NeuroCom International, Inc., Clackamas, OR) was used to perform this test. This test is graphically represented in

Figures 1 and 2. A harness was worn by the subject and attached to an overhead bar to prevent a fall should loss of balance occur during the test. The subject stood barefoot on the forceplate with feet placed according to the protocol recommended by the manufacturer, to align the axis of ankle motion with the axis of forceplate rotation. The subject was instructed to remain standing as steady as possible (minimize sway) during the test. Movement of the COG (body sway) was detected by the forceplate and calculated by the computer.

Six test conditions were presented to the subject. In the first three conditions (C-1, C-2, C-3), the forceplate was stable, providing accurate somatosensory cues. In the last three conditions (C-4, C-5, and C-6), the forceplate moved in a one-to-one ratio with the sway of the subject, rendering the somatosensory cues inaccurate for postural control. The eyes were open (visual cues available and accurate) in conditions one and four, but were closed (visual cues unavailable) in conditions two and five. The visual surround moved in a one-to-one ratio with the sway of the subject during conditions three and six, making the visual cues inaccurate for postural control. This systematic reduction of available and accurate sensory information made the task of balancing progressively more difficult: the individual had to accomplish the same result with less resources.

Each trial of each condition lasted 20 s. For scoring purposes, one trial of conditions 1 and 2 were given; three trials each of conditions 3, 4, 5, and 6 were given, per the protocol recommended by the manufacturer. The composite equilibrium score was used for the purposes of this study. Test-retest reliability for this method using the equilibrium composite score has been reported by Ford-Smith (1995) to be moderate (R = .68).  
*older adults*

**FIGURE 1**  
**SENSORY ORGANIZATION TEST**



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**FIGURE 2**  
**SENSORY ORGANIZATION TEST**

<b>SENSORY ANALYSIS</b>			
<b>RATIO NAME</b>	<b>TEST CONDITIONS</b>	<b>RATIO PAIR</b>	<b>SIGNIFICANCE</b>
SOM Somatosensory	 	<u>Condition 1</u> Condition 2	Question: Does sway increase when visual cues are removed?  Low scores: Patient makes poor use of somatosensory references.
VIS Visual	 	<u>Condition 4</u> Condition 1	Question: Does sway increase when somatosensory cues are inaccurate?  Low scores: Patient makes poor use of visual references.
VEST Vestibular	 	<u>Condition 5</u> Condition 1	Question: Does sway increase when visual cues are removed and somatosensory cues are inaccurate?  Low scores: Patient makes poor use of vestibular cues, or vestibular cues unavailable.
PREF Visual Preference	 	<u>Condition 3 + 6</u> Condition 2 + 5	Question: Do inaccurate visual cues result in increased sway compared to no visual cues?  Low scores: Patient relies on visual cues even when they are inaccurate.

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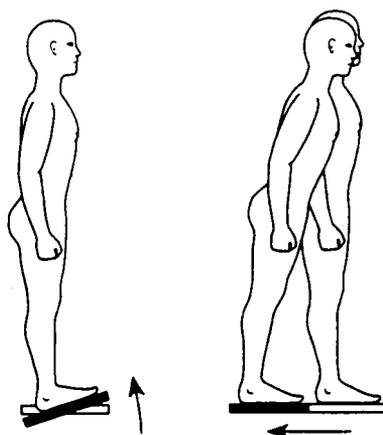
## Central Motor Control Tests

### Reactive Postural Control: Motor Control Test®

When the relationship between the center-of-gravity and the base-of-support is suddenly disturbed by a perturbation, the body normally produces automatic postural responses to bring the center-of-gravity back into alignment over the base-of-support. These responses normally occur in less than 250 ms., and the size of the corrective response is normally appropriately matched to the size of the perturbation. In this test, a programmable dual forceplate provided the perturbation (anterior or posterior translations) and recorded the latency (time to onset) and amplitude of the automatic postural responses to be measured. The EquiTest® computerized dynamic posturography system (NeuroCom International, Inc.) was used to perform this test. This test is graphically represented in Figure 3.

A harness was worn by the subject and attached to an overhead bar to prevent a fall should loss of balance occur during the test. The subject stood barefoot on the forceplate with feet placed according to the protocol recommended by the manufacturer, to align the axis of ankle motion with the axis of forceplate rotation. The subject was instructed to remain standing as steady as possible during the test. Sequential exposure to several surface translation perturbation trials were provided. Perturbations occurred in either the anterior or posterior direction, and were small, medium, and large in size. Three trials of each perturbation direction were presented, in order from smallest to largest, according to the manufacturer's recommended protocol. The small perturbations in each

**FIGURE 3**  
**MOTOR CONTROL TEST**



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direction were considered practice trials. Latency scores, averaged from the six medium and six large perturbation trials were used for the purposes of this study. No measure of reliability has been reported for this test.

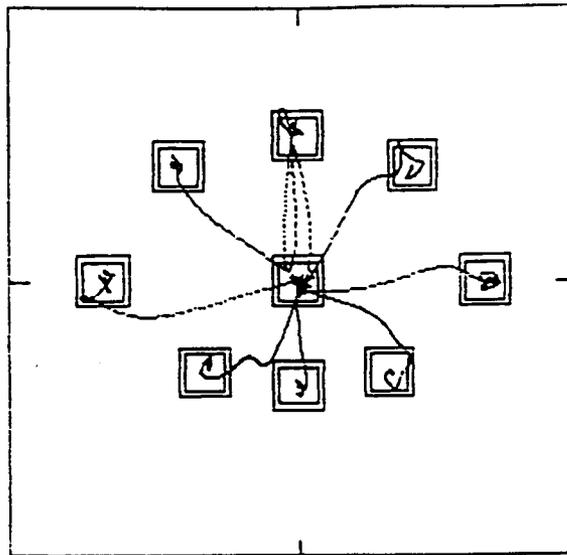
### Central Processing Speed: Simple Reaction Time Test

Simple reaction time is defined for the purpose of this study as the time in milliseconds that elapses between the presentation of a single visual stimulus and the depression of a key by the index finger of the subject's right hand. This measure served as an indicator of central processing speed. A Macintosh computer, monitor, and keyboard, with software "Microcomputer Based Labs in Motor Learning and Control" (Simon Fraser University, Burnaby, BC), were used for this test. The subject was seated at the computer with the right hand placed on the keyboard and index finger positioned on the "J" key. The subject was instructed to press the key immediately each time the visual stimulus appears (darkened box on screen). The foreperiod was automatically varied from one to three seconds for each trial to control for anticipation. Five practice trials were provided; scores from these trials were discarded. Ten scored trials were given, and the average of these trials was used as the final score. Responses that were too early or incorrect were not counted; additional trials were run until 10 scored trials had accumulated, per the manufacturer's protocol.

### Volitional Postural Responses: Limit of Stability Test®

The Limit of Stability (LOS) is the furthest distance an individual can lean away from a centered position without changing the original base of support (stepping or reaching) or falling. The PRO Balance Master® (NeuroCom International, Inc., Clackamas, OR) was used to perform this test. This test is graphically represented in Figure 4. The subject wore a harness attached to an overhead bar to prevent a fall should loss of balance occur during the test. The subject stood barefoot on the forceplate with feet placed according to the protocol recommended by the manufacturer. During this test, on a monitor screen in front of the subject, a cursor representing the subject's Center-of-Gravity (COG) point was displayed. This cursor moved when the subject moved the COG in any direction. Also on the screen were nine stationary targets, one in the center, and eight peripheral targets placed in an ellipse around the center target. The general objective during this test was for the subject to move the cursor from the center target to each of the eight peripheral targets; each of these eight movements was termed a transition. At the beginning of each transition, a visual cue located in the center target disappeared from that target and appeared in one of the eight peripheral targets. The subject was instructed to begin with the cursor in the center (standing still) and watch for the cue to reappear in one of the peripheral targets. When the cue reappeared, the subject was required to move the cursor (by shifting body weight over the feet) as quickly and accurately as possible to the indicated peripheral target, and to remain in that target as long as the visual cue remained present. When the cue disappeared from the peripheral target and reappeared in the center target (as it does

FIGURE 4  
LIMIT OF STABILITY TEST



between each peripheral target transition), the subject was to move the cursor back to the center target and become still again, awaiting the next transition. Targets were highlighted in a clockwise order. Several measures were available from this test, however, for the purposes of this study, only the distance measure “maximum excursion” (i.e., how far the subject can lean away from the center) was used. Scores from the first administration of the test were discarded, as it was considered a practice trial. Eight transition scores from the second test were averaged and used in this study. Test-retest reliability for this measure has been reported by Clark et al. (1997) to be high ( $G = .89$  to  $.91$ )

### Peripheral Motor System Tests

#### Strength

Strength is the amount of force generated during muscle contraction. A specific measure of strength to be used in this study was “power”, or the amount of force that can be generated at a certain velocity of motion. The KinCom Isokinetic Dynamometer® (Chattanooga Corporation, Knoxville, TN) was used to perform this test. For quadriceps and hamstrings testing, the subject was seated on the KinCom with a hip angle range of 100 to 115 degrees, and a right knee angle of 90 degrees. The waist and right thigh were secured to the seat with straps. The anterior right leg was placed against a pad (attached to the movement lever) and secured with a strap. The subject was instructed to kick the

leg up as quickly and forcefully as possible, then relax. The subject was then instructed to pull the leg down (to the starting position) as quickly and forcefully as possible, then relax. Three practice trials at the 90-degree per second speed were given; then three scored trials were performed. The left knee was subsequently tested in the same manner. The average of the six scored trials (three for each knee) was used for this study.

For anterior tibialis and gastrocsoleus testing, the subject was seated on the KinCom with a hip angle range of 100 to 115 deg/s, and a knee angle range of 45 to 60 degrees. The waist and left thigh were secured to the seat with straps, and the left leg was secured to a calf support with a strap. The left foot was placed on the movement arm such that the ankle was as plantarflexed as comfortably possible, and secured at the forefoot with a strap. The subject was instructed to “pull the toes up” as quickly and forcefully as possible, then relax. The subject was then instructed to “push down” (to the starting position) as quickly and forcefully as possible, then relax. Three practice trials at the 90-degree per second speed were given; then three scored trials were performed. The right ankle was subsequently tested in the same manner. The average of the six scored trials (three for each ankle) was used for this study. Combining the average knee and the ankle scores generated a total lower extremity strength score.

### Range-of-Motion

Range of motion is the degree of joint excursion through an arc of motion. A goniometer and a mat table were used for this test. Placement of the goniometer at the

hip, knee, and ankle joints was performed according to Norkin and White (1985). For measurement of right hip extension, the subject was positioned prone on the mat table if tolerated, alternately positioned on the left side with left leg slightly flexed and right forearm on the mat. The examiner passively moved the right hip to maximal extension position, and the degree of excursion recorded. This procedure was repeated for the left hip. For measurement of knee extension, the subject was positioned supine on the plinth, with thigh support if needed for comfort. The examiner passively extended the right knee maximally, and recorded the degree of excursion. This procedure was repeated for the left knee. For measurement of ankle dorsiflexion, the subject was positioned supine on the plinth, with thigh support if needed for comfort. The right ankle was passively maximally dorsiflexed by the examiner, and the degree of excursion recorded. This procedure was repeated for the left ankle. Intrarater reliability of goniometric joint measurement has been reported to be  $ICC = .98$  for the knee (Watkins, 1991) and  $ICC = .92$  for the ankle (Clapper & Wolf, 1988). The number of degrees of restriction at each joint measured was subtracted from the possible maximal range, and the total degrees available were summed and used as the score for this study.

## Tests for Disability (Inability to Perform Activities)

### Berg Balance Scale

The Berg Balance Scale (BSS) is an activity-based clinical test battery of 14 ordinarily scored items (See Appendix 2). In the process of test administration, two chairs, one six inch curb or step, a stopwatch, a yardstick, and an object to retrieve from the floor were used. The subject was asked to perform each activity in the test battery in order, from easiest to most difficult. Each subject was “guarded” by an assistant (to prevent a fall) in case balance was lost. Each item has specific instructions for the subject (See the scoring form in Appendix 2). The instructor scored each item on an ordinal rating scale of zero to four, then summed the scores for a total score. The maximum total score possible is 56. Test-retest reliability for this method in an older adult population has been reported by Berg et al. (1995) to be  $ICC = .97$ , with agreement between raters at  $ICC = .98$ .

### Timed Get-Up-and-Go Test

The Timed Get-Up-and-Go Test (TGUGT) employed a stopwatch and a chair. The subject began seated in the chair. The sequence of activities that the subject performed was: rise from the chair, walk three meters (to a designated point) as quickly as possible, turn, walk back to the chair, turn and sit down. The observer measured the

number of seconds that it took the subject to complete these tasks. One practice trial was given, and the score discarded. Two scored trials were performed, and the average of those two scores was used for this study. Test-retest reliability for this method has been reported by Podsiadlo (1991) to be  $ICC = .99$ , and interrater reliability reported at  $ICC = .99$ . The use of assistive devices during this test results in higher scores (Medley & Thompson, 1997)

### Data Analysis

Prior to statistical analysis, the two somatosensory scores (proprioception and vibration), the two vision scores (depth perception and contrast sensitivity), and the two vestibular scores (gaze stabilization and motion-provoked dizziness) were collapsed into one somatosensory, one vision, and one vestibular score, respectively. Because the two types of vision score and two types of vestibular score were expressed in dissimilar units, final scores were derived by converting the raw scores to standardized z-scores, then averaging them. Canonical correlation analysis was used to explore the relationship between the two sets of variables: nine impairment test scores and 16 disability test scores, (14 items from the Berg Balance Scale, the total Berg Balance Scale score, and the Timed Get-Up-and-Go score). SPSS® for Windows (Version 6.0) statistical software package was employed. Two subjects were found to have missing data points: subject 003 was missing (B)LE strength data and subject 011 was missing Motor Control Test data. For both subjects, the missing data was replaced by the group mean for those

variables. Screening for univariate outliers was accomplished with boxplots of each variable. Multivariate outliers were determined using the Mahalanobis D-squared statistic. Assumptions of normality, linearity and homoscedasticity were tested using scatterplots and histograms of the canonical variates. Correlation matrices for all impairment variables and all disability variables were inspected for multicollinearity and singularity. Nine independent canonical correlations were developed.

Each canonical correlation was checked for statistical significance using Bartlett's  $F$ -test of Wilk's Lambda ( $p \leq .05$ ). Only those correlations that were statistically significant were subjected to further analysis. Each statistically significant canonical correlation was also checked for practical significance through inspection of the squared canonical correlation. The minimum criteria for practical significance chosen was 10% (Tabachnick & Fidell, 1996, p. 221). Only those that were judged practically significant were continued in the analysis.

Structure coefficients from the loading matrices were examined to determine the contributions of each variable within a set to the canonical variate of that set. Redundancy matrices were examined to determine the amount of variance in the disability canonical variates explained by the impairment variables, and the amount of variance in the impairment canonical variate explained by the disability variables.

Correlations between pairs of impairment and disability variables were examined using Spearman's rho (to accommodate the ordinal BBS scores) to identify which BBS items were most closely related to specific impairments. Post-hoc multiple regression using a forward elimination procedure was used to indicate which of the impairment variables best predicted BBS item, BBS total, and TGUGT scores.

## RESULTS

Ninety-six subjects completed each of the tests presented. Means and standard deviations for performance on all tests are presented in Tables 1 and 2.

Examination of the boxplots revealed univariate outliers in both the impairment and disability variable sets. There were two outliers each for the reaction time and vestibular variables, and four for the vision variable. The only BBS items that did not have outliers were items eight, 10, and 13; the total BBS score was also devoid of outliers. The remaining BBS items had from 7 to 22 outliers. The TGUGT had two outliers. Multivariate outliers were explored using the Mahalanobis D-squared statistic with 22 degrees of freedom. A significance level of  $p < .001$  was adopted; five outliers were found. Outliers were not deleted from the analyzed data set or altered toward the mean to minimize their effect: these subjects, though different from the group as a whole on certain variables, were legitimate members of the (highly variable) population under consideration.

Univariate histograms (each with normal curve overlay) and normal probability plots, as well as skewness and kurtosis values, were examined to check assumptions of normality (See Appendix 4). Visual analysis of the normal curves revealed that normality was acceptable for the eight of nine impairment variables, the more difficult BBS items (#8, #10, #11, #13, #14) and the total BBS score, but poor for the easier BBS items (#1, #4, #5, #7, #9, #12) and the TGUGT score. Visual analysis of the univariate scatterplots indicated that assumptions of linearity and homoscedasticity were not met for seven of

**TABLE 1: IMPAIRMENT TESTS**

	<b>NORMAL RANGE</b>	<b>MEAN +/- S.D.</b>	<b>PERCENT OF SUBJECTS WITH NORMAL SCORE</b>
<b>LIMIT OF STABILITY (Maximum COG Excursion)</b>	60 - 100%	72 +/-13%	83%
<b>MOTOR CONTROL TEST (Automatic Postural Response Latency)</b>	< 160 ms	138 +/- 11 ms	96%
<b>RANGE OF MOTION (Bilateral Lower Extremities)</b>	90 - 100%	58 +/- 30%	20%
<b>REACTION TIME (Upper Extremity)</b>	Not available	358 +/- 99 ms	Not applicable
<b>SOMATOSENSORY (Combined Proprioception and Vibration)</b>	8 joints	6 +/- 2 joints	49%
<b>SENSORY ORGANIZATION TEST (Composite Equilibrium Score)</b>	57 - 100 %	62 +/- 15%	66%
<b>STRENGTH (Bilateral Lower Extremities)</b>	Not available	251 +/- 91	Not applicable
<b>VESTIBULAR: (Motion Sensitivity)</b>	0	2.22 +/- 6.6	77%
<b>VESTIBULAR: (Smooth Pursuit)</b>	$\geq 2$ cycles/s.	2.41 +/- .73 cycles/ s.	85%
<b>VISION: (Contrast Sensitivity)</b>	$\geq 1.35$ log units	1.68 +/- .22 log units	89%
<b>VISION: (Depth Perception)</b>	10 correct choices	8.37 +/- 3.3 correct choices	73%

**TABLE 2: DISABILITY TEST ITEM AND TOTAL SCORES**

	<b>NORMAL SCORE</b>	<b>MEAN +/- S.D.</b>	<b>SUBJECTS WITH NORMAL SCORE</b>
<b>1. SIT-TO-STAND</b>	4	3.8 +/- .57	88%
<b>2. STAND FOR TWO MINUTES</b>	4	4	99%
<b>3. SITTING BALANCE</b>	4	4	100%
<b>4. STAND TO SIT</b>	4	3.9 +/- .31	89%
<b>5. TRANSFER</b>	4	3.9 +/- .36	85%
<b>6. STAND WITH EYES CLOSED</b>	4	4	100%
<b>7. STAND WITH FEET TOGETHER</b>	4	3.9 +/- .56	93%
<b>8. FUNCTIONAL REACH</b>	4	3.6 +/- .57	63%
<b>9. PICK UP OBJECT FROM FLOOR</b>	4	3.9 +/- .28	92%
<b>10. TURN TO LOOK OVER SHOULDERS</b>	4	3.5 +/- .74	66%
<b>11. TURN 360 DEGREES</b>	4	3.6 +/- .74	77%
<b>12. ALTERNATE TOE TOUCH ON CURB</b>	4	3.7 +/- .83	83%
<b>13. TANDEM STANCE</b>	4	2.9 +/- 1.3	42%
<b>14. SINGLE LEG STANCE</b>	4	2.5 +/- 1.2	29%
<b>TOTAL BERG BALANCE SCALE SCORE</b>	56	51 +/- 5	17%
<b>TIMED GET UP AND GO TEST SCORE</b>	Less than 10 s.	9 +/- 4 s.	80%

nine impairment variables or any of the disability variables. Visual analysis of the bivariate scatterplots (of each impairment variable against each disability variable), however, revealed that assumptions of linearity were generally met for BBS items 10 through 14, the total BBS score, and the TGUGT score, but were not met for the easier BBS items (one through nine). The range of correlation was  $r = .01$  to  $.53$  for impairment variables;  $r = .12$  to  $.65$  for the BBS item variables with each other,  $r = .45$  to  $.80$  for the BBS items with the BBS composite score, and  $r = -.28$  to  $-.76$  for the TGUGT score with all BBS scores. (The negative correlation between the BBS and TGUGT scores occurs because high numbers indicate better performance on the BBS, whereas low scores reflect better performance in the TGUGT.) A review of the variable correlation matrix revealed no multicollinearity. Berg Balance Scale items #2 (stand with eyes open), #3 (sitting balance) and #6 (stand with eyes closed) were eliminated from further analysis when it was discovered that 98% to 100% of the subjects received full score for those items. Those three items did not offer sufficient discrimination between the frail versus healthy elderly subjects. The deletion of these three test items reduced the number of variables in the disability set from 16 to 13.

Of the nine canonical correlations derived, only the first was statistically and practically significant, and was subjected to further analysis. No other canonical correlation was either statistically or practically significant. The first canonical correlation indicated that the overall multivariate relationship between the two sets of variables (nine impairment variables and 13 disability variables) was statistically significant [Wilk's lambda = .065,  $F(117, 567) = 2.14$ ,  $p < .001$ ] and that the correlation between them was strong [ $R_c = .86$ ]. Practical significance was established with 74%

overlapping variance between the two sets of variables. To preclude any undue influence of the total BBS score, which was a composite score, the canonical correlation was performed a second time with this variable removed. The results were almost identical: Wilk's lambda = .08,  $F(108, 558) = 2.14$ ,  $p \leq .001$ ,  $R_c = .86$  with 74% overlapping variance between the two canonical variates.

Correlations between the study variables (impairment and disability) and their respective canonical variates are presented in Table 3, in descending order. Correlations greater than +/- .5 were considered to be practically significant (Wood, 1996) and are indicated by an asterisk.

The proportion of variance that a canonical variate extracts from its own variables, as well as the proportion extracted from the opposite set of variables, can be examined using structure coefficients and redundancy analysis. Simply stated, it is possible to identify the amount of variance in the impairment variables and disability variables explained by the "impairment" canonical variate, and the amount of variance in the impairment variables and disability variables explained by the "disability" canonical variate. Using the first canonical correlation, 38% of the amount of variance in the disability variables is explained by their own "disability" canonical variate while 28% is explained by the opposite "impairment" canonical variate. For the impairment variables, 33% of the variance is explained by their own "impairment" canonical variate and 24% by the opposite "disability" canonical variate.

Correlations between individual variables were examined next. Because the BBS item scores are ordinal values, Spearman's rho was used to examine the correlations

**TABLE 3:  
CORRELATION OF STUDY VARIABLES  
WITH THEIR RESPECTIVE CANONICAL VARIATES**

<b>CORRELATION OF IMPAIRMENT VARIABLES WITH THE IMPAIRMENT CANONICAL VARIATE</b>		<b>CORRELATION OF DISABILITY VARIABLES WITH THE DISABILITY CANONICAL VARIATE</b>	
LIMITS OF STABILITY	.85*	TOTAL BBS SCORE (Composite of items 1-14)	.91*
STRENGTH	.69*	TGUGT SCORE	-.84*
SENSORY ORGANIZATION	.67*	14. SINGLE LEG STANCE	.77*
RANGE OF MOTION	.63*	12. TOE TOUCH ON CURB	.65*
SOMATOSENSORY	.57*	11. TURN 360 DEGREES	.62*
REACTION TIME	-.43	8. FUNCTIONAL REACH	.60*
VISION	.42	13. TANDEM STANCE	.55*
VESTIBULAR	.39	5. TRANSFER	.53*
MOTOR CONTROL	-.28	7. STAND WITH FEET TOGETHER	.52*
		10. TURN TO LOOK OVER SHOULDERS	.51*
		1. SIT-TO-STAND	.42
		4. STAND-TO-SIT	.41
		9. PICK UP OBJECT FROM FLOOR	.38

KEY: Asterisk (\*) indicates those correlations considered to be practically significant.

**TABLE 4:  
CORRELATIONS BETWEEN IMPAIRMENT AND DISABILITY VARIABLES**

	LOS	MCT	ROM	RT	SOM
<b>1. Sit to stand</b>	<b>.32</b> (.002) <b>10%</b>	<b>-.07</b> (.486)	<b>.31</b> (.002) <b>10%</b>	<b>-.12</b> (.245)	<b>.02</b> (.839)
<b>4. Stand to sit</b>	<b>.23</b> (.023)	<b>-.25</b> (.017)	<b>.36</b> ( <b>&lt;.001</b> ) <b>13%</b>	<b>.22</b> (.032)	<b>.24</b> (.020)
<b>5. Transfer</b>	<b>.30</b> (.003) <b>9%</b>	<b>-.19</b> (.069)	<b>.39</b> ( <b>&lt;.001</b> ) <b>15%</b>	<b>-.29</b> (.004)	<b>.35</b> (.001) <b>12%</b>
<b>7. Stand with feet together</b>	<b>.39</b> ( <b>&lt;.001</b> ) <b>15%</b>	<b>-.20</b> (.056)	<b>.21</b> (.042)	<b>.01</b> (.918)	<b>.27</b> (.008)
<b>8. Functional Reach</b>	<b>.39</b> ( <b>&lt;.001</b> ) <b>15%</b>	<b>-.16</b> (.122)	<b>.36</b> ( <b>&lt;.001</b> ) <b>13%</b>	<b>-.39</b> ( <b>&lt;.001</b> ) <b>15%</b>	<b>.31</b> (.002) <b>10%</b>
<b>9. Pick up object from floor</b>	<b>.16</b> (.130)	<b>-.11</b> (.281)	<b>.19</b> (.066)	<b>-.05</b> (.608)	<b>.29</b> (.005)
<b>10. Turn to look over shoulders</b>	<b>.38</b> ( <b>&lt;.001</b> ) <b>14%</b>	<b>-.05</b> (.606)	<b>.36</b> ( <b>&lt;.001</b> ) <b>13%</b>	<b>.31</b> (.002) <b>10%</b>	<b>.28</b> (.008)
<b>11. Turn 360 degrees</b>	<b>.40</b> ( <b>&lt;.001</b> ) <b>16%</b>	<b>.30</b> (.003) <b>9%</b>	<b>.46</b> ( <b>&lt;.001</b> ) <b>21%</b>	<b>-.28</b> (.006)	<b>.28</b> (.007)
<b>12. Toe touch on curb</b>	<b>.47</b> ( <b>&lt;.001</b> ) <b>22%</b>	<b>-.19</b> (.061)	<b>.39</b> ( <b>&lt;.001</b> ) <b>15%</b>	<b>-.23</b> (.027)	<b>.30</b> (.003) <b>9%</b>
<b>13. Tandem stance</b>	<b>.43</b> ( <b>&lt;.001</b> ) <b>19%</b>	<b>-.05</b> (.622)	<b>.33</b> (.001) <b>11%</b>	<b>-.26</b> (.010)	<b>.36</b> ( <b>&lt;.001</b> ) <b>13%</b>
<b>14. Single leg stance</b>	<b>.53</b> ( <b>&lt;.001</b> ) <b>28%</b>	<b>-.17</b> (.115)	<b>.32</b> (.002) <b>10%</b>	<b>-.20</b> (.051)	<b>.38</b> ( <b>&lt;.001</b> ) <b>14%</b>
<b>Total Berg Balance Score</b>	<b>.66</b> ( <b>&lt;.001</b> ) <b>44%</b>	<b>-.22</b> (.030)	<b>.53</b> ( <b>&lt;.001</b> ) <b>28%</b>	<b>.34</b> (.001) <b>12%</b>	<b>.44</b> ( <b>&lt;.001</b> ) <b>19%</b>
<b>Timed Get Up and Go Test</b>	<b>-.59</b> ( <b>&lt;.001</b> ) <b>35%</b>	<b>.25</b> (.015)	<b>-.51</b> ( <b>&lt;.001</b> ) <b>26%</b>	<b>.36</b> ( <b>&lt;.001</b> ) <b>13%</b>	<b>-.42</b> ( <b>&lt;.001</b> ) <b>18%</b>

**TABLE 4, cont.:**  
**CORRELATIONS BETWEEN IMPAIRMENT AND DISABILITY VARIABLES**

	SOT	STR	VEST	VIS
<b>1. Sit to stand</b>	.31 (.002) 10%	.32 (.002) 10%	.07 (.484)	.09 (.408)
<b>4. Stand to sit</b>	.17 (.103)	.22 (.032)	.28 (.005)	.06 (.594)
<b>5. Transfer</b>	.24 (.017)	.37 ( <b>&lt;.001</b> ) 14%	.11 (.300)	.073 (.479)
<b>7. Stand with feet together</b>	.21 (.040)	.18 (.075)	.24 (.019)	.16 (.117)
<b>8. Functional Reach</b>	.23 (.024)	.43 ( <b>&lt;.001</b> ) 19%	.17 (.100)	.30 (.003) 9%
<b>9. Pick up object from floor</b>	.20 (.048)	.21 (.040)	.30 (.003) 9%	.16 (.115)
<b>10. Turn to look over shoulders</b>	.22 (.033)	.30 (.003) 9%	.18 (.076)	.28 (.006)
<b>11. Turn 360 degrees</b>	.31 (.002) 10%	.33 (.001) 11%	.29 (.005)	.27 (.007)
<b>12. Toe touch on curb</b>	.43 ( <b>&lt;.001</b> ) 19%	.32 (.002) 10%	.17 (.106)	.11 (.289)
<b>13. Tandem stance</b>	.43 ( <b>&lt;.001</b> ) 19%	.44 ( <b>&lt;.001</b> ) 19%	.16 (.115)	.14 (.181)
<b>14. Single leg stance</b>	.54 ( <b>&lt;.001</b> ) 29%	.49 ( <b>&lt;.001</b> ) 24%	.22 (.033)	.35 (.001) 12%
<b>Total Berg Balance Score</b>	.56 ( <b>&lt;.001</b> ) 31%	.59 ( <b>&lt;.001</b> ) 35%	.28 (.006)	.37 ( <b>&lt;.001</b> ) 14%
<b>Timed Get Up and Go Test</b>	-.50 ( <b>&lt;.001</b> ) 25%	-.59 ( <b>&lt;.001</b> ) 35%	.29 (.004)	-.35 (.001) 12%

**KEY:** Each cell contains the correlation and, in parenthesis, the significance. Cells with significant correlations of .30 or greater also contain the variance in the disability variable explained by that impairment variable.

between each of the impairment and disability variables. Each of the correlations, and their significance, are reported in Table 4. Pairs of variables with correlations of  $r = .30$  or greater (explaining a minimum of 9% of the variance) and reaching a significance level of  $p < .05$  or less, are indicated in bold print, and the amount of variance explained is also indicated.

Difficulty or unwillingness to move the COG away from midline, as evidenced by the poor performance on the LOS test, was significantly correlated with 11 of 13 disability variables. In descending order, LOS test scores were significantly correlated with the total BBS score, the TGUGT score, single leg stance, toe touch on curb, tandem stance, turning 360 degrees, standing with feet together and functional reach, turning to look over shoulders, sit to stand, and transfers. Reduced bilateral lower extremity range of motion was also significantly correlated with 11 disability variables. ROM scores were significantly related to the total BBS score, the TGUGT score, turning 360 degrees, transfers and toe touch on curb, stand-to-sit and functional reach and turn to look over shoulders, tandem stance, sit-to-stand and single leg stance. Weakness was significantly associated with 10 of 13 disability variables. Low muscle strength was significantly correlated with the total BBS score and the TGUGT score, single leg stance, tandem stance, functional reach, transfers, turning 360 degrees, sit-to-stand and toe touch on curb, and turn to look over shoulder.

Somatosensory loss and low scores on the SOT were each significantly correlated with seven disability variables. Somatosensory loss was significantly associated with the total BBS score, the TGUGT score, single leg stance, tandem stance, transfers, functional reach, and toe touch on curb. Reduced performance on the SOT was significantly related

to the total BBS score, single leg stance, the TGUGT score, toe touch on curb and tandem stance, sit-to-stand and turning 360 degrees. Slow reaction times and visual deficits were each significantly correlated with four disability variables. Slow reaction time was significantly associated with functional reach, the TGUGT score, the total BBS score, and turning to look over shoulder.

Visual difficulties were significantly related to the total BBS score, single leg stance and the TGUGT score, and functional reach. Slow postural response latencies and vestibular deficits were significantly correlated with only one disability variable each. Poor MCT scores were significantly associated with turning 360 degrees, while vestibular problems were significantly related to picking an object up from the floor.

All correlations between impairment and disability variables for BBS items one through 13 were weak ( $r \leq .47$ ), while correlations between impairment variables and BBS item 14 (single leg stance), total BBS scores, and TGUGT scores ranged from weak to moderate ( $r \leq .66$ ).

Post-hoc analysis employed a forward stepwise multiple regression procedure ( $p \leq .05$  to enter) to indicate which impairment or combination of impairments best predicted specific disability item scores. The results are presented in Table 5. Sit-to-stand score was best predicted by the LOS score, although this variable alone accounted for only 10% of the variance in the disability item. Stand-to-sit score was best predicted by a combination of range of motion and reaction time scores, together accounting for 15% of the disability item variance. Transfer abilities were best predicted by a combination of range of motion and somatosensory scores, jointly accounting for 21% of the variance in

**TABLE 5:  
PREDICTION OF DISABILITY ITEM SCORES FROM IMPAIRMENT SCORES**

	<b>First Step</b>	<b>Second Step</b>	<b>Third Step</b>	<b>Fourth Step</b>	<b>Total Variance</b>
<b>1. Sit to stand</b>	<b>LOS</b> .30 (.002) 10%				10%
<b>4. Stand to sit</b>	<b>ROM</b> .32 (.002) 10%	<b>RT</b> .39 (<.001) 5%			15%
<b>5. Transfer</b>	<b>ROM</b> .39 (<.001) 15%	<b>SOM</b> .46 (<.001) 6%			21%
<b>7. Stand with feet together</b>	<b>LOS</b> .40 (<.001) 16%	<b>RT</b> .46 (<.001) 5%	<b>VEST</b> .49 (<.001) 3%		24%
<b>8. Functional Reach</b>	<b>RT</b> .49 (<.001) 24%	<b>VIS</b> .56 (<.001) 7%	<b>LOS</b> .59 (<.001) 4%		35%
<b>9. Pick up object from floor</b>	<b>SOM</b> .26 (.009) 7%				7%
<b>10. Turn to look over shoulders</b>	<b>LOS</b> .34 (<.001) 12%	<b>RT</b> .41 (<.001) 4%			16%
<b>11. Turn 360 degrees</b>	<b>ROM</b> .45 (<.001) 20%	<b>LOS</b> .51 (<.001) 6%	<b>VEST</b> .55 (<.001) 4%		30%
<b>12. Toe touch on curb</b>	<b>LOS</b> .50 (<.001) 25%	<b>SOT</b> .53 (<.001) 3%			28%

**TABLE 5, cont.:**  
**PREDICTION OF DISABILITY ITEM SCORES FROM IMPAIRMENT SCORES**

	<b>First Step</b>	<b>Second Step</b>	<b>Third Step</b>	<b>Fourth Step</b>	<b>Total Variance</b>
<b>13. Tandem stance</b>	<b>SOT</b> .39 ( <b>&lt;.001</b> ) 15%	<b>STR</b> .45 ( <b>&lt;.001</b> ) 5%			20%
<b>14. Single leg stance</b>	<b>SOT</b> .57 ( <b>&lt;.001</b> ) 33%	<b>STR</b> .64 ( <b>&lt;.001</b> ) 8%	<b>LOS</b> .68 ( <b>&lt;.001</b> ) 5%	<b>SOM</b> .69 ( <b>&lt;.001</b> ) 2%	48%
<b>Total Berg Balance Scale Score</b>	<b>LOS</b> .66 ( <b>&lt;.001</b> ) 43%	<b>SOT</b> .71 ( <b>&lt;.001</b> ) 8%	<b>STR</b> .75 ( <b>&lt;.001</b> ) 5%	<b>ROM</b> .77 ( <b>&lt;.001</b> ) 3%	59%
<b>Timed Get Up and Go Test Score</b>	<b>LOS</b> .56 ( <b>&lt;.001</b> ) 32%	<b>STR</b> .62 ( <b>&lt;.001</b> ) 9%	<b>SOM</b> .67 ( <b>&lt;.001</b> ) 3%	<b>ROM</b> .69 ( <b>&lt;.001</b> ) 3%	47%

KEY: Each "Step" cell contains the impairment, the correlation (multiple R), the significance, and the percent of variance explained respectively. Each "Variance" cell contains the cumulative variance predicted by the combination of significant impairments.

the disability item. Stand-with-feet-together score was best predicted by a combination of LOS, reaction time, and vestibular scores, together accounting for 24% of the disability item variance. Functional reach score was best predicted by three impairments, reaction time, vision, and LOS, in combination they accounted for 35% of the variance in the disability item. Somatosensory score best predicted pick-up-object-from-floor score, though only 7% of the variance in this disability item was explained by this impairment. Turn-to-look-over-shoulders score was best predicted by the combination of LOS and reaction time scores, which jointly accounted for 16% of the variance in this disability item. Turn-360-degrees score was best predicted by the combination of range of motion, LOS and vestibular scores, to account for 30% of the variance in the disability item. LOS and sensory organization scores, together explaining 28% of the variance in the disability item, best predicted toe-touch-on-curb score. Sensory organization and strength scores, accounting for 20% of the variance in the disability item best predicted tandem stance score. Single leg stance score was best predicted by a combination of sensory organization, strength, LOS and somatosensory scores, which together accounted for 48% of the variance in this disability item. The total BBS score and the TGUGT were both best predicted by a combination of four variables, three of which were shared: LOS, strength (second step for TGUGT and third step for total BBS score), and range of motion. Sensory organization deficits contributed to the prediction of the total BBS score (second step), while somatosensory loss contributed to the prediction of the TGUGT score (third step). The two combinations of four impairment variables explained 47% of the variance in the TGUGT scores and 59% of the variance in the total BBS scores.

## DISCUSSION

Review of the literature strongly suggested a potential link between impairments within the postural control system and limitations in the ability to perform activities requiring balance skills. However, the majority of previous studies investigated single, or at most a few, impairments and their relationship to a similarly small number of functional activities. Investigators searching for the key impairments that cause falls have likewise narrowed the variables under consideration. However, Duncan, Chandler, Studenski, Hughes and Prescott (1993) suggested that it is the number of impairments, versus which impairment, which may best explain imbalance and falls in the elderly. Thus, consideration of a large number of impairments is preferred. Based on the theoretical “systems model of postural control”, nine physical impairments previously demonstrated to be associated with imbalance and falls in the elderly were selected for inclusion in this study. The Berg Balance Scale and Timed Get Up and Go Test offered multiple balance-intensive activities, ranging from easy to difficult. The more difficult BBS items, the total BBS, and the TGUGT offered the spread of performance scores necessary for demonstration of correlation.

Despite low power level related to the relatively small sample size, and variable distributions that did not consistently meet assumptions for normality, linearity and homoscedasticity, the canonical correlation revealed a significant and strong relationship between postural control system impairments and disabilities. Further exploration using Spearman’s rho demonstrated that specific impairments were significantly associated with reduced performance of certain disability test items, though the strength of the correlations was weak to moderate. Both motor and sensory impairments contributed to reduced performance of balance-intensive activities. Posteriori exploratory regression analysis indicated the disability items scores could be predicted primarily from a core set of impairment variables (i.e., LOS, ROM, strength, somatosensory and SOT scores).

### Does an impairment/disability relationship exist?

Canonical correlation is an exploratory analysis method that permits the discovery of relationships between two multivariate data sets. In this study, it was used to answer the first research question: is there a substantial relationship between postural control system impairments and balance-related disability? The nine variable impairment data set and the 13 variable disability data set were submitted to the analysis. Canonical correlation analysis produces equations which attempt to maximize the relationship between the two sets of data; the number of equations produced is always equal to the number of variables in the smaller set, in this case, nine. (See Appendix 5). Only those equations that are statistically significant ( $p < .05$ ) are considered further. Practical significance, the extent of the “overlap” between the two sets of variables, must also be established. There is no accepted convention by which a level of practical significance is chosen, as it may appropriately vary with the type of data used or the question being asked. Of course, the greater the amount of overlap, the better. Tabachnik and Fidell (1996) suggest that a minimum of 10% overlapping variance is acceptable. For this study a shared variance of 25% or greater was deemed acceptable for the canonical correlations, to ensure that only equations making a substantial contribution would be considered. Only the first canonical correlation equation met both the statistical and practical significance criteria. A strong correlation ( $R_c = .86$ ) was shown to be statistically significant ( $p \leq .001$ ), with a 74% overlap in variance between the two canonical variates. The answer to the first question, then, is most certainly yes. Impairments in the postural control system are substantially related to difficulty performing balance-intensive activities (disabilities).

The formation of each canonical correlation equation involves the creation of a composite “canonical variable” for each of the two data sets (the correlation maximizes the relationship between the two canonical variables). Each canonical variable is formed

from a linear combination of the variables in its own set, with some variables contributing more to this “master” canonical variable than others. The correlation between each variable and its own canonical variable indicates the extent to which that variable contributed to the formation of the canonical variable. The impairment variables that contributed most to the impairment canonical variable were (in order of significance): limits of stability (LOS), strength, central sensory organization, range of motion, and somatosensory loss. This information offered an early indication that five of the nine postural control impairments were more influential (in the relationship between these particular impairments and disabilities) than the remaining four. The disability variables which contributed most to the disability canonical variable were: the total BBS score (itself a composite score of the 14 BBS items), the TGUGT score, single leg stance, toe touch on curb, turn 360 degrees, functional reach, tandem stance, transfer, stand with feet together, and turn to look over shoulders. (To ensure that the composite total BBS score was not unduly influencing the disability canonical variable, the analysis was conducted again with the total BBS score removed. There were no significant differences in the results obtained.) These findings indicated that the remaining three of the 13 disability variables (sit-to-stand, stand-to-sit, and pick-up-object-from –floor) were less influential in the impairment-disability relationship. The results of this portion of the canonical correlation provided preliminary discrimination between variables of greater or lesser influence within each set.

The amount of variance that each canonical variable could extract from the variables of its own set is a second way to consider the strength of the association between the variables in a set and their canonical variable. For the impairment variables, 33% of the variance was explained by the impairment canonical variable. For the disability variables, 38% of the variance was explained by the disability canonical variable. The amount of variance that each canonical variable could extract from the variables of the opposite set is a third way to consider the extent of the association

between the sets of variables. For the impairment variables, 24% of the variance was explained by the disability canonical variate. For the disability variables, 28% was explained by the impairment canonical variate. These were well over the minimum 10% of variance suggested by Tabachnik and Fidell (1996), and provided further indication that the relationship between the two sets of variables was both significant and meaningful. Had there been more than one significant canonical correlation equation, a greater proportion of the total, within-set, and between-set variances might have been accounted for.

An important component in the interpretation of a canonical correlation analysis is the (exploratory) search for “dimensions” which offer meaningful explanations for the mathematical relationships developed in the analysis. For example, in this study, the nine impairment variables were derived from multiple components of the postural control system - peripheral sensory reception, central sensory perception, central motor control, and peripheral motor execution. It is hypothetically possible that the results of the analysis could have indicated that only variables from the two “central” components contributed to the relationship between variable sets, thus establishing “central processes” as a critical dimension in the relationship. Alternately, had there been two significant canonical correlation equations, the results might have indicated that one equation was developed predominantly from variables belonging to the two sensory components, while the other might have been developed largely from variables belonging to the two motor components. This would indicate two separate dimensions (sensory and motor) which each contributed to the overall relationship between variable sets. The actual results, however, do not support the existence of any such dimensions. Instead, the five impairment variables most associated with the impairment canonical variable collectively represent each of the four components. This finding is consistent with the well-established premise that balance skills (as represented here by the BBS and TGUGT) are the result of a multifactorial, multi-“dimensional” postural control process.

Are specific impairments associated with particular disabilities?

The earlier work of Buchner and deLateur (1991) pointed to the existence of a relationship between an impairment (diminished lower extremity strength) and the inability to perform two specific activities - rise from a chair and climb stairs. Other investigators (Duncan et al., 1993; Lord et al., 1991; Lord, Ward, Williams & Anstey, 1994) have also concluded that postural control system impairments were related to the performance of balance-intensive activities. The second research question in this study asked: are specific postural control impairments associated with the ability to perform certain balance and mobility tasks? The strength and significance of the correlation between each pair of impairment and disability variables was explored using Spearman's rho (to accommodate the ordinal rating scale of the Berg Balance Scale). Due to the number of subjects involved ( $n = 96$ ), significance was achieved for a majority of correlations. However, almost half of the correlations were of insufficient size ( $r < .30$ ) to be considered meaningful. For all the BBS items except single leg stance, the total BBS score, and the TGUGT score, correlations between individual impairment and disability variables were weak ( $r = .30$  to  $.49$ ). Moderate correlations ( $r = .51$  to  $.66$ ) were found between four impairment variables and the single leg stance, the total BBS score, and the TGUGT score. (The low strength of the correlations may be due to the fact that the correlation methods used are sensitive to linear relationships, but the data in the present study were frequently not linearly related.) All but three of the 13 disability variables were associated with multiple impairments, a finding consistent with the supposition that postural control is a multifactorial process. Individual correlations are thus meaningful despite their modest strength as it is understood that no single impairment variable is likely to explain poor performance of a balance task.

Dynamic, volitional control of the COG over the base of support was represented by the Limits of Stability test score, which indicated how far an individual could lean in

eight directions. Performance of activities that require controlled movement of the trunk over the feet might be expected to diminish if COG excursion is limited. Of the 11 individual BBS items in the final analysis, eight required such weight shifting to some degree, while three demanded that the subject hold still. The TGUGT requires constant COG movement over the base of support. Reduced performance on the LOS test was moderately correlated with the total BBS score, the TGUGT score, and difficulty maintaining single leg stance. It was weakly correlated with toe touch on curb, tandem stance, turn to look over shoulders, stand with feet together, functional reach, sit-to-stand, and transfer. The association of COG excursion with both the total BBS score and the TGUGT score is understandable in light of the high percentage of BBS items requiring weight shifting and the very dynamic nature of the TGUGT activities. Similarly, the relationship of COG excursion abilities to performance of BBS items requiring weight shifting may be expected. Two BBS items requiring weight shifting, stand-to-sit and pick-up-object-from-floor, were not sufficiently correlated with the LOS test scores. Both activities involve a substantial lowering of the COG using controlled lower extremity flexion, a movement strategy that is quite different from the upright position and sway skill necessary to perform well on the LOS test. This dissimilarity in movement patterns may explain the low correlations. Three BBS items require the restriction (versus the controlled expansion) of COG movement over the base of support: stand-with-feet-together, tandem stance, and single leg stance. At first glance, the association between the LOS test scores and performance on these “static” activities may seem surprising, since the goal in the LOS test is to move the COG while the goal in static balance tasks is to hold it still. However, all three of these “static” tasks involve the progressive shrinkage of the base of support, in effect bringing the LOS boundary to the COG (instead of moving the COG to the LOS boundary, as in the LOS test). Yet the net effect is the same: the “problem” which must be solved in both the LOS test and these “static” tasks is how to control the COG when it is near the LOS boundary. Subjects who have COG control

deficits appear to have difficulty with any activity - static or dynamic - that places the COG near the LOS boundary. In this study, impairment of COG control was associated with the particular disabilities mentioned above.

To avoid a fall, individuals must either maintain the COG within the LOS boundary, or quickly step or reach to recover their balance when the COG exceeds the boundary. The proximity of the LOS boundary to the COG thus reflects a relative risk for falls. Two studies (King, Judge and Wolfson, 1994; Schiepetti, Hugon, Grasso, Nardone & Galante, 1994) have documented an age-related reduction in the limits of stability. However, neither study examined clinical balance skills or disability levels to establish a relationship between COG excursion deficits and the ability to perform functional activities. Subsequently, King et al. (1995) found that loss of mobility (walking, carrying, climbing stairs, etc.) was associated with decreased stability limits in older adults, and advocated that interventions to improve mobility should include balance exercises designed to increase the limits of stability. In 1995, Alonte, Grosch and Brenneman explored the relationship between LOS test performance (with targets at 75%) and the total BBS score in 30 subjects with neurological diseases or amputation. They reported (using Pearson  $r$  correlation coefficients) a moderate ( $r = .60$ ) and significant ( $p < .001$ ) relationship between COG excursion and the total BBS score. The results of the present study are consistent with the findings of these previous studies. In addition, the results of this study further indicate that diminished COG excursion is associated with specific items on the BBS, and with the TGUGT. Clinicians using the BBS and the TGUGT should therefore suspect diminished COG excursion in patients who do poorly on these two clinical tests.

Restrictions in range of motion at the ankles (dorsiflexion) , knees (extension) and hips (extension) were common in the elderly subjects studied. Activities requiring joint flexibility in the directions tested might be expected to be more sensitive to reduced range of motion. Range of motion deficits were frequently (11 of 13 items) associated with

difficulty performing the activities of the BBS and the TGUGT. The highest correlations were with the total BBS score (again, due to the large number of BBS items requiring lower extremity flexibility) and the TGUGT score, which included a gait measure. During normal gait, the position of the lower limb in hip and knee extension with ankle dorsiflexion occurs at each step, and is necessary for the production of the “push off” force that propels the body forward when walking. Inability to achieve this extended “trailing limb” position would reduce “push off” forces as well as stride length, thus slowing the gait velocity. Performance on nine of the 11 BBS items was weakly correlated with decreased range of motion. Seven of these nine activities require active lower extremity extensibility, thus their association may be expected. Two of the nine correlated items, tandem stance and single leg stance, do not demand such flexibility, and an explanation for their association is less apparent. Both of these activities are easiest to perform (require the least muscle force) if the trunk can be directly aligned above the feet so that the force of gravity helps to hold the COG over the narrower and smaller base of support. Subjects who cannot adopt this “plumb line” posture would have to use more muscle force and make more frequent balance corrections than those who can. For these two items, there may be an interaction between limited range of motion and strength. The loss of flexibility may not directly cause reduced performance of these tasks, but may indirectly impact these scores by increasing the need for higher muscle forces and more frequent corrective motions. Two of the 11 BBS items did not meet the correlation criteria with reduced range of motion, “stand with feet together” and “pick up object from floor”. As mentioned above, the standing activity would be easiest to perform if the individual could adopt a posture with lower extremity extension to place the trunk directly over the base of support. This standing task, however, is less challenging than tandem or single leg stance, and may therefore not demand the forceful and/or frequent balance corrections necessary for the more difficult stance tasks. So the range of motion limitation may be of less consequence for performance of this item. The “pick up object

from floor” task requires hip and knee flexion (versus extension) ranges, which were not tested in these subjects. This dissimilarity may explain the low correlation. In this study, range of motion impairments were associated with poor performance of the disability items listed above.

These findings linking impaired lower extremity range of motion to imbalance and disability are consistent with previous studies. Gibbs, Hughes, Dunlop, Singer and Chang (1996) reported an association between joint flexibility and walking velocity, a result very similar to the association in this study between reduced range of motion and scores on the TGUGT. Souren, Franssen and Reisberg. (1995) also documented a relationship between impaired joint flexibility and diminished scores on the Functional Assessment Staging Scale, a measure of functional performance in patients with Alzheimer’s disease. Loss of joint flexibility has also been found to be related to reduced performance on balance tests, including tandem stance (Gehlsen & Whaley, 1990; Prieto, Myklebust & Myklebust, 1992). No previous studies, however, explored the relationship between lower extremity range of motion and two commonly used clinical balance and mobility tests, the BBS and the TGUGT. The current results certainly imply that patients with poor scores on these two tests may well have reduced lower extremity range of motion.

Earlier studies have clearly identified reduced strength as a major contributing factor to falls and functional decline in the elderly (Fiatarone, 1994; Tinetti & Speechley, 1989). In this study, weakness was correlated with poor performance on 10 of the 13 disability items. The correlation between strength loss and poor performance on the BBS (total score) and TGUGT (known indicators of fall risk or functional decline in the elderly) was to be expected. Interestingly, however, the correlation was only moderate, not strong, as the literature might indicate. It is possible that the tasks studied have a low strength threshold; even somewhat weak subjects can perform the tasks satisfactorily. Or, perhaps the failure of this study to scale the force measurement to body size may have

confounded the results. Smaller individuals with good balance may produce small forces, while larger individuals with poor balance may generate equivalent or larger forces, obscuring the relationship between strength and performance of balance activities. Alternatively, the severity of the strength loss may need to be considered relative to the severity of impairments of COG excursion and range of motion. Perhaps in this sample of older adults, strength loss was not a greater problem than the latter two impairments.

Diminished strength was weakly correlated with eight of 11 BBS items: single leg stance, tandem stance, functional reach, transfers, turning 360 degrees, sit-to-stand, toe touch on curb, and turn to look over shoulders. It did not meet the correlation criteria for the stand-to-sit or pick-up-object-from-floor items, both of which require eccentric muscle control. The strength measure in this study included concentric force only, and may not have reflected the degree of eccentric control possible for each subject. This may explain the low correlations for tasks requiring eccentric muscle control. Strength was not significantly associated with the stand-with-feet-together task, probably because this activity does not demand high forces at the knees and ankles (the two joints tested in this study). The “stand with feet together” position allows control of medial-lateral sway by shifting from foot to foot, a compensatory strategy using hip musculature that is not possible in the two more difficult stance tasks which were correlated with strength measures.

The results of the current study are consistent with the literature insofar as they agree that strength is correlated with performance of balance and mobility tasks. Buchner and deLateur (1991) found a strong relationship between leg strength and the ability to rise from a chair and climb stairs. Hunter et al. (1995) also found an association between strength and the ability to rise from a chair, walk quickly, and carry groceries while walking. Gibbs et al. (1996) noted the relationship between knee extensor weakness and reduced walking velocity, an indicator of functional decline and risk for falls in the elderly. Schultz et al. (1995) demonstrated a significant association between lower

extremity strength and the ability to perform chair rise, ambulation, and balance tasks. However, unlike the aforementioned studies, results from the current study do not imply that strength is the dominant impairment in subjects with poor BBS and TGUGT scores, but rather is one of several critical impairments. Rather, this finding provides support for the findings of Duncan et al. (1993) and King and Tinetti (1995) who found that strength was only one of multiple impairments associated with mobility problems and functional decline. Reduced lower extremity strength may reasonably be suspected in patients with poor BBS and TGUGT scores.

The Sensory Organization Test (SOT) composite equilibrium score was assumed to reflect the central processing of visual, vestibular, and somatosensory information for the purpose of determining body position in space. Reduction of sensory information, such as walking across a dark room, or sensory conflict situations such as riding on escalators or elevators, would most stress this processing system. The only BBS activity in which sensory information was reduced was the eyes closed task, which was removed from analysis since 100% of participants received full score on this item. No activities that directly challenge the visual or vestibular systems are included in this clinical test. Hence, the number of significant correlations (seven of 13) between low scores on the SOT and poor performance on the BBS and TGUGT is somewhat surprising. The total BBS score, the single leg stance task, and the TGUGT were moderately correlated with reduced SOT scores. Four additional BBS items were weakly associated with sensory organization deficits: tandem stance, toe touch on curb, turn 360 degrees and sit-to-stand. Though neither of the two stance tasks are specifically designed to stress the sensory systems, both require very tight control of the COG over a constricted base of support. This, in turn, demands rapid and accurate perception of the whereabouts of the COG to allow prompt corrective actions. If central sensory processing is impaired, perception of the COG position in space may be slowed or inaccurate. The resultant delay or incorrect selection of equilibrium responses would reduce the performance of these stance tasks.

The TGUGT involves a sit-to-stand component, a rapid reciprocal weight shifting component (walking), and a complete 360-degree turn component. These components are very similar to the sit-to-stand, toe touch on curb, and 360 degree turn items of the BBS. Each of these activities requires transitions of the head in space, either forward (sit-to-stand), sideways (toe touch on curb) or rotationally (360 degree turn) which may disadvantage visual and vestibular inputs and require somatosensory inputs to temporarily “override” the former two. This recognition of the usefulness of certain inputs compared to others is a function of the central sensory process. The SOT composite equilibrium score was associated with the TGUGT and each of the three listed BBS items, indicating that the integration of sensory inputs is a critical factor in the successful performance of these tasks. The correlation of the SOT score with the total BBS score may be easily explained. Three of the five BBS items associated with the SOT score are strongly associated with the total BBS score, as evidenced by the preliminary analysis correlation coefficients.

Very few previous studies have investigated the relationship between impairments of sensory organization and functional abilities or falls. Sheperd and Telian (1996) found that, in patients of various ages with vestibular disorders, the SOT score was predictive of functional level. Parry (1994) documented that elderly fallers had below-normal equilibrium scores on the SOT, compared to non-fallers, who all scored within the normal range on this test. The findings of the current study support the results of these previous two investigations, namely, that the central sensory organization process is related to functional abilities and risk for falls. Patients whose performance on the BBS and the TGUGT is poor may well have impaired sensory organization processes.

Somatosensory loss in the lower extremities would reduce the amount of information received by the central nervous system for use in determining the position of the body relative to the support surface. Impairments of somatosensation would most likely be associated with difficulty performing tasks in which the other senses (vision and

vestibular) were eliminated, such as “stand with eyes closed”. However, this item was excluded from analysis because all but one subject received the highest score on this activity (ceiling cluster of scores). Apparently the challenge level of this task was too low, or the somatosensory impairments in this sample of subjects were not severe enough to result in a loss of balance during this activity. No activities in the BBS or TGUGT require standing with neck extension and rotation, or rapid head movements, to disadvantage the vestibular system, so subjects with diminished somatosensory inputs may have been able to use vestibular inputs to succeed at the eyes closed task.

Impairments of somatosensation were weakly correlated with difficulty performing five out of 11 BBS activities, the total BBS score, and the TGUGT score. Two of the five BBS tasks (single leg stance, tandem stance) demand very accurate perception of the COG position, since with such a small base of support, the COG is so close to the limit of stability boundary. Reduced somatosensation might delay or reduce the perception of COG position, making it difficult for the subject to sense the need for a corrective balance response. The other three correlated BBS activities (transfer, functional reach, and toe touch on curb) all require weight shifts, or movement of the COG over the base of support. Perception of the COG location would be very important for the successful performance of these tasks. None of the items requiring lower extremity flexion (sit-to-stand, stand-to-sit, and pick-up-object-from-floor) or body rotation (turn-to-look-over-shoulder and turn-360-degrees) were sensitive to somatosensory loss at the ankles and toes. Perhaps the changing sensory input from the hips and knees assists subjects to have a sense of their position in the “squatting” activities. It is possible that ankle and toe somatosensation is not as critical for rotation tasks where hip and trunk somatosensation would be stimulated first as the body turns. The ability to “stand with feet together” was also not greatly impacted by somatosensory loss. While this activity does involve a narrowed base of support, it is not as rigorous as

the tandem and single leg stance tasks, and may permit success with a less precise or delayed perception of COG position.

Previous studies have pointed to a link between somatosensory loss and falls/functional decline. Whipple and Wolfson (1989) documented reduced vibration sense in elderly fallers versus non-fallers. Duncan et al. (1993) found proprioceptive loss to be one of several physiological impairments related to functional decline in elderly men. Schultz et al. (1995) reported that proprioceptive sense thresholds were strongly associated with performance of chair rise, ambulation and balance tasks by older adults. Lord and colleagues (Lord, Clark & Webster, 1991; Lord, Ward, Williams & Anstey, 1994) indicated that proprioception and vibration sense were associated with both forceplate sway measures, clinical tests of balance and falls in elderly individuals. Era et al. (1996) also demonstrated a correlation between vibration sense and forceplate measures of postural sway. The results of the current study are in agreement with these prior investigations, and imply to clinicians that somatosensory loss is not unlikely in patients who score poorly on the BBS and TGUGT.

The volitional simple reaction time measure was considered to reflect central processing speed. An upper extremity reaction time task was chosen to eliminate the possibility of reduced performance due to physical factors that might impact balance, such as lower extremity strength or range of motion impairments. Several of the activities in the BBS, as well as the TGUGT, were timed, so it might be expected that slowed reaction times would be related to reduced performance on these timed tasks. However, results indicated that reaction time was weakly associated with only four disability variables: functional reach, TGUGT, the total BBS score, and turn to look over shoulders. Only one of these, the TGUGT, is timed, although the total BBS score is certainly influenced by its own timed items. Failure of the reaction time scores to correlate with the timed task scores may have occurred because the time frames allotted for satisfactory performance of these tasks is so great (four seconds, 10 seconds, etc.) compared to the

impairments of reaction time, which were on the order of a few hundred milliseconds. The rationale for the correlation of central processing speed with performance on the functional reach and turn-to-look-over shoulder is obscure, since neither task was timed or demanded rapid movement.

A prior study by Lord et al. (1994) found slow reaction times to be associated with forceplate measures of postural sway, clinical tests of balance, and falls in older adults. A 1996 study by Era et al. also documented a relationship between reaction time and forceplate measures of postural sway. The current study found few (four) balance and mobility variables to be weakly correlated with reaction time, and thus offers only minimal support to the findings of previous studies. The choice of a simple reaction time test may not have been ideal. Maylor and Wing (1996) and Shumway-Cook, Woollacott and Baldwin (1995) have both found that performance on divided attention tasks clearly demarcates elderly fallers from non-fallers. A greater number of correlations, and increased strength of correlations, between reaction time and the disability variables might have been found if a multiple choice reaction time test had been used. Clinicians should be aware that patients with slow reaction times may perform well on the BBS and TGUGT, yet still be at risk in real-life situations where rapid reaction times may mean the difference between balance maintenance and loss.

Visual deficits of depth perception and contrast sensitivity are known risk factors for falls in the elderly. These visual abilities are most necessary for balance when an individual is encountering hazards in the environment which need to be accurately detected, such as a step down or a crack in the sidewalk. None of the activities in either the BBS or the TGUGT present older adults with such visually-challenged tasks. So the low number (four) of weak associations between visual loss and the disability variables may be expected. Visual impairment was associated with the total BBS score, the TGUGT, single leg stance time, and functional reach. The only disability variable requiring any navigation in the open environment (i.e., requiring vision) was the TGUGT.

The relationship between visual loss and single leg stance time may perhaps be explained by the need to use vision to improve stabilization during a challenging task where contact with the floor (source of somatosensory information) is so limited. The correlation of visual loss with the functional reach task is not readily explainable, unless subjects with depth perception problems have a poor sense of distance that may impact their perception of position in space and their willingness to lean further.

There are few studies relating visual impairments to functional decline and falls in the elderly. Duncan et al. (1993) found vision to be one of several physiological impairments correlated with functional decline in elderly men. Lord et al. (1994) found visual acuity and contrast sensitivity to be associated with forceplate measures of postural sway and falls in older adults. The results of the current study, which found infrequent, weak correlations between visual impairment and the disability variables, lend minimal support to these prior investigations. This is largely due to the use of the disability test instruments, however, neither of which offer visually challenging navigation tasks. So a relationship between visual loss and falls may well exist, albeit within a different context where detection of environmental hazards is critical to successful performance of the task(s). Clinicians should be aware that their patients with visual loss may do very well on the BBS and the TGUGT, and still have a high risk for falls in more visually challenging, “real life” environments.

The vestibular system contributes to the sense of head position in relation to gravity, and acceleration of the head. It also supports the coordination of eye and head movements. Individuals with vestibular loss are most likely to have difficulty performing tasks when somatosensory and visual inputs are simultaneously reduced, such as standing on a piece of foam with eyes closed, or when the head must move rapidly through space. None of the activities in the BBS or the TGUGT specifically challenge the vestibular system by removing somatosensory and visual information simultaneously, or by requiring rapid head movements. Only one BBS item met the correlation criteria for

association with vestibular impairment. “Picking up an object from the floor” requires eye-head-hand coordination as well as tipping the head down as the object is retrieved, both may challenge the vestibular system. The absence of a relationship between vestibular loss and performance on other disability items may be explained by the fact that they can be performed (relatively) slowly; and slow head movements are far less provoking to the vestibular system.

Despite the fact that age-related vestibular changes are well-documented, and that dizziness is a prevalent complaint among the elderly, few studies have explored the relationship between vestibular loss and functional decline or falls in the elderly. Duncan et al. (1993) found vestibular loss to be one of several impairments associated with functional decline in elderly men. Ledin et al. (1991) reported improved balance in a group of older adults who underwent balance retraining exercises that included vestibular stimulation, compared to a control group. The results of the current study do not indicate a relationship between vestibular impairment and falls or functional decline in the elderly. However, this finding is likely due to the use of the BBS and TGUGT as disability measures. Neither test offers activities that would be highly provoking to the vestibular system. Clinicians should therefore be aware that patients with vestibular loss may demonstrate satisfactory performance on the BBS and TGUGT, yet still be at high risk for falls in situations where rapid eye and head movements are needed, or in environments where somatosensory and visual inputs are simultaneously disturbed.

The Motor Control Test provides surface perturbations to unpredictably disturb the relationship of the COG and the base of support, thus provoking automatic postural responses to realign the COG over the base of support. None of the activities in the BBS or TGUGT involve unexpected perturbations, so automatic postural response strategies are not required to perform well on these disability tests. Only one of 13 disability variables, the “turn 360 degrees” task, was weakly correlated with longer automatic postural response latencies. It is not clear why the performance of this relatively slow

(four seconds to each side) voluntary action would be associated with involuntary postural response latencies on the order of less than 200 milliseconds.

Only one previous study (Duncan et al., 1993) included postural response latency as a “physiological impairment” variable in its exploration of the relationship between postural control impairments and functional decline in the elderly. They established that this impairment was one of several impairments that were correlated with functional loss in elderly men. The results of the current study do not support an association between the time-to-onset of an automatic postural response and falls or functional decline in the elderly. According to Alexander (1996), the time-to-onset of a postural response may not be the best indicator to distinguish between elderly fallers and non-fallers. Once the response to a perturbation has been initiated, it may be the time taken to re-establish pre-perturbation levels of stability that better delineates fallers from non-fallers. Although statistically significant age-related increases in the time to automatic postural response onset have been documented, this variable may not have nearly the functional impact as the “time to execution” variable described by Alexander. Clinicians working with elderly fallers may therefore need to focus their evaluation and treatment methods on execution time, versus initiation time, when addressing automatic postural responses to balance perturbations.

In summary, then, the answer to the second research question is provided by the results of the Spearman’s correlation analysis, which indicate that specific impairments are associated with the ability to perform certain balance and mobility tasks. Further, the frequency with which an impairment is associated with these particular disability items indicates its relative influence. In this portion of the study, limits of stability, range of motion, strength, sensory organization and somatosensory loss were the impairment variables most frequently related to the disability items. It is important to note here that the canonical correlation discussed earlier in this chapter had also identified these same

five impairments as the practically significant variables contributing to the formation of the impairment canonical variable.

Are there any impairments to which these disability tests are “blind”?

The third research question was: are there any impairments which are known risk factors for falls that are not associated with any of the activity items on the selected disability tests? This is important to know, so that therapists can test for those impairments separately. The canonical correlation found four impairment variables that were not practically significant contributors to their impairment canonical variable: reaction time, vision loss, vestibular loss, and automatic postural response latency. The Spearman's correlation found reaction time and vision loss were each weakly associated with only four of the 13 disability variables, and vestibular loss and automatic postural response latency were each weakly associated with only one of the 13 variables. So the BBS and the TGUGT are not very sensitive to these four impairments. In other words, older adults with these four impairments (assuming the absence of other impairments) would probably perform well on the BBS and the TGUGT, thus appearing to have a low risk for falls. Yet the presence of these impairments does render them at risk for falls.

The inability of the BBS and TGUGT to signal peripheral vestibular loss is not surprising. Neither of these tests include activities that demand rapid head movement, eye-head coordination, or balance in the absence of visual and somatosensory cues, all of which would be difficult to perform if peripheral vestibular systems were impaired. Elderly individuals with vestibular loss are at risk for falls, however, in situations where rapid head movement, eye-head coordination, or balance in the dark or on unstable surfaces is required. Separate tests for peripheral vestibular deficits should be performed when screening for risk for falls in older adults, even if they perform well on the BBS and TGUGT.

Both the BBS and the TGUGT also fail to signal the presence of visual loss. Neither of these tests include environments which would challenge contrast sensitivity or depth perception abilities, such as an uneven walkway, curbs, stairs, etc. Elderly persons with visual loss are at risk for falls, though, when they encounter such situations in everyday life. Tests for visual loss should therefore be performed when screening for fall risk in older adults, despite satisfactory performance on the BBS and the TGUGT.

The fact that the BBS and TGUGT tests were not sensitive to reaction time impairments is probably because the timed BBS items and the TGUGT allowed several seconds for an activity to be performed. These are relatively long time periods compared to the reaction time deficits, which were on the order of a few hundred milliseconds. Alternatively, the lack of association between impaired reaction time and the disability items may have occurred because of the choice of a simple reaction time measure. Recent literature (Maylor and Wing, 1996; Shumway-Cook et al., 1995) suggests that divided attention tasks may better discriminate fallers from non-fallers. Therefore multiple choice reaction time tests may be superior to simple choice tests for the purpose of impairment identification in older adults. Perhaps a stronger association between this impairment and the disability items might have emerged had a multiple choice reaction time test been used.

Neither the BBS nor the TGUGT provides unpredicted balance perturbations that would (normally) result in automatic postural responses. The lack of association between automatic postural response impairments and the disability items is thus understandable. Responses to backward perturbations have been found to discriminate elderly fallers from non-fallers, however (Whipple & Wolfson, 1989). It may be important, then, to test for such postural responses separately when screening for fall risk in older adults. However, the “time to onset” portion of a postural response measure (as was used in this study) does not appear to be the best parameter for discrimination of fallers and non-fallers. The presence or absence of an adequate stepping response, as shown by Whipple and Wolfson

(1989), or the “time to execute” a successful response, as described by Alexander (1996), may be more meaningful characteristics of the postural response to measure.

The positive features of the BBS and the TGUGT should not be overshadowed by their insensitivity to these four impairments. However, clinicians using these two disability tests need to be aware of these limitations. When screening older adults for fall risk, clinicians should take additional steps to identify whether or not these four impairments/risk factors are present.

### Prediction of Disability Scores by Impairment

Multiple regression was used to examine the ability of specific impairment variables to predict disability item scores. A forward stepwise selection procedure was chosen, as the nature of this study was exploratory. This method provided a list of all impairment variables, in order of contribution, that best predicted a single disability variable. The cumulative correlation of the impairment variables with each disability variable is presented at each step of the regression equation, permitting the additional contribution of each successive variable to be calculated. All 13 disability variables had at least one predictive impairment variable; 11 had two predictors, six had three predictors, and three had four predictors. Impairment variables accepted in the first step may be considered the best single predictor. In this study, the amount of variance in a disability variable explained by the primary impairment variable ranged from 7 to 44%. Subsequent impairment variables entered into an equation explained from 5 to 16% of the remaining variance. Impairment variables entered in the second and third steps increased the strength of the multiple correlation only minimally ( $R = .03$  to  $.07$  per step); those in the fourth step even less ( $R = .01$  to  $.05$ ).

The impairments most frequently appearing in the first step of a prediction equation, in other words, those that were the best predictors of the disability items, were COG maximum excursion (6/13), range of motion (3/13), sensory organization (2/13), somatosensory loss (1/13) and reaction time (1/13). Of the 11 equations with a second (weaker) predictor identified, strength (3/11), reaction time (3/11), sensory organization (2/11), COG excursion (1/11), somatosensory loss (1/11) and visual loss (1/11) were the contributing impairments. Six disability items had a third predictor identified; COG excursion (2/6), vestibular loss (2/6), strength (1/6) and somatosensory loss (1/6) were the impairments contributing to prediction at this level. Only three disability items (single leg stance, the total BBS score and the TGUGT score) had a fourth identified predictor; range of motion (2/3) and somatosensory loss (1/3) impairments added slightly to the prediction equations.

Previous studies have identified impairments that are risk factors for falls (Studenski, Duncan, Weiner & Chandler, 1989; Tinetti & Speechly, 1989; Tinetti et al., 1994; Tobis & Reinsch, 1989); indeed, the decision regarding which impairments would serve as variables in this study was based upon their results. Earlier investigations have also documented the predictive validity of the BBS to distinguish elderly fallers from non-fallers (Berg, Wood-Dauphinee, Williams & Gayton, 1989; Berg, Maki, Williams, Holliday & Wood-Dauphinee, 1992; Berg, Wood-Dauphinee, & Williams, 1995; Shumway-Cook, Baldwin, Polissar & Gruber, 1997; Thorbahn & Newton, 1997), and the ability of the TGUGT to discriminate levels of physical independence (frailty) in older adults (Podsiadlo & Richardson, 1991). No prior study, however, has explored which of the impairments/risk factors are predictive of scores on the BBS and the TGUGT. Just as the correlational analysis indicated that certain impairments are more strongly associated with poor disability item scores than others, the results of the regression analysis in the current study demonstrated that certain impairments are better predictors of BBS and TGUGT scores than others.

Though the two methods of analysis used in the present study differ, a comparison of their overall results indicates substantial agreement. The Spearman's correlation analysis found the five impairments most often associated with the disability items to be COG excursion, range of motion, strength, sensory organization and somatosensory loss. The regression analysis indicated that the five impairments that best predicted disability item scores to be COG excursion, range of motion, sensory organization, somatosensory loss and reaction time.

### Implications

The results of the current study demonstrate that activity-based balance and mobility tests indicate not only functional decline and/or fall risk, but also the presence of certain physical impairments. Clinicians working with at-risk older adults now know not only who needs intervention, but also specifically what interventions are likely to be needed. Low total BBS scores may signal (in order of correlation) constricted limits of stability, reduced lower extremity strength, central sensory processing problems, restricted range of motion, somatosensory loss, visual deficits, and prolonged reaction time. Poor performance on the TGUGT may indicate constricted limits of stability, reduced lower extremity strength, restricted lower extremity range of motion, central sensory processing problems, somatosensory loss, prolonged reaction time, and visual loss. The results of the current study suggest that clinicians should (1) strongly suspect the presence of these impairments in the patients who perform poorly on the BBS and the TGUGT, (2) specifically assess for the presence and severity of these impairments, and (3) design and implement treatment plans to reduce or eliminate them. Interventions should be aimed at remediating the specific impairments present in each individual. Treatment to increase limits of stability, strength and range of motion, and to improve

sensory organization is possible and efficacious in older adults (Fiatarone, 1994; Harada et al., 1995; Moore & Woollacott, 1994; Rose, Clark & Hobbel, 1995). The development of compensatory measures for those impairments which are permanent (i.e. somatosensory loss, vision loss, etc.) is recommended.

Neither disability test as a whole is very sensitive to vision loss, vestibular loss, prolonged reaction times or prolonged automatic postural response latencies. Therefore, assuming previous studies implicating these impairments as risk factors for fall are correct, clinicians using the BBS or the TGUGT should - in addition - test for these “hidden” impairments separately. Failure to recognize their presence might negatively impact treatment design and efficacy. Treatment to remediate their effects, such as vestibular rehabilitation for motion-provoked dizziness, can benefit older adults and may reduce their risk for falls. Alternatively, test items that are sensitive to these impairments/risk factors could be developed and added to the BBS or TGUGT.

Specific postural control system impairments impact selected activities differently. Clinicians can now consider not only the total BBS score in their assessment of an older client, but also review which items the client had trouble performing. This information may direct their attention to the probable impairments most strongly associated with those items. Older individuals with difficulty rising from sit-to-stand may be likely to have restricted limits of stability, strength loss, limited lower extremity range of motion, and central sensory processing problems; those having difficulty with stand-to-sit may well have restricted lower extremity range of motion and prolonged reaction times. Elderly persons having trouble transferring from chair to chair may have restricted lower extremity range of motion, strength loss, somatosensory loss and restricted limits of stability. Inability to stand with the feet together may signal the presence of restricted limits of stability, prolonged reaction times, and vestibular loss. Poor performance of the functional reach test could indicate strength loss, restricted limits of stability, prolonged reaction times, limited range of motion, somatosensory loss and visual loss. Problems

retrieving an object from the floor may alert the clinician to somatosensory and vestibular loss. Older adults who cannot turn to look over their shoulders may be suspected of having restricted limits of stability, reduced lower extremity range of motion, prolonged reaction time and strength loss. Inability to turn 360 degrees quickly may be related to limited range of motion, restricted limits of stability, strength loss, central sensory processing problems, prolonged postural response latencies, and vestibular loss.

Difficulty with reciprocal toe touches on a curb could indicate the presence of restricted limits of stability, central sensory processing problems, limited lower extremity joint range of motion, strength loss and somatosensory loss. Inability to assume and maintain a tandem stance position may reflect strength loss, restricted limits of stability, central sensory processing problems, somatosensory loss and limited range of motion. Elderly individuals who cannot stand on one leg may have central sensory processing problems, restricted limits of stability, reduced strength, somatosensory loss, and limited range of motion.

During the design of this study it was thought that “clusters” of disability items implicating specific impairments might occur. The fact that five impairments were associated with 54% to 85% of the disability items, however, means that almost every “cluster” contains some combination of these five impairments. So the use of “clusters” to lead the clinician to the offending impairments may be unnecessary in some cases and impossible in others. The major impairments to which most of these items/tests are sensitive are already identified in this study, and no clusters for vestibular loss, vision loss, reaction time or automatic postural response latency were identified.

The results of this study support the existence of a strong relationship between postural control system impairments and balance-related disabilities, but (due to the exploratory nature of the study) causality cannot be implied. However, these findings could certainly be used to design prospective experimental studies to determine whether

the remediation of these postural control impairments does produce an increase in BBS and TGUGT scores, and a decrease in falls, among older adults.

### Critique

Because canonical correlation analysis permits the examination of multivariate sets of data, it is ideally suited to the study of multifactorial processes such as balance. Other methods of analysis, used by most previous investigators, have limited their explorations to very few variables and thus been unable to capture the multifactorial nature of the balance processes they were studying. However, canonical correlation also poses several problems for those who would adopt this method of analysis. First, the number of subjects required is high; 10 for each combination of variables. For this study, with nine impairment variables and 13 disability variables, 220 subjects would have been the ideal minimum number (Tabachnick and Fidell, 1996). Only 96 subjects completed the testing. The potential consequence of having too few subjects is that relationships that actually exist will not be apparent. The fact that one of the canonical correlation equations demonstrated such a strong and significant relationship between the impairment and disability variables despite the less than optimal sample size testifies to the strength of that relationship. Had the sample size been larger, however, perhaps a few more of the remaining eight canonical correlations would have reached significance. This would have increased the amount of shared variance between the two sets of variables, meaning that more of the variation in disability scores could have been attributed to the selected impairment variables.

Second, canonical correlation analysis is sensitive to the presence of outliers, of which there were many in this study. This was due not so much to the fact that outlier subjects earned unusual scores on any of the tests, but that for many of the BBS items, a

large majority of subjects received full scores, rendering any score less than a full score extreme. The outlier subjects were deemed to be legitimate members of the (admittedly variable) population of interest, therefore they were not deleted from the study. Since a spread of scores on any given variable was necessary to demonstrate correlation, the extreme values were not altered to bring them closer to the central cluster of scores. As a consequence, the outliers may have caused some of the data distributions to be skewed.

Third, canonical correlation is best suited for the detection of linear relationships, and is not recommended for use with non-linear data distributions. The variable distributions in this study often did not meet assumptions of normality, linearity, or homoscedasticity. This is primarily due to the “ceiling effect” caused by the great number of high scores on all but the most difficult BBS items. This effect could be minimized in future studies if (1) an equal number of fit and frail subjects were included, and (2) more difficult test items were developed. Both approaches would produce a more normal distribution of scores. Alternatively, the data in this study could have been transformed to improve their normality, as other researchers have done (Lord et al., 1991, 1994). This option was declined as the interpretation of transformed variables becomes problematic. It may be that the nature of impairment and disability relationships are curvilinear, as Buchner and deLateur (1991) found with their strength versus sit-to-stand task. (A certain minimum threshold of force was necessary to do the task at all, yet forces over a certain higher amount did not improve performance of the task. The only part of their strength data distribution that was linear was the portion between the minimum and maximum thresholds.) If this is so, then impairment/disability relationships that cannot be illuminated by analytical methods appropriate for linear data distributions may still exist. The non-linearity of the data distributions in the present study may also have caused the Spearman’s correlations to be weak.

Other limitations to this study should be mentioned. First, this study examined only physical impairments. Recent studies by Shumway-Cook et al. (1995, 1997) have

shown that allocation of attention during dual tasks, and perceptions of self-efficacy, both impact risk for falls. No cognitive or emotional impairment variables were included in the present study. The amount of variance in the disability scores explained by the impairment variables might have increased if these cognitive and emotional components were added to the model. Second, some physical impairment variables that could have been measured were not. Specifically, range of motion of the neck and trunk; strength of the hips, neck and trunk; and automatic postural response execution time (versus time to onset) have all been associated with imbalance and risk for falls in the elderly. Third, the methods of measurement, while providing external validity, may not have been optimal. Reaction time could have been fractionated to allow the distinction of premotor time from movement time if electromyographic data had been collected. Strength could have been evaluated using a hand-held dynamometer; this would have allowed the inclusion of hip, neck and trunk strength measures. As mentioned earlier, scaling the strength measures to body size might have improved the value of the force measures. A vibrometer would have allowed more sensitive and precise measurement of somatosensory loss; likewise electronystagmography would have permitted better detection of vestibular dysfunction than the clinical screening tests which were used. The BBS and the TGUGT may be too easy for community-dwelling older adults, resulting in a ceiling effect with large clusters of high scores on all but the most difficult items. This problem was so severe in BBS items #2, #3 and #6 that these items had to be removed from the analysis. Failure to achieve a "spread" of scores reduces the likelihood that relationships will be detected. The make-up of the sample of older adults in this study may also have contributed to sub-optimal distributions of data, as there were twice as many subjects with no falls versus subjects with two or more falls. The distribution of scores might have been broader with a greater number of repeat fallers. More skilled manipulation of the data, including management of outliers and possibly transformation of the data, would have resulted in more normal and linear data distributions and thus a

greater ability to identify significant relationships using canonical correlation methods. Lastly, an unavoidable consequence of the large number of correlations is the high probability of Type I error. Therefore, this study should be repeated to cross-validate these results.

## SUMMARY AND CONCLUSION

The purpose of this study was to explore the multidimensional nature of the relationships between impairments in the postural control system and disabilities in older adults. Specifically, this study addressed three major questions: Is there a substantial relationship between postural control system impairments and balance-related disability? Are specific impairments associated with the ability to perform certain balance and mobility tasks? Finally, are there impairments that are known risk factors for falls that are not associated with any of the activity items on the selected disability tests? Subjects underwent a battery of tests designed to identify physical impairments known to increase the risk for falls, and to indicate fall risk and frailty.

A total of 96 (65 female and 31 male) elderly volunteers completed the testing during the summer of 1996. Subjects ranged in age from 65 to 94 years. Forty subjects (42%) reported no unexplained falls, 35 (37%) reported one unexplained fall, and 19 (20%) reported two or more unexplained falls within the last five years.

Multiple tests were performed, using separate equipment and procedures. Impairments in the peripheral sensory systems (somatosensory, vision and vestibular inputs) were identified using clinical tests for proprioception, vibration, and smooth pursuit; the University of Michigan Motion Sensitivity Quotient; the Pelli-Robson Contrast Sensitivity Chart®, and the Frisby Stereotest®. Impairments of central sensory processing were identified using the Sensory Organization Test (EquiTest®). Central motor control impairments were identified using a simple reaction time test, the Motor Control Test (EquiTest®), and the Limits of Stability Test (PRO Balance Master®). Peripheral motor impairments were identified via lower extremity strength testing (KinCom®) and clinical range of motion tests. Disabilities were indicated by the 14 item Berg Balance Scale (fall risk) and the Timed Get-Up-and-Go Test (frailty). Nine impairment variables and 13 disability variables were included in the final analysis.

Canonical correlation was used to examine the relationship between the two sets of variables (impairment versus disability). Individual correlations between impairment and disability variables was accomplished via Spearman's rho. Post hoc analysis used stepwise multiple regression to indicate the relative predictiveness of the impairment variables for each disability variable.

The results of this study imply that the presence of sensory and motor impairments in the postural control system is strongly related to diminished performance on activity-based balance and mobility tests. Clinicians using the BBS and TGUGT should be aware that reduced performance on these tests signals the presence of multiple impairments, most likely in limits of stability, lower extremity joint range of motion, lower extremity strength, lower extremity somatosensation, and sensory organization. They should also recognize that performance on these tests is generally independent of deficits in vision and vestibular inputs, as well as prolonged voluntary reaction time and automatic postural response latencies. Separate tests to identify the presence of these impairments should be performed, as older adults at risk for falls due to these four impairments may currently be mistakenly identified as not at risk. Prediction of the total BBS and TGUGT scores may be accomplished largely through a combination of three shared impairment variables (LOS, strength, ROM), with sensory organization also predictive of the total BBS score and somatosensory loss predictive of the TGUGT score, in combination with the aforementioned three shared impairments.

Further, individual activity items on the BBS place different demands on the postural control system and are thus particularly sensitive to certain impairments but not others. Clinicians using the BBS, in addition to using the total score for the purpose of assessing fall risk, may further explore the test results to identify which particular items were poorly performed. Low scores on specific items, especially in combination with low scores on certain other items, should lead to strong suspicion that specific impairments are present. In other words, when a patient exhibits low scores on a certain "cluster" of

activity items, the clinician would be well advised to investigate further, searching (through further assessment) for the suspected impairment. In this way, the time taken to administer the BBS, and the BBS results, are of greater worth, since the results may guide clinical decision making regarding which impairment tests to perform. Efficient detection of impairments associated with imbalance and falls is thus more apt to occur. Treatment focused on the specific impairments of an individual is much more likely to result in improved balance and mobility outcomes.

Although this study was limited to impairments in the postural control system and balance-related disabilities, it serves as a preliminary model for future studies investigating the relationships between any two multivariate sets of impairments and disabilities. Specific recommendations for future research in postural control system impairments and balance-related disability include the following:

1. This study should be repeated with the following improvements: an increased number of total subjects; an increased ratio of repeat fallers to non-fallers; the addition of more difficult activity items, such as stair climbing; the addition of activity items that challenge the visual and vestibular systems; the addition of activity items requiring responses to unpredictable perturbations; the replacement of the simple reaction time task with a multiple choice or divided attention reaction time task; the replacement of the “time to onset” latency score of an automatic postural response with the “time to execution” recovery score; the addition of hip, trunk and neck strength measures; the scaling of strength measures to body size; replacement of clinical measures with objective measures of somatosensation, such as vibrometry; replacement of clinical measures with objective measures of peripheral vestibular function, such as electronystagmography; the addition of psychological indices of self-efficacy; and the addition of cognitive scores.

2. Investigation of the mediating roles that some impairments may have on others in relation to final disability level. For example, the presence of strength impairments may be far more deleterious in combination with range of motion loss than alone.
3. Exploration of the concept of “threshold” for each impairment in relation to selected disabilities, in other words, how severe does an impairment have to be to cause functional decline, and, to what level must an impairment improve before functional improvement occurs?
4. Expansion of this type of study with other “prone to fall” populations, including elderly people with cognitive loss such as Alzheimer’s disease or senile dementia, and neurological populations with balance disorders such as stroke, head injury, etc.
5. Further investigation of the effects of exercise training for the reduction of balance-related disability, geared toward the remediation of (or compensation for) postural control system impairments.

It is critical that health professionals explore and understand the relationship between impairments and disabilities in any population of patients seeking rehabilitation services. The recent, intense focus of rehabilitation professionals on “functional outcomes” (pre and post intervention levels of disability) has occurred to the point of near total exclusion of impairment considerations. This trend is unfortunate, as it is possible to document disability, but not to reduce or eliminate it, without attention to impairments. Since the role of rehabilitation professionals is to alter (minimize) the level of disability, they must know which impairments, of what severity, cause disability, and be able to treat the underlying impairments effectively to accomplish reductions in disability.

Knowledge of the relationships between impairments and disabilities will facilitate the development and validation of optimal clinical practice.

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## **APPENDICES**

## **APPENDIX 1: Institutional Review Board Application and Informed Consent Form**

### **APPLICATION FOR THE APPROVAL OF THE OSU INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN SUBJECTS**

**Title: Relationships Between Postural Control System Impairments and Disabilities.**

#### **1. Significance of the Research Project:**

Falls in the elderly are prevalent, dangerous and costly. Falls are the leading cause of injury in older adults, and the leading cause of accidental death in those over the age of 85. Five percent of falls lead to a fracture; more than 200,000 hip fractures occur each year at an annual cost of seven billion dollars per year. Even falls that do not result in injury can have serious consequences. Psychological trauma and fear of falling produce a downward spiral of self-imposed activity reduction which leads to loss of strength, flexibility and mobility, thereby increasing the risk of future falls. Falls and instability contribute to 40% of nursing home admissions.

Research to identify which older people are likely to fall, and which intervention strategies are most successful at reducing the risk and number of falls is now occurring. Low-cost, activity-based screening tests have been developed which may be useful for determination of faller versus non-faller status, however, they do not provide sufficient information for the development of intervention programs. Numerous tests for physical impairments (strength, sensation, etc.) must subsequently be performed to order to establish why a particular individual is experiencing falls before a program to remediate the risk of falls for that individual can be planned. However, clinicians with limited time cannot perform all the impairment tests needed to produce a comprehensive list of risk factors for an older adult faller, and must decide which of those tests to perform.

It is possible that the screening tests may contain "clues" about which impairments an individual may have. Certain impairments may reduce the ability to perform specific activities. Low scores on particular items (activities) of a screening test may signal the likely presence of one or more specific impairments. Clinicians using such screening tests may be able to obtain guidance regarding which impairment tests to perform by noting which items (activities) on the screening test(s) were problematic for each older adult. It is the purpose of this study to determine which postural control impairments are associated with difficulty performing certain balance-intensive activities on commonly used screening tests.

#### **2. Methods and Procedures:**

##### **Testing Equipment and Procedures**

Two activity-based screening tests and twelve postural control system impairment tests will be administered to each subject. Testing will be divided into two sessions, one on the OSU campus using non-portable computerized equipment, and one either at the subject's place of residence or at the OSU campus using portable equipment. Each session is estimated to take no more than two hours. Rest periods between tests will be given whenever necessary. Sessions will be performed on consecutive days when possible.

**Screening Tests:** Two commonly used, geriatric clinical screening tests will be administered to each subject. The Berg Balance Scale is a 14 item test used to rate the level of disability observed during the performance of functional balance activities (a copy of this scale is provided in Appendix A). The "Timed-Get-Up-and-Go" test is a mobility measure requiring the subject to rise from a seated position, walk three meters, turn, and return to a seated position on the chair. The time required to complete the activity sequence is recorded using a stopwatch. One practice trial and two scored trials will be performed. Two examiners will administer both tests; one examiner stays with the subject at all times to provide instructions and demonstrations, and to prevent balance loss if necessary. The second examiner observes and scores the test(s). Subjects will wear a safety belt which the examiner can grasp quickly and easily if needed during these tests.

**Postural Control Impairment Tests:**

**Vision:** Contrast sensitivity will be tested using the Pelli-Robson Contrast Sensitivity Chart (Clement Clarke, International), much like a visual acuity test except that the letters fade versus shrink as the test proceeds. The subject sits in a chair and views the chart, reporting to the examiner letters as they are recognized. Depth perception will be tested using the Frisby Stereotest Screening Plate (Clement Clarke, International). This square plate presents four visual displays which appear similar on the surface, however, one of them has a raised (or lowered, depending on which side of the plate is viewed) portion. The subject sits at a table to view the plate, reporting to the examiner which of the visual presentations contains the raised/lowered portion. Five trials are performed, with the plate rotated (out of the subject's view) between trials.

**Vestibular:** Peripheral vestibular abnormalities will be tested for using the University of Michigan's Motion Sensitivity Test, during which the subject performs various head and body motions and reports to the examiner the intensity and duration of any dizziness that might occur (a copy of the test is presented in Appendix B). Vestibular-ocular interaction will be tested using a clinical test of "smooth pursuit", in which a visual target held by the examiner is moved in front of the subject. The subject sits in a chair with head fixed (resting on hands), and follows the target with their eyes.

**Somatosensory:** Vibration sense will be tested using two tuning forks (high and low frequency). The subject will lie supine on a bed or mat table with bare feet. A fabric screen will obstruct the subject's view of their feet. The examiner will cause a fork to

vibrate, then place it lightly against a bony prominence (first metatarsal head and medial malleolus, bilaterally). The subject will report whether or not the fork is vibrating, and if so, whether or not the vibration is fast or slow. Two practice trials (one with each fork placed at the chin) are provided, and four scored trials at each of the four joints are performed. Proprioception will be tested manually by a licensed physical therapist. The subject remains in the same position as described above. A goniometer is used to indicate to the therapist the number of degrees of motion achieved. The first metatarsal and ankle joints bilaterally will be tested. The therapist will move the toe or foot a small amount (two to five degrees) to place the joint alternately in flexion or extension. The subject will report whether or not the limb has moved, and if so, which direction (up/down). Two practice trials will be provided; four scored trials at each of the four joints are performed.

**Sensory Organization Test (SOT):** The SOT indicates the relative contribution of visual, vestibular, and somatosensory system inputs to postural control. The EquiTest® Computerized Dynamic Posturography system (NeuroCom International, Inc.) is used for this test. The EquiTest is equipped with a movable dual forceplate that measures postural sway, and a movable visual surround (booth). During the SOT, the forceplate or the surround, or both, can be rotated (toes up/down) to match the sway of the subject (termed “sway-referencing”). The system is outfitted with an overhead harness designed to prevent the subject from falling during the testing sessions. (A graphic depiction of this equipment/test is provided in Appendix C.) Postural sway is measured by a forceplate upon which the subject stands (with shoes off). The subject wears a safety harness attached to an overhead bar to prevent a fall, and maintains a stable, upright posture for 20 seconds per trial. Six sensory conditions are presented: (1) eyes open, stable surface, (2) eyes closed, stable surface, (3) eyes open, sway-referenced surround, (4) eyes open, sway-referenced surface, (5) eyes closed, sway-referenced surface, and (6) eyes open, sway-referenced surface and surround. One trial each of conditions one and two, and three trials each of conditions three through six, are performed per test. The SOT in its entirety will be performed twice, with a rest permitted between tests.

**Motor Control Test (MCT):** The MCT measures the latency and amplitude of the subjects automatic postural responses to surface perturbations. The EquiTest® Computerized Dynamic Posturography system (NeuroCom International, Inc.) is used for this test. The EquiTest is equipped with a movable dual forceplate that measures postural sway. During the MCT, the forceplate “translates” (moves forward or backward) underneath the subject. (Please see Appendix D). When this occurs, the subject will press with the feet against the forceplate to return the body to a completely upright position. The system is outfitted with an overhead harness designed to prevent the subject from falling during the testing sessions. The latency and amplitude of the subject’s responses are measured by the forceplate upon which the subject stands (with shoes off). The subject wears a safety harness attached to an overhead bar to prevent a fall. The forceplate will provide three translations at each of three sizes of perturbation - small, medium, and large (all perturbations are scaled to subject height). The small perturbations serve as practice trials, while the medium and large translations are scored.

**Simple Reaction Time:** A Macintosh computer, monitor, and keyboard with software "Microcomputer Based Labs in Motor Learning and Control" (Simon Fraser University) will be used for this test. The subject sits at a table with the dominant hand placed on the keyboard such that the index finger rests on the "J" key. The subject presses the key immediately upon seeing a visual stimulus appear on the monitor. Five practice trials are provided, then 15 scored trials are performed.

**Limit-of-Stability (LOS):** The LOS test indicates the furthest distance a subject can lean away from a centered position in eight directions. The PRO Balance Master® (NeuroCom International, Inc.) will be used for this test. The PRO is equipped with a dual forceplate which measures postural sway, and a monitor which the subject views during the test. The system is outfitted with an overhead harness designed to prevent the subject from falling during the testing sessions. Postural sway is measured by the forceplate upon which the subject stands (with shoes off). The subject wears a safety harness attached to an overhead bar to prevent a fall. When a visual cue is presented on the monitor, the subject leans in the direction of the cue as far and as fast as possible without stepping or reaching. Eight cues per LOS test are presented, in a clockwise pattern. This test will be performed twice; a rest period between tests is permitted.

**Strength:** Lower extremity strength will be tested (knee flexion/extension and ankle dorsi/plantarflexion bilaterally). The KinCom® Isokinetic Dynamometer will be used for this test. Movement velocity will be set at 90 degrees per second. The subject sits on the seat, secured with a waist belt and a thigh strap on the leg being tested. For quadriceps and hamstring testing, the lower leg is attached with a strap to a pad on the movement lever arm. The subject kicks up (straightens the knee) as quickly and forcefully as possible, rests, and then pulls down (bends the knee) as quickly and forcefully as possible. For anterior tibialis and gastrosoleus testing, the left foot is placed against and strapped to a foot-plate attached to the movement lever arm. The subject pulls the toes/foot up as quickly and forcefully as possible, rests, then pushes the toes/foot down as quickly and forcefully as possible. For both the knees and the ankles, three practice trials followed by five scored trials will be performed.

**Range-of-motion:** Joint flexibility at the hips, knees and ankles bilaterally will be manually tested by a licensed physical therapist. A goniometer is used to measure the degree of joint excursion. For hip extension testing, the subject will lie face down on a mat table or bed if tolerated. Alternately, the subject will lie on their side. For hip flexion testing, knee motions, and ankle motions, the subject will lie supine on the mat table or bed. Each joint is passively moved by the therapist, with the maximum excursion in each direction recorded.

### **3. Benefits and/or Risks to Subjects:**

The proposed study is designed to identify postural control system impairments and balance disabilities in older adults. The risks to subjects participating in this study are considered minimal. The use of an overhead harness for the SOT, MCT and LOS tests, as well as the use of a safety belt and the provision of a “spotter” for the Berg Balance Scale and the Timed Get-Up-and-Go test activities should ensure safety and increase subject confidence during testing. The performance of those tests requiring manual handling skills by a licensed physical therapist with 12 years of clinical experience will minimize risks of injury or discomfort. Frequent rests will be provided whenever necessary to reduce fatigue. The major benefit to each participating subject will be a comprehensive, individualized balance assessment capable of identifying risk factors for falls. A summary report will be provided to each participant. Subjects who are at moderate or high risk will be advised to seek further consultation with their primary physician.

#### **4. Subject Population:**

One-hundred older adults (male and female) over the age of 65 years who meet the following eligibility criteria will be selected to participate in the proposed study:

- a) The mental ability to understand the purpose of the study, and to perform the tests.
- b) The ability to walk with supervision or independently, with or without an assistive device, a distance of 25 feet.
- c) The ability to stand unsupported without any external assistance for two minutes.
- d) The visual acuity to see the visual cues presented on the computer monitors during the reaction time and LOS tests.
- e) The verbal ability to reply to the examiner during the tests.
- f) The absence of pre-existing pain, significant discomfort, or acute/recent injury in any of the joints to be tested.
- g) The absence of acute illness and any chronic illness with acute exacerbations.

#### **5. Informed Consent and Confidentiality:**

Each subject will be required to sign an informed consent (Appendix E). The subject will be asked to read and sign the form prior to participating in the study. An identification number/letter code will be assigned to each subject to ensure the anonymity of the subject's files. All files will be securely stored. No subject will be identified by name in any presentation or publication of research-related results.

## INFORMED CONSENT

**TITLE:** Relationships between postural control system impairments and disabilities.

**PRINCIPAL INVESTIGATOR:** Dr. Debra Rose

**PURPOSE:** The purpose of this study is to discover the relationship between physical problems (such as weakness or vision loss) and the ability to perform activities that require balance skills. We hope to help health care professionals who are working with older adults know which tests ought to be performed in order to identify who might fall, and to plan a treatment program for those at risk for falls.

I understand that:

- a) I will be participating in two balance testing sessions which should last no more than two hours each.
- b) I will attend both sessions on the same day if I feel up to it, however, if I am tired and want or need to rest between sessions, I may attend the second session on a subsequent day (but not more than three days later than the first session).
- c) during each session, I will be given several different tests. Some of the tests will determine if I have a loss of sensation in my legs, vision, or vestibular function. Other tests will show how quickly I can respond to visual cues and balance disturbances. Certain tests will indicate if there is a loss of strength or joint flexibility in my legs.
- d) during the different tests, I will be asked to do the following: sit and push my feet and legs forcefully against resistance; remove my shoes and socks; lie on a mat table on my back, side or stomach; sit and look at a wall chart; sit and look at items on a table; sit and press a key on a computer keyboard; stand on a forceplate which may move; stand in a booth which may move, sit and move my eyes quickly to follow a target; move my head and body quickly in different directions; stand and lean (shift my weight) in different directions; stand up from a chair; sit down in a chair; move from one chair to another; stand with my eyes closed; stand with my feet together; stand and pick up an object from the floor, stand and turn my body to look to the right or left, or turn my body all the way around; stand as though I were on a "tightrope", with one foot in front of the other; stand on one foot; walk as quickly as I can for a short distance (less than 25 feet).

e) a licensed physical therapist will perform those tests requiring my head, body or limbs to move or be moved. During the different tests, she will: ask me if I am experiencing any dizziness when my eyes or head move quickly; touch my toes and ankles with a vibrating tuning fork and ask me if I can detect the vibration; passively move my toes and ankles and ask me if I can detect the direction of the movement; passively move my ankles, knees and hips to measure the flexibility in those joints.

f) I will be able to rest between tests if I want or need to.

g) the tests requiring computerized equipment will be performed on the Oregon State University campus; other tests which can be performed with portable equipment may be performed either on the OSU campus or at my residential facility.

h) if necessary, transportation will be provided to and from the OSU campus.

i) my confidentiality will be maintained at all times throughout the study. At no time will my name appear on record forms or in computer files related to the study. All documentation will be securely stored, and only the investigator and the assistants conducting the study will have access to the records.

j) the risks associated with the study are minimal, but some of the tests performed may cause fatigue in my legs or cause me to lose my balance or cause me to feel dizzy. To minimize these risks, my fatigue level will be carefully monitored during each session and testing will be delayed or discontinued if my fatigue level is too great. I will wear a safety belt during the mobility tests and an overhead harness during the computerized balance tests. This harness is designed to prevent me from falling if I should lose my balance during a test. An assistant will be with me during all tests, and will carefully supervise me during the mobility tests, using the safety belt to help me regain my balance if necessary.

k) participation in this study will give me a better understanding of my balance abilities, and help me to recognize if I am at moderate or high risk for falls in the future.

l) the University does not provide a participant involved in a research project with compensation or medical treatment in the event that the participant is injured as a result of participation in the project.

m) I have been informed about the nature of this study and understand why it is being conducted. The principal investigator has provided me with an opportunity to ask further questions about any aspects of the study. **I understand that my participation is voluntary and that I may withdraw my consent to participate at any time without prejudice to my relations with Oregon State University.** Any questions about the research or any aspect of my participation should be directed to Dr. Debra Rose at 737-5934.

n) I have received a copy of this consent form for my records.

Subject's Signature \_\_\_\_\_

Date: \_\_\_\_\_

Address: \_\_\_\_\_

\_\_\_\_\_

Telephone: \_\_\_\_\_

## APPENDIX 2: University of Michigan Motion-Provoked Dizziness Test

UNIVERSITY OF MICHIGAN VESTIBULAR TESTING CENTER HABITUATION TRAINING

NAME: \_\_\_\_\_ MRN: \_\_\_\_\_ AGE: \_\_\_\_\_ SEX: \_\_\_\_\_

DATE: \_\_\_\_\_

DATE: _____	INTENSITY	DURATION	SCORE
BASELINE SYMPTOMS			
1. SITTING → SUPINE			
2. SUPINE → LEFT SIDE			
3. →→ RIGHT SIDE			
4. SUPINE → SITTING			
5. LEFT HALLPIKE			
6. →→ SITTING			
7. RIGHT HALLPIKE			
8. →→ SITTING			
9. SITTING → NOSE TO LEFT KNEE			
10. SITTING → ERECT LEFT			
11. SITTING → NOSE TO RIGHT KNEE			
12. SITTING → ERECT RIGHT			
13. SITTING → HEAD ROTATION			
14. SITTING → HEAD FLEX. AND EXT.			
15. STANDING → TURN TO RIGHT			
16. STANDING → TURN TO LEFT			

INTENSITY: SCALE FROM 0 TO 3 (0=NO SX, 3=SEVERE SX)

DURATION: SCALE FROM 0 TO 3 (0-10 SEC=1 POINT, 11-30 SEC=2 POINTS, >30 SEC=3 POINTS)

TOTAL

MOTION SENSITIVITY QUOTIENT:  $\frac{\text{# POSITIONS} \times \text{SCORE}}{2040} \times 100 =$  \_\_\_\_\_

## APPENDIX 3: Berg Balance Scale

### Berg Balance Scale

Subject Number \_\_\_\_\_

Date \_\_\_\_\_

**1. Sit to Stand**

**Instructions: Please stand up. Try not to use your hands for support.**

**Grading: Please mark the lowest category which applies.**

- 0 Needs moderate or maximal assist to stand ( )
- 1 Needs minimal assist to stand or to stabilize
- 2 Able to stand using hands after several tries
- 3 Able to stand independently using hands
- 4 Able to stand with no hands and stabilize independently

**2. Standing Unsupported**

**Instructions: Stand for two minutes without holding.**

**Grading: Please mark the lowest category which applies.**

- 0 Unable to stand 30 seconds unassisted ( )
- 1 Needs several tries to stand 30 seconds unsupported
- 2 Able to stand 30 seconds unsupported
- 3 Able to stand 2 minutes with supervision
- 4 Able to stand safely for 2 minutes

**IF SUBJECT ABLE TO STAND 2 MINUTES SAFELY, SCORE FULL MARKS FOR SITTING UNSUPPORTED. PROCEED TO POSITION CHANGE STANDING TO SITTING.**

**3. Sitting Unsupported with Feet on Floor**

**Instructions: Sit with arms folded for two minutes.**

**Grading: Please mark the lowest category which applies.**

- 0 Unable to sit without support for 10 seconds ( )
- 1 Able to sit for 10 seconds
- 2 Able to sit for 30 seconds
- 3 Able to sit for 2 minutes under supervision
- 4 Able to sit safely and securely for 2 minutes

4. **Standing to Sitting**

**Instructions:** Please sit down.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs assistance to sit ( )  
 ( ) 1 Sits independently but has uncontrolled descent  
 ( ) 2 Uses back of legs against chair to control descent  
 ( ) 3 Controls descent by using hands  
 ( ) 4 Sits safely with minimal uses of hands

5. **Transfers**

**Instructions:** Please move from chair to bed and back again. One way toward a seat with armrests and one way toward a seat without armrests.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs two people to assist or supervise to be safe ( )  
 ( ) 1 Needs one person to assist  
 ( ) 2 Able to transfer with verbal cueing and/or supervision  
 ( ) 3 Able to transfer safely definite need to hands  
 ( ) 4 Able to transfer safely with minor use of hands

6. **Standing Unsupported with Eyes Closed**

**Instructions:** Close your eyes and stand still for 10 seconds.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs help to keep from falling ( )  
 ( ) 1 Unable to keep eyes closed for 3 seconds but stays steady  
 ( ) 2 Able to stand for 3 seconds  
 ( ) 3 Able to stand for 10 seconds with supervision  
 ( ) 4 Able to stand for 10 seconds safely

7. **Standing Unsupported with Feet Together**

**Instructions:** Place your feet together and stand without holding.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs help to attain position and unable to hold for 15 seconds ( )  
 ( ) 1 Needs help to attain position but able to stand for 15 seconds  
 with feet together  
 ( ) 2 Able to place feet together independently but unable to hold for 30  
 seconds  
 ( ) 3 Able to place feet together independently and stand for 1 minute with  
 supervision  
 ( ) 4 Able to place feet together independently and stand for 1 minute safely

The following items are to be performed while standing unsupported.

8. **Reaching Forward With Outstretched Arm**

**Instructions:** Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position.)

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs help to keep from falling ( )  
 ( ) 1 Reaches forward but needs supervision  
 ( ) 2 Can reach forward >2 inches safely  
 ( ) 3 Can reach forward >5 inches safely  
 ( ) 4 Can reach forward confidently >10 inches

9. **Pick Up Object From the Floor**

**Instructions:** Pick up the shoe/slipper which is placed in front of your feet.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Unable to try/needs assistance to keep from falling ( )  
 ( ) 1 Unable to pick up and needs supervision while trying  
 ( ) 2 Unable to pick up but reaches 1-2 inches from slipper and keeps balance independently  
 ( ) 3 Able to pick up slipper but needs supervision  
 ( ) 4 Able to pick up slipper safely and easily

10. **Turning to Look Behind Over Left and Right Shoulders**

**Instructions:** Turn your upper body to look over your left shoulder. Now try turning to look over your right shoulder.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs assist to keep from falling ( )  
 ( ) 1 Needs supervision when turning  
 ( ) 2 Turns sideways only but maintains balance  
 ( ) 3 Looks behind one side only other side shows less weight shift  
 ( ) 4 Looks behind from both sides and weight shifts well

## 11. Turn 360 Degrees

**Instructions:** Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs assistance while turning ( )  
 ( ) 1 Needs close supervision or verbal cueing  
 ( ) 2 Able to turn 360 safely but slowly  
 ( ) 3 Able to turn 360 safely one side only < 4 seconds  
 ( ) 4 Able to turn 360 safely in < 4 seconds each side

**Dynamic Weight Shifting While Standing Unsupported**

## 12. Count Number of Times Step Touch Measured Stool

**Instructions:** Place each foot alternately on the stool. Continue until each foot has touched the stool four times.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Needs assistance to keep from falling/unable to try ( )  
 ( ) 1 Able to complete >2 steps needs minimal assist  
 ( ) 2 Able to complete 4 steps without aid with supervision  
 ( ) 3 Able to stand independently and complete 8 steps > 20 seconds  
 ( ) 4 Able to stand independently and safely and complete 8 steps in 20 seconds

## 13. Standing Unsupported One Foot In Front

**Instructions:** (Demonstrate to subject)

Place one foot directly in front of the other. If you feel that you can't place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Loses balance while stepping or standing ( )  
 ( ) 1 Needs help to step but can hold for 15 seconds  
 ( ) 2 Able to take small step independently and hold for 30 seconds  
 ( ) 3 Able to place foot ahead of other independently and hold for 30 seconds  
 ( ) 4 Able to place foot tandem independently and hold for 30 seconds

14. **Standing On One Leg**

**Instructions:** Stand on one leg as long as you can without holding.

**Grading:** Please mark the lowest category which applies.

- ( ) 0 Unable to try or needs assist to prevent fall ( )  
( ) 1 Tries to lift leg unable to hold 3 seconds but remains standing independently  
( ) 2 Able to lift leg independently and hold = or > 3 seconds  
( ) 3 Able to lift leg independently and hold for 5-10 seconds  
( ) 4 Able to lift leg independently and hold > 10 seconds

**TOTAL SCORE ( )**  
**maximum = 56**

**APPENDIX 4: Univariate Skewness and Kurtosis Values**

<b>VARIABLE</b>	<b>SKEWNESS</b>	<b>KURTOSIS</b>
<b>Limit of Stability</b>	.86	.22
<b>Motor Control Test</b>	.288	.167
<b>Range of Motion</b>	.02	.99
<b>Reaction Time</b>	1.97	5.9
<b>Somatosensory</b>	-.621	-1.08
<b>Sensory Organization Test</b>	.591	.449
<b>Strength</b>	.956	1.478
<b>Vestibular</b>	.94	1.953
<b>BBS 1: Sit-to-Stand</b>	3.18	9.72
<b>BBS 4: Stand-to-Sit</b>	2.6	5.0
<b>BBS 5: Transfers</b>	2.0	2.2
<b>BBS 7: Stand with Feet Together</b>	4.0	15.99
<b>BBS 8: Functional Reach</b>	1.0	.062
<b>BBS 9: Pick Up Object from Floor</b>	3.0	7.5
<b>BBS 10: Turn to Look Over Shoulders</b>	1.34	.8
<b>BBS 11: Turn 360 Degrees</b>	1.77	1.82
<b>BBS 12: Toe-Touches on Curb</b>	2.86	8.27
<b>BBS 13: Tandem Stance</b>	1.09	.07
<b>BBS 14: Single Leg Stance</b>	.157	1.07
<b>Berg Balance Scale (BBS) Total</b>	1.54	3.26
<b>Timed-Get-Up-And-Go</b>	2.6	9.11

**APPENDIX 5: Canonical Correlations**

<b>ROOT NUMBER</b>	<b>CANONICAL CORRELATION</b>	<b>SQUARED CORRELATION</b>	<b>SIGNIFICANCE</b>
1	.85893	.73777	< .001
2	.58151	.33815	.203
3	.48012	.23052	.672
4	.42461	.18030	.876
5	.38579	.14883	.963
6	.26826	.07196	.996
7	.20234	.04094	.997
8	.14824	.02197	.994
9	.07126	.00508	.980