Postural Sway in Elderly Females During the Six Sensory Conditions of the Clinical Test for Sensory Interaction in Balance

Selena Horner  
*Grand Valley State University*

Gregory Vidro  
*Grand Valley State University*

Deborah Wildenhaus  
*Grand Valley State University*

Follow this and additional works at: [http://scholarworks.gvsu.edu/theses](http://scholarworks.gvsu.edu/theses)

Part of the [Physical Therapy Commons](http://scholarworks.gvsu.edu/theses)

Recommended Citation

Horner, Selena; Vidro, Gregory; and Wildenhaus, Deborah, "Postural Sway in Elderly Females During the Six Sensory Conditions of the Clinical Test for Sensory Interaction in Balance" (1994). *Masters Theses*. 189.  
[http://scholarworks.gvsu.edu/theses/189](http://scholarworks.gvsu.edu/theses/189)
POSTURAL SWAY IN ELDERLY FEMALES DURING THE SIX SENSORY CONDITIONS OF THE CLINICAL TEST FOR SENSORY INTERACTION IN BALANCE

By

Selena Horner
Gregory Vidro
Deborah Wildenhaus

THESIS

Submitted to the Department of Physical Therapy at Grand Valley State University in Allendale, Michigan in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN PHYSICAL THERAPY 1994
This study was designed to quantify postural sway in healthy elderly females during the Clinical Test for Sensory Interaction in Balance. Sixteen females who ranged in age from 65 to 83 participated. Each individual performed three trials of the test on the Balance Master®, which recorded percent postural sway area. Sway values from the third trial were used in data analysis.

Using a repeated measures ANOVA ($F(5,75) = 33.38$, $p < .01$), statistical significance was found between conditions. The post hoc Tukey's determined increased postural sway in conditions 5 and 6 ($M = 1.8175$ and $1.7425$ respectively, $p < .05$). Results indicated postural sway increased with intersensory conflict (altered somatosensation and altered or eliminated vision) leading to the conclusion that healthy elderly females relied heavily on somatosensory and visual input for maintenance of standing balance.
ACKNOWLEDGEMENTS

The authors would like to express a special thanks to the following:

1. Our committee members, Karen Ozga, Cathy Harro, and Ronald Garrett for their dedication, counsel and commitment throughout our project.

2. The volunteers and staff, especially Rose MacDoniels, at Evergreen Commons Senior Center in Holland, Michigan for participating in our study and for the use of their facility.


4. William Bell, Ph.D. for his assistance in the design of the study and Yousceek Jeong, Ph.D. for his assistance in statistical analysis.
PREFACE

Definition of Terms

Ankle strategy - response to anterior-posterior center of gravity movements with movement of the body occurring around the ankle joint during standing balance.

Anterior postural sway - oscillating movements of the body occurring in a forward direction over the feet while quietly standing.

Balance Master® - computerized force platform distributed by NeuroCom® International, Inc.

Biomechanical alignment - position in which body segments are aligned vertically in erect posture and the line of gravity falls close to most joint axes (Norkin & Levangie, 1992).

Center of gravity - a hypothetical point in which all mass tends to be concentrated and where gravity appears to act (Norkin & Levangie, 1992).

Clinical Test for Sensory Interaction in Balance (CTSIB) - a test of balance which systematically eliminates sensory inputs or presents inaccurate information during standing to gain insight into an individual’s sensory integration.

Dynamic posturography - a balance test using a moving platform to provide insight into an individual’s sensory integration.

Equilibrium - sense of the body’s orientation in space (Norkin & Levangie, 1992).

Fall - failure to maintain upright posture during activities of daily living (Chandler, Duncan, & Studenski, 1990).

Goniometer - a device which measures range of motion.

Healthy - a state of being functionally independent without neurological or vestibular diagnoses and without requiring assistive devices for mobility.
Hip strategy - activity of hip musculature to correct postural alignment.

Intersensory conflict - a situation in which the various sensory systems are not providing consistent information.

Kinesthesia - information from muscles, tendons, and joint receptors regarding movement (Newton, 1991).

Lateral postural sway - side to side oscillating movements of the body while quietly standing.

Limits of stability - the area around the base of support within which equilibrium can be maintained.

Motor control - various aspects of the body that are responsible for governing posture and movement (Brooks, 1986).

Physiologic aging - the process of natural aging in the absence of disease (Daleiden & Lewis, 1990).

Posterior postural sway - oscillating movements of the body occurring in a backward direction over the feet while quietly standing.

Postural control - the ability to maintain a given body position against one or more forces which threaten the body's equilibrium (Norkin & Levangie, 1992).

Postural sway - oscillating movements of the body over the feet (Daleiden & Lewis, 1990; Perry, 1992).

Proprioception - information from afferent receptors of the skin, muscles, tendons, and joints regarding position in space.

Quiet standing balance - a normal standing posture which includes continual movements to maintain the upright position.

Reflex-hierarchical model - a theory regarding movement in which the movement is regulated by reflexes (Connolly & Montgomery, 1991).

Romberg test - a balance test which requires a person to stand on one or both feet with eyes open and eyes closed.

Sensory integration - see sensory organization.
Sensory interaction - see sensory organization.

Sensory organization - interpretation and integration of sensory information by the nervous system to maintain the upright body position (Berg, 1989; Crutchfield, Shumway-Cook, & Horak, 1989; Woollacott & Shumway-Cook, 1990).

Somatosensory input - information which enables an individual to gauge weight, pressure, texture of materials, and judge shapes of objects (Newton, 1991).

Static balance - a term often used to describe quiet standing balance, which does not account for muscle adjustments to maintain the upright position.

Stepping strategy - movement of the base of support to prevent a fall when the center of gravity moves outside the limits of stability (Horak, 1987).

Synergies - basic units of movement in which groups of muscles act together to accomplish specific movements (Crutchfield et al., 1989).

Systems model - a theory which maintains that motor control stems from a network of subsystems which interact with each other (Crutchfield et al., 1989; Woollacott & Shumway-Cook, 1990).

Target sway - "the area around a target that is covered by the patient’s COG [center of gravity] after the target is reached; measured in per cent [sic] of total limits of stability sway area (Balance Master® Operator’s Manual, 1991-1992)."

Theoretical limits of stability sway area - maximum area (based on the individual’s height) one may sway without exceeding the base of support and falling (Balance Master® Operator’s Manual, 1991-1992).

Vestibular system - an internal reference that determines the orientation of the head in space (Nashner, 1989).
List of Abbreviations

CNS - central nervous system
CTSIB - Clinical Test for Sensory Interaction in Balance
df - degrees of freedom
DF - dorsiflexion
ECC - eyes closed on compliant foam surface
ECF - eyes closed on a firm surface
EOF - eyes open on a firm surface
EOC - eyes open on a compliant foam surface
HW - heel walking
M - mean
MMT - manual muscle test
MS - mean square
N - total number of subjects
n - number of subjects in a group
NS - not significant
P - p-value
SAS-PC - statistical analysis system - personal computer
SD - standard deviation
SLS - single leg stance
SOT - Sensory Organization Test
SS - sum of squares
TST - timed-stands test
### Table of Contents

**Abstract** ........................................................... i

**Acknowledgements** .................................................. ii

**Preface** ........................................................... iii

  - Definition of Terms .............................................. iii
  - List of Abbreviations ......................................... vi

**List of Tables** .................................................. ix

**List of Figures** .................................................. x

**Chapter**

1. **Introduction** ............................................ 1

   - Statement of the Problem ................................... 3
   - Purpose of this Study ......................................... 3

2. **Literature Review** ...................................... 5

   - Postural Control ........................................... 5
   - Sensory Organization ....................................... 6
   - Dysfunction in the Sensory Systems ....................... 7

   - Other Influences on Balance .............................. 12
     - Postural Strategies ....................................... 12
     - Muscle Strength ........................................ 14
     - Joint Mobility ........................................... 16
     - Pharmacology ............................................. 17

   - Evaluation of Balance ..................................... 17
     - The Sensory Organization Test ........................... 18
     - The Clinical Test for Sensory Interaction in Balance ........................................ 21
     - Application of Postural Control Studies .............. 23

   - Summary and Implications ................................. 26
     - Hypothesis ................................................. 26

3. **Methodology** .......................................... 28

   - Design ......................................................... 28
   - Subjects ...................................................... 28
   - Instrumentation ........................................... 29
   - Reliability ................................................ 31
   - Procedure .................................................. 32
     - Recruiting ................................................ 32
     - Pretest Data Collection ................................ 33
     - CTSIB ..................................................... 34
   - Data Analysis .............................................. 35
   - Basic Assumptions ......................................... 36
   - Limitations of the Study .................................. 36
**CHAPTER**

4. RESULTS ............................................... 38
   Pretest Measures/Descriptive Analysis ............... 38
   Sway Differences Between Conditions ................. 38
   Learning Effect ....................................... 40
   Performance Between Age Groups ...................... 45
   Performance with Visual Differences .................. 45
   Performance Based on Pretest Measurements ........... 45

5. DISCUSSION ............................................ 48
   Limitations of CTSIB ................................ 54
   Stratification of Sway Responses .................... 55
   Learning Effect ...................................... 56
   Clinical Implications ............................... 57
   Limitations and Suggestions for Further Studies ... 59
   Summary ............................................... 62

REFERENCES ............................................. 63

APPENDIX A. Diagram of the CTSIB ....................... 70
APPENDIX B. Description/Diagram of the Balance Master® 72
APPENDIX C. Participant Questionnaire/Data Collection Form . 74
APPENDIX D. Informed Consent ............................ 78
APPENDIX E. Raw Data ................................... 81
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Conditions for Evaluation of Sensory Interaction in Balance</td>
<td>19</td>
</tr>
<tr>
<td>2.</td>
<td>Summary of Repeated Measures ANOVA</td>
<td>42</td>
</tr>
<tr>
<td>3.</td>
<td>Summary of Tukey's Studentized Range Test</td>
<td>43</td>
</tr>
<tr>
<td>4.</td>
<td>Comparison of Subjects' Sway Values to Normative Data</td>
<td>52</td>
</tr>
<tr>
<td>5.</td>
<td>Interpretation of the CTSIB</td>
<td>53</td>
</tr>
<tr>
<td>6.</td>
<td>Trial Three Raw Data of % Postural Sway Area</td>
<td>82</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gross visual acuity of subjects</td>
<td>39</td>
</tr>
<tr>
<td>2. Sway responses of subjects during CTSIB</td>
<td>41</td>
</tr>
<tr>
<td>3. Falls in conditions 5 and 6 throughout the trials</td>
<td>44</td>
</tr>
<tr>
<td>4. Performance between age groups</td>
<td>46</td>
</tr>
<tr>
<td>5. Performance between subjects with visual differences</td>
<td>47</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

In 1989 12.48 percent of the population in the United States was 65 years of age or older (U. S. Department of Health & Human Service, Centers for Disease Control, National Center for Health Statistics, 1992). By the year 2000 it is estimated that this population will comprise 13 percent of the total population in the United States and will increase to 22 percent in the year 2030 (Institute of Medicine, 1990). The elderly female population represented 60.13 percent of those aged 65 and older in 1989 (U. S. Department of Health & Human Services, Public Health Service, 1992).

Studies and health care statistics demonstrate that incidences of dysequilibrium and falls increase with normal aging (Briggs, Gossman, Birch, Drews, & Shaddeau, 1989; Crosbie, Nimmo, Banks, Brownlee, & Meldrum, 1989; Maki, Holliday, & Topper, 1991; Stelmach, Teasdale, Di Fabio, & Phillips, 1989). Manifestations of dysequilibrium include increased postural sway and complaints of dizziness or unsteadiness (Lichtenstein, Burger, Shields, & Shiavi, 1990; Shepard, 1999; Stelmach et al., 1989). By 80 years of age, one third of elderly people will have already experienced a damaging fall (Isaacs, 1978). In 1988 2,721 hip fractures per 100,000 occurred in white females 85 years of age and older (U. S. Department of Health & Human Services, Public Health Service, 1992). In 1987 the death rate from falls and fall-related injuries was 18 per 100,000 for those between 65 and 84 years and 131.2 per 100,000 for those 85 years and older (U. S. Department of Health & Human Service, Centers for Disease Control, National Center for Health Statistics, 1992). Balance related falls account for greater than 50% of accidental deaths in the elderly population (Hart, 1992).
Reasons that elderly have an increased risk of falling have been proposed. Physiological changes such as decreased strength, decreased range of motion, and altered sensory systems may result in reduced functional abilities including decreased mobility, increased risk of injury, and decreased independence (Berg, 1989; Patla, Frank, & Winter, 1990). Other variables such as disuse of muscles, physiologic changes in sensory systems, and disease processes disrupt functional balance (Anacker & Di Fabio, 1992; Gehlsen & Whaley, 1990; Lewis & Bottomley, 1990; Vandervoort, Hill, Sandrin, & Vyse, 1990;). Inadequate control of balance increases the risk of falling (Daleiden & Lewis, 1990).

Various tests have been developed to assess balance. The Clinical Test for Sensory Interaction in Balance (CTSIB), developed by Shumway-Cook and Horak (1986), assesses how effectively an individual maintains quiet standing balance under systematically varied conditions (Appendix A). The visual, somatosensory, and vestibular systems are methodically eliminated or altered such that conflicting sensory information must be interpreted to maintain equilibrium efficiently. The CTSIB provides insight into which of the three sensory systems is relied upon in situations of intersensory conflict (Shumway-Cook & Horak, 1986). Conclusions about which sensory systems are under-utilized or over-utilized may also be made based on the performance of the individual.

Limited data is available about performance of the elderly population during standing balance tests (Briggs et al., 1989). Studies utilizing dynamic posturography have provided normative data for persons ranging in age from 20 to 69 years (Shepard, 1989). Although the data is available for dynamic posturography, the number of subjects in each age group is not provided and performance cannot be correlated with the CTSIB. Few studies comprehensively assess factors that influence quiet standing balance in a mobile, functionally independent elderly population (Duncan, Wilson, McLennan, & Lewis, 1992; Lord, Clark, &
Webster, 1991). Physical therapists play an important role in the assessment of balance control.

Physical therapists, among other health professionals, are important providers of care for geriatric patients. The role of the physical therapist includes the following: a) physiological assessment, b) functional assessment, c) goal setting, d) treatment and management of current status, e) providing assistance with gaining optimal functional capacity, and f) prevention of further complications. Because of their active role in the treatment of geriatric patients, physical therapists must have an understanding of physiological changes due to the aging process and the impact these changes have on functional abilities.

Statement of the Problem

A clinical problem is lack of baseline information on balance during the normal aging process. The relationship between quiet standing balance and the sensory integration process in healthy elderly female subjects has not been analyzed. Test-retest reliability of the CTSIB on elderly individuals has not been established.

Purpose of this Study

The purpose of this study was to evaluate postural sway in healthy elderly female individuals under altered sensory conditions through the use of the Clinical Test for Sensory Interaction in Balance. The Balance Master® was used to objectively quantify postural sway in quiet standing during the performance of the CTSIB (Appendix B).

The researchers provided objective information on the relationship between sensory interactions and quiet standing balance in healthy elderly individuals. Although test-retest reliability of the CTSIB on the Balance Master® for these individuals was not established, the investigators were able to document a learning effect.

Clinicians involved in the rehabilitation of elderly individuals who have balance deficiencies need a normal frame of reference about the
performance of elderly individuals during the CTSIB. This baseline information provides direction to the clinician for goal setting and treatment planning for the patient, resulting in optimal functional capacity outcomes.
Postural control is the ability to maintain a body position against one or more forces which threaten the body's equilibrium or sense of orientation in space (Norkin & Levangie, 1992). In quiet standing the force is often gravity, which is dynamic and results in a constant state of unstable equilibrium. A standing person lacks stability because none of the body's joints are locked. To counteract a disturbing force, muscular energy may alter joint positions to adjust alignment (Horak, 1987; Perry, 1992). Continuous corrections of body alignment result in anterior, posterior and lateral postural sway; that is, oscillating movements of the body over the feet (Daleiden & Lewis, 1990; Perry, 1992). The term "static" balance is often used to describe quiet standing but is an inaccurate label due to the presence of continuous normal movement.

One theory regarding central nervous system (CNS) control of posture and movement is the systems model. The systems model maintains that motor control stems from a network of subsystems which interact in a context specific manner (Crutchfield, Shumway-Cook, & Horak, 1989; Woollacott & Shumway-Cook, 1990). This theory is opposed to the reflex-hierarchical model in which each system has a level in a stratified arrangement.

The systems model is the basis of this study. From this perspective, balance requires efficient interaction of several systems, including musculoskeletal and sensory systems (Horak, 1987). The musculoskeletal system consists of muscle strength, postural alignment and joint range of motion. These factors will be discussed following explanation of the sensory system role in postural control.
Sensory Organization

A variety of sensory inputs are available from the visual, vestibular, and somatosensory (cutaneous sensation, kinesthesia, and proprioceptive) systems regarding orientation of the body. Afferent inputs can compliment or contradict each other. Intersensory conflict occurs when one of the three sensory systems provides information that contradicts the input from another system (Shumway-Cook & Horak, 1986). An example of intersensory conflict is when a person in a stationary automobile briefly experiences the sensation of moving backward when a nearby automobile begins moving forward. In this example, conflict occurs when the visual system provides inaccurate information regarding motion and the vestibular system provides accurate information regarding lack of motion.

For postural control, the nervous system must interpret, integrate and select from a surplus of sensory information. This is referred to as sensory organization, integration or interaction (Berg, 1989; Crutchfield et al., 1989; Woollacott & Shumway-Cook, 1990). Information can be used from the sensory systems individually or in combination when necessary due to challenging environmental circumstances.

Each sense has a role in a healthy system. When all three systems are intact, and inputs to all senses are available, somatosensory input provides information regarding the support surface and is predominantly relied on for postural control (Nashner, 1982, 1989). Visual input measures body orientation regarding the environment and is the information primarily used to restore balance when equilibrium is disturbed (Nashner, 1989). Finally, the vestibular system is an internal reference that determines orientation of the head in space (Nashner, 1989; Flores, 1992).

In situations when sensory inputs conflict, the vestibular system dominates to provide information on the body's orientation. The intact vestibular system is used to determine and select accurate and necessary
information (Dickins, Cyr, Graham, Winston, & Stanford, 1992; Nashner, 1982, 1989; Nashner, Black, & Wall, 1982). Such conflict can arise from outside of the body, despite intact sensory systems, or from within the body due to CNS or peripheral lesions resulting in one or more dysfunctional system(s) (Crutchfield et al., 1989).

Dysfunction in the Sensory Systems

Impaired sensory integration may result in dysequilibrium, increased postural sway (Crutchfield et al., 1989) or imbalance, which may lead to a greater incidence of unprovoked falls (Dickins et al., 1992). Dysfunction in only one of the three sensory systems will not necessarily result in functionally deficient postural control. For example, a person who is blind or has bilateral vestibular loss may still have the balance skills to function adequately (Flores, 1992). A sensory deficit requires a shift of reliance from the dysfunctional system to another remaining sense (Flores, 1992). The extent of dependency on a particular system and the ability to compensate with other systems are factors which affect the degree of postural control impairment.

Any disease or process which decreases the accuracy of inputs from the visual, somatosensory or vestibular systems may adversely affect postural control. Pathologic conditions such as cerebrovascular accident, arthritis, multiple sclerosis, cerebral palsy, Parkinsonism and brain tumor or trauma have been associated with impairment of balance (Berg, 1989). In addition, natural processes secondary to disuse or aging may alter postural control.

Physiologic aging, the process of natural aging in the absence of disease (Daleiden & Lewis, 1990), is associated with declines in the performance of the visual, vestibular and somatosensory systems. One theory regarding the decline in postural control with age maintains that the aged nervous system is less efficient with sensory integration and
sensory conflict resolution than the younger adult system (Anacker & Di Fabio, 1992; Woollacott, Shumway-Cook, & Nashner, 1982).

Patla et al., (1990) state that the extent to which age related declines in the various systems affect balance is not easily predicted. Age related sensory impairments may lead to decreased postural control and adversely affect functional ability (Maguire, 1990). Therefore, persons with imbalance should be evaluated for dysfunction (secondary to pathological or natural process) in any of the influencing systems including visual, somatosensory and vestibular.

Visual deficits can alter or eliminate some of the orientation input available. Elimination of visual input results in increased postural sway in young and old subjects with normal vision. However, this postural instability slightly improves over time (Teasdale, Stelmach, & Brunig, 1991). According to Maguire (1990), visual acuity of 20/40 can be functional. Beyond that, postural control may be threatened.

Diseases such as glaucoma, cataracts, and macular degeneration and natural processes such as aging may result in decreased visual acuity, contrast sensitivity, depth perception or peripheral vision (Maguire, 1990). In the elderly eye, a progressive loss of transmissivity through the optical media results in less available light (Simoneau, Leibowitz, Ulbrecht, Tyrrell, & Cavanagh, 1992). Although nearly normal sight throughout life is possible (Maguire, 1990), aging is more commonly associated with cataracts, presbyopia, decreased visual acuity as well as decreased tolerance of bright lights and glare (Daleiden & Lewis, 1990; Simoneau et al., 1992). The lens becomes more rigid with age, resulting in difficulty accommodating rapidly between far and near distance (Maguire, 1990). Disorientation may result as the eyes slowly accommodate to a quick change in focus.

Lord et al. (1991) measured sway of elderly subjects (mean age 82.7 years) via a sway meter during four conditions (eyes open on a firm
surface, eyes closed on a firm surface, eyes open on a foam surface, and eyes closed on a foam surface). Prior to balance testing, visual acuity, muscle strength, proprioception and vibration sense were measured. Decreased visual acuity correlated with increased sway with eyes open on foam, but not on a firm surface. No other recent studies found a correlation between decreased visual acuity and increased sway.

While visual dysfunction is of importance and should be evaluated in patients with imbalance, Daleiden and Lewis (1990) maintain that healthy elderly persons should be able to maintain a standing posture with their feet together and eyes open or closed for 30 seconds. Inability to do so indicates a need for evaluation for diseases of neurologic function such as cerebrovascular accident, Parkinsonism, or brain tumors (Daleiden & Lewis, 1990) as well as dysfunctions in the remaining sensory systems.

Somatosensory impairments may also affect postural control. In the above study by Lord et al. (1991), decreased proprioception and sensitivity to vibration correlated with increased sway with the eyes open and eyes closed on a firm surface. Additionally, the results of increased sway for subjects with decreased visual acuity on foam but not on the firm surface implies that in the presence of visual impairments, somatosensation may be relied on for postural adjustments when all input is available. However, when the input from somatosensation is altered via the foam surface, postural control is adversely affected.

Duncan et al. (1992) used a modified Wright's ataxiometer to measure anterior-posterior and lateral sway during eyes open and eyes closed conditions for healthy elderly men and women. Increased sway was found with decreased vibration sense for men only.

Anacker and Di Fabio (1992) used the clinical test for sensory interaction in balance (Appendix A) to assess quiet standing in elderly subjects with a history of falls and compared them to elderly subjects without a history of falls. Subject's ability to maintain standing
posture was timed while standing first on a firm surface then on a foam surface. On each surface, the subjects stood with their eyes open, eyes closed and with a dome over their heads which altered their vision. The results of this test indicated significantly decreased stance time for members of the "fall" group as compared to the control group during conditions when somatosensory input was altered. However, no significant difference was found for conditions when vision was altered or removed. The researchers concluded that vision's influence on preventing falls in older persons is secondary to that of somatosensation from the ankle. If so, then damage to the peripheral nervous system as with neuropathies or altered kinesthetic sense secondary to ankle and foot sprains (Norkin & Levangie, 1992), may decrease the accuracy of somatosensation and place increased demands on the other systems for maintenance of balance.

As stated before, somatosensation is a primary sense influencing postural control for healthy adults (Shumway-Cook & Horak, 1990). However, Horak, Nashner, and Diener (1990) imposed somatosensory loss on subjects via ischemic block above the ankle and postural sway values did not increase. These results support the theory that the multiple systems can compensate for deficiencies in one another with regard to postural control.

Teasdale et al., (1991) measured postural sway responses (via a force platform) of young and elderly adult subjects during conditions of eyes open on a firm surface (EOF), eyes closed on a firm surface (ECF), eyes open on a compliant foam surface (EOC), and eyes closed on foam (ECC). Sway parameters (velocity, range, variability and dispersion) did not increase significantly for either group during ECF. Significantly greater sway parameters in the elderly group existed during ECC. Once again, results suggest redundancy in the postural control system allowing compensation for deficiencies if multiple senses are not impaired. In this study, the elderly group demonstrated less
ability to compensate than the young adult group when both vision and somatosensation were altered.

Kinesthetic sense also decreases with physiologic aging due to an increase in thresholds for excitability in cutaneous sensation, vibration sensation and proprioception (Maguire, 1990). Circulatory changes may result in decreased blood flow to the extremities and contribute to decreased tactile sensitivity. These changes are especially significant in the lower extremity where sensation normally provides information regarding the location of the feet and this information is used to formulate motor responses to disturbances in postural alignment and balance.

The above studies suggest that decreased sensitivity of the somatosensory or visual systems, alone or in combination, may lead to postural instability (Berg, 1989). Maguire (1990) claims that such sensory deficits may increase a person's vulnerability to falls.

Vestibular participation in balance is critical. Vestibular damage results in an inability to identify inaccurate or conflicting sensory information (Nashner, 1982). Flores (1992) stated that patients with bilateral vestibular loss were unable to control postural sway with decreased or absent somatosensory or visual input. Kantner et al. (1991) performed a balance study utilizing the six conditions of the CTSIB (Appendix A) with patients who had dizziness and vestibular disorders. Patients with vestibular disorders and complaints of dizziness demonstrated greater sway with eyes closed on a firm surface and visual dome on foam than a healthy population.

Degeneration in the vestibular system occurs with age. The otoliths sometimes become detached or fragmented and the number of hair cells in the semicircular canals decrease (Berg, 1989; Daleiden & Lewis, 1990). A damaged vestibular system may result in a decreased capacity to resolve intersensory conflict (Woollacott et al., 1982) and in a loss of balance when vestibular information is necessary for spatial
orientation. Also, symptoms of dizziness and imbalance often result from an abnormal vestibular system (Dickins et al., 1992). Daleiden and Lewis (1990) state fluid imbalance in the semicircular canals, common in people over the age of 50, results in symptoms of dizziness. Therefore, vestibular symptoms and potential resultant deficits in stability may not be uncommon in the elderly population.

Postural Strategies

In addition to intact sensory systems, adequate biomechanical alignment, motor control, strength and range of motion are required for normal postural control (Daleiden & Lewis, 1990). The systems model includes an assumption that the basic units of movement are preprogrammed synergies in which groups of muscles act together to accomplish specific movements (Crutchfield et al., 1989). The term strategy is often used to describe postural control and can be used interchangeably with synergy in this context. There are four basic postural strategies which can exist individually or in combination. These include the ankle, hip, stepping strategies (Nashner, 1989) and suspensory (Woollacott & Shumway-Cook, 1990) strategies. Strategy selection for postural control depends on environmental and sensory circumstances. Adequate motor response requires efficient organization of sensory cues. If conflict between cues cannot be resolved rapidly, an inappropriate strategy may be chosen and balance dysfunction may result (Crutchfield et al., 1989; Nashner, 1989).

In a healthy adult, the ankle strategy is used in response to anterior-posterior movements of the center of gravity during standing balance when the surface is firm, stable and supports the entire foot (Horak, 1987). Stelmach et al. (1989) used a force platform and electromyography to determine that the gastrocnemius muscles respond first to large anterior perturbations in base of support. The tibialis
anterior muscle often reacts to compensate and the quadriceps and hamstrings muscles follow as needed.

Use of the ankle strategy requires activity of the muscles around the ankle joint. The tibialis anterior muscle activates to counteract excessive posterior sway and the gastrocnemius muscle activates to counteract excessive anterior sway (Nakagawa, Ohashi, Watanabe, & Mizukosi, 1993). When controlled by the ankle strategy, the body sways as an inverted pendulum with the ankles serving as axes of rotation (Ratliffe, Alba, Hallum, & Jewell, 1987).

According to Woollacott and Shumway-Cook (1990), the adult’s muscle response time for the ankle strategy is fast enough to be used to react to external threats to balance. In the elderly, however, slower postural muscle responses as well as slower recognition of perturbed balance can effect postural control. Older adults have less inhibition of inappropriate responses to postural disturbance (Alexander, 1994). More frequent proximal to distal EMG readings have been found with elderly subjects (Woollacott & Shumway-Cook, 1990). This order of muscle recruitment implies that many elderly favor the hip strategy.

A hip strategy utilizes the hip musculature to correct postural alignment. Use of the hip strategy is necessary when there are large, quick perturbations in balance, the surface is smaller than the feet or unstable, or the ankle strategy is otherwise insufficient, for example when standing on a narrow beam (Horak, 1987).

When a perturbation is such that the center of mass exceeds the limits of stability (that area around the base of support within which equilibrium can be maintained) a stepping strategy is used to prevent a fall (Horak, 1987). In this strategy, the person takes one or more steps to counteract the altered center of mass. Another strategy which is less frequently documented is the suspensory strategy. This includes flexion of the ankle, knee and hip to lower the center of gravity toward the base of support (Woollacott & Shumway-Cook, 1990).
Muscle Strength

As postural adjustments are made and sway occurs, the strength of the muscles involved in the chosen strategy becomes crucial (Gehlsen & Whaley, 1990). General strength and endurance as well as strength of key muscle groups involved in erect posture and postural responses are necessary for adequate postural control. Physiological aging is accompanied by decreased number and size of muscle fibers and motor units (Lewis & Bottomley, 1990; Mitolo, 1968). Also, the permeability of muscular membranes change and potassium is not adequately stored. Potassium is required for maximum force of contraction and thus the elderly muscle is deficient in strength. Concurrently, an altered cardiovascular system provides less circulation to the muscle, and less protein and other nutrition is available. Decreased circulation to the muscles leads to muscle atrophy, decreased speed of contraction and impaired coordination (Daleiden & Lewis, 1990).

Strength can be measured by manual muscle testing (MMT). This method alone is not a good indicator of functional abilities because the muscles are isolated in non-functional positions (Crutchfield et al., 1989). Ideally, specific muscle groups of interest during standing (hip extensors, knee extensors and ankle dorsiflexors) should be measured with an objective tool (such as MMT with a hand held dynamometer) and referenced to a functional skill which requires use of those muscles.

Crutchfield et al. (1989) suggest a partial squat for quadriceps strength and one-legged stance, while raising the pelvis on the unsupported side, for gluteus medius strength. Studenski, Duncan, and Chandler (1991) used a single leg stance test in their postural response study with a group of elderly persons who had a history of falls and a control group without a history of falls. They found that 79.2% of the control group versus only 20% of the "fall" group were able to maintain a one-legged stance for 15 seconds. While Studenski et al. (1991) were
primarily concerned with balance, their results demonstrate that healthy elderly should be able to perform a single leg stance test.

Another functional test of lower extremity strength, especially the knee flexor and extensor muscles, is the timed-stands test (Csuka & McCarty, 1985). In this test, a person is timed while moving from a seated position to a standing position 10 times as fast as possible. Csuka and McCarty (1985) tested 139 healthy 20-85 year old individuals and found that the time of performance correlated with published data of knee flexor and extensor muscle strength for the age groups tested. The timed-stands test results also correlated with isokinetic strength and manual muscle strength for a healthy population of males (Newcomer, Krug, & Mahowald, 1993) but not for males with rheumatoid arthritis. The results of the normative values are questionable because the testers claimed to be testing a healthy population, but mentioned subjects within the group with polymyositis.

During normal quiet standing, the body sways as an inverted pendulum with the axis at the ankle joint (Patla et al., 1990a). Therefore, the strength of the ankle muscles is important for the majority of quiet standing posture. Functional tibialis anterior muscle strength can be assessed by asking the person to walk on his or her heels with inverted feet. Individuals with weak tibialis anterior muscles will have difficulty with heel walking (Hoppenfeld, 1976). One limitation of the heel walking test is that measurement of the ankle musculature strength via a weight bearing task assumes adequate balance as well as strength.

Vandervoort et al. (1990) stated that impaired postural control secondary to deficits in muscle function may result in falls. While direct correlation of strength and falls cannot be assumed, lower extremity strength deficits have been demonstrated in subjects with a history of falling as compared to non fallers. Decreased ankle dorsiflexion and quadriceps strength was correlated with increased
postural sway in the study by Lord et al. (1991). Similarly, Gehlsen and Whaley (1990) established that concentric contractions (as measured by the Cybex®) of the hip, knee and ankle were significantly less for elderly subjects with a history of falls than for a group with no history of falls. These strength differences did not correlate with one-legged balance tests of the same groups, therefore no assumption could be made that the weakness contributed to the falls in this population sample.

**Joint Mobility**

To maintain standing, adequate range of motion is necessary throughout the spine and lower extremities. Decreased flexibility is accompanied by decreased stability and mobility (Shephard, 1984). A natural decrease in collagen integrity with advance age results in decreased flexibility (Lewis & Bottomley, 1990; Vandervoort et al., 1990). This may be compounded by lack of activity, improper diet and the presence of arthritis in the elderly individual.

Measurement of range of motion via a goniometer provides objective assessment of any deficits. Any lower extremity joint which is not able to attain normal position (such as full extension in the hips and knees and neutral to slight dorsiflexion in the ankles) will threaten the equilibrium of a quiet standing person (Maguire, 1990).

Since the ankle strategy is the most commonly used strategy, weakness or reduced range of motion at the ankle can result in noticeably decreased postural stability. According to Nashner (1989), decreased ankle range of motion may actually result in a smaller sway area than normal during quiet standing due to less available area within which sway can occur before stability is disrupted (Lewis & Bottomley, 1990; Nashner, 1989). Another result of deficient ankle mobility may be large compensatory hip and trunk motions (Horak, 1987). Postural sway resulting from these motions, which involve the hip strategy, is faster
than that from the ankle strategy (Nashner, 1989) and may not provide the most efficient form of postural control for the situation.

**Pharmacology**

Sensory organization, muscle strength, flexibility, range of motion, and absence of pain have all been credited for having some potential effect on postural control. One final influencing factor should be mentioned. The use of medications, especially multiple types of medications, can cause many side effects. Orthostatic hypotension is associated with many medications used for hypertension and may lead to decreased postural stability (Alexander, 1994). Dizziness, vertigo and postural instability are common side effects of many drugs, too numerous to mention (Malone, 1989). A person's drug interaction may be a primary cause of balance dysfunction. Thus, it is important to know which medications (including over-the-counter drugs) a person is taking.

**Evaluation of Balance**

In physical therapy, the specificity and thus efficacy of a treatment program for an unstable patient partially depends on adequate knowledge of the patient's sensory integration (Horak, 1987). It is important to know which sense the patient most often relies on for orientation information and how well the patient adapts to intersensory conflict (Shumway-Cook & Horak, 1986).

Many tests exist to evaluate standing balance, but few include altered sensory conditions beyond the presence and absence of vision. The commonly used Romberg test consists of standing on one or both legs with eyes open and eyes closed (Flores, 1992; Goldie, Matyas, Spencer, & McGinley, 1990). Other clinical tests involve asking the patient to maintain a posture against resistance or with various foot positions such as tandem (the heel of one foot directly in front of the toes of the other foot). Many balance tests are not objectively measured and often the expected results are not clear (Crutchfield et al., 1989;
Flores, 1992). For this reason an objective tool is necessary which separates "static" balance into measurable components.

**The Sensory Organization Test**

Systematic elimination of sensory inputs during standing and presentation of inaccurate information are necessary to gain insight into the patient’s sensory integration and its effect on standing balance. A protocol for such evaluation was developed by Nashner (1982) utilizing a moving platform. This protocol is often referred to as the Sensory Organization Test (SOT) and is one component of computerized dynamic posturography. Six sensory conditions are utilized to test quiet standing balance in the SOT (Table 1).

The first three conditions involve standing on a firm surface. Conditions 4 through 6 involve standing on an unstable surface, a rotating platform. The rotating platform is sway referenced such that when the body sways forward, the base tips forward to maintain neutral alignment of the ankle joints. Sway referencing of the platform provides the somatosensory system with an inaccurate sense of vertical orientation, requiring the vestibular and visual systems to determine orientation. On each surface, firm and unstable, the person attempts to stand for a set amount of time during three conditions: eyes open (conditions 1 and 4), eyes closed (conditions 2 and 5) and eyes open with inaccurate visual information (conditions 3 and 6). Inaccurate visual information is provided via a sway referenced foreground which moves as the body does to falsely appear vertically oriented.

Performance on the SOT is measured by the amount of time a position can be maintained. The amount of sway which occurs during each trial is also recorded by the Equitest® (NeuroCom® International, Inc.), the computerized platform device used to perform the SOT. Results of the SOT can provide information regarding senses which are over or under utilized for standing balance (Flores, 1992). Additionally, the degree
Table 1

Conditions for Evaluation of Sensory Interaction in Balance

<table>
<thead>
<tr>
<th>Condition #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm stable</td>
<td>Eyes open</td>
</tr>
<tr>
<td>1</td>
<td>Eyes closed</td>
</tr>
<tr>
<td>2</td>
<td>Eyes open/inaccurate visual field</td>
</tr>
<tr>
<td>Unstable</td>
<td>Eyes open</td>
</tr>
<tr>
<td>4</td>
<td>Eyes closed</td>
</tr>
<tr>
<td>5</td>
<td>Eyes open/inaccurate visual field</td>
</tr>
<tr>
<td>surface</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
to which a person relies on a particular system during conditions of intersensory conflict may be estimated by the ability to maintain postural stability when the relied on system is challenged (Shumway-Cook & Horak, 1986).

Interpretation of performance on the sensory interaction tests was provided in detail by Flores (1992). Condition 1 is used as a reference for each subject’s performance. Poorer performance on condition 2 as compared to condition 1 implies a reliance on vision for postural control. Condition 4 challenges the somatosensory system by providing inaccurate information. According to Flores (1992), results of conditions 3 and 6 should be referenced to conditions 2 and 5 to determine if a person relies on vision even when it is inaccurate.

Additional interpretation has been provided by Dickins et al. (1992). Stability in condition 5 is maintained solely by the vestibular system since vision is eliminated and somatosensation is altered. Poor performance on this section alone is rare. When a person does perform poorly on condition 5, a vestibular deficiency is most often indicated. However, CNS abnormalities may also result in increased postural instability during condition 5. A specific pattern has been identified in which greater postural sway occurs during conditions 5 and 6 for patients with uncompensated unilateral or bilateral vestibular dysfunction and central nervous system pathology (Dickins et al., 1992). Conditions 3 and 6 evaluate how well a person accommodates in the presence of intersensory conflict.

Healthy adults are able to disregard the sway-referenced sensory inputs, and rely instead on the available accurate inputs. Normative data for healthy adult subjects, aged 20-69 years have been established for the SOT protocol. The following responses have been established (Nashner, 1982). Healthy subjects were able to maintain the posture throughout the test. Conditions 1-3 result in very little sway (condition 3 was slightly greater than the first two). With addition of
the inaccurate somatosensory information, normal subjects had a significantly greater amount of sway. Conditions 5 and 6 resulted in the greatest amount of sway.

Black & Nashner (1985) tested patients with known vestibular disorders and dysequilibrium on the SOT. These persons did not sway more on the first two conditions than healthy individuals. Since the Romberg test involves identical conditions as the SOT conditions 1 and 2, the results of this study suggest that the Romberg is inaccurate in detecting dysequilibrium in patients with vestibular dysfunction (Crutchfield et al., 1989).

The Clinical Test for Sensory Interaction in Balance

The principles behind the six sensory conditions used in the SOT protocol have since been utilized in other studies of sensory integration, including the Clinical Test for Sensory Interaction in Balance (CTSIB) (Shumway-Cook & Horak, 1986). Two substitutions occur in the CTSIB in comparison to the SOT. A piece of compliant foam replaces the moving platform and a paper dome replaces the sway referenced foreground.

The foam is not sway referenced, but more generally provides inaccurate somatosensation at the foot and ankle. The ankle joint is no longer able to monitor body sway accurately because of the instability of the support surface. A paper dome with vertical lines is placed over the person’s head to act as the altered visual field. In this case, some sway referencing may take place as the dome tilts with the person’s body, thus indicating vertical alignment despite an altered position of the body. However, any available point of reference can be used to maintain balance.

The CTSIB provides a clinical application of the SOT. It does not require expensive equipment yet still provides objective information pertaining to a patient’s sensory organization. Originally, the test was scored based on the person’s ability to maintain standing posture.
for up to 30 seconds during each of the conditions. Other suggested scoring applications include observing and ranking postural sway via various methods and scales (Horak, 1987; Shumway-Cook & Horak, 1986).

Very few studies have been conducted utilizing the CTSIB. This test has not been proven valid nor have normative values been established for sway responses in healthy population samples. Di Fabio and Badke (1991) state that healthy adults maintain stance during all conditions of the CTSIB. Anacker and Di Fabio (1992) examined community dwelling elders with a history of falling. Scoring was based on time. Test-retest reliability was established for a 7 day time span between tests. Age was found to be a significant predictor of total score for 65-96 year old participants. No significant results were obtained to differentiate fallers from non fallers, however, the examiners noted that somatosensation was relied on greatly for fallers who had shorter stance time on foam than non fallers.

Kantner, Rubin, Armstrong, and Cummings (1991) applied the CTSIB to healthy and dizzy individuals (ages 20-74). A forceplate was used to measure sway. Normal subjects generally increased sway throughout the conditions. The exceptions were conditions 3 and 6 (dome on each surface) which were less than 2 and 5 (eyes closed on each surface) respectively. Patients with vestibular lesions presented with greater sway than healthy individuals during all conditions. Another study (Cohen, Blatchly, & Gombash, 1993) found that patients with vestibular deficits and healthy elderly individuals were unable to maintain stance for 30 seconds in conditions 4, 5 and 6. Cohen et al. (1993) also established test-retest reliability for the CTSIB.

Composite time scores were also acquired for patients with cerebral vascular accident (Di Fabio & Badke, 1990, 1991). Reliability of the CTSIB for this population was established. Hemiplegic patients were able to maintain stance during conditions 1 through 3 but not with introduction of the foam surface. Visual field deficits and decreased
integration efficiency were named as possible reasons for the results. In their initial presentation of the CTSIB, Shumway-Cook and Horak (1986) stressed that factors other than sensory information can influence postural control and that the CTSIB is not a diagnostic indicator. Therefore, care should be taken when assumptions are made about the results.

Application of Postural Control Studies

Results from studies focusing on postural sway in quiet standing have been used to assess standing balance control (Vandervoort et al., 1990). Differences in values are most often found between young and old subjects, in which older adults demonstrate more postural sway than younger adults (Kollegger, Baumgartner, Wöber, Oder, & Deecke, 1992; Teasdale et al., 1991; Woollacott et al., 1986). Additionally, men have been found to have more postural sway than women in a middle aged or older sample whereas differences between men and women in a younger (age 21-35) sample were insignificant (Kollegger et al., 1992).

The prevalence of falls in the elderly is a concern of clinicians. Attempts have been made to reveal aspects of balance which influence incidences of falling. Anacker and Di Fabio (1992) reported elders in a faller group had lower bilateral stance durations during the CTSIB than the elders in a non faller group. However, when the scores were statistically adjusted for expected declines secondary to age, there was no significant difference between the faller and non faller groups.

Postural sway studies have reported increased postural sway for elders with a previous history of falling (Gehlsen & Whaley, 1990). Since falling most often occurs during ambulation or other dynamic balance tasks, the results of static posture studies can not guarantee any correlation between standing postural ability and risk of falling.

Few tests have examined the effects of the six sensory conditions of the CTSIB on postural sway of the healthy elderly or any other age group. The responses of adults during the SOT were discussed
previously. Woollacott et al. (1986) revealed increased sway on the SOT for elderly versus younger adult subjects only during conditions 5 and 6. Direct correlation cannot be made between the CTSIB and the SOT since the two tests utilize different equipment.

Teasdale et al. (1991) found that sway, as measured by a force platform for 80 seconds (versus 30 seconds in the CTSIB) was greater in elderly (age 70-80) versus younger (age 21-22) subjects during conditions which were similar to conditions 1-2 and 4-5 of the CTSIB. Di Fabio and Badke (1991) administered the CTSIB to subjects with hemiplegia but postural sway was not measured. Kanter et al. (1993) provided postural sway data for 26 healthy women ages 21 to 74 in the performance of the CTSIB. The mean age of the women was 38.1 years with a standard deviation of 19.1. Since analyzing the performance of healthy individuals versus those with vestibular deficits was the focus of the study, the number of elderly women tested is unclear. Postural sway gradually increased from condition 1 through condition 6 with the exceptions of conditions 3 and 6 which were less than 2 and 5, respectively. No other application of the CTSIB was found in which objective data was given for postural sway responses of the healthy elderly.

An additional consideration when performing postural sway tests is the issue of motor learning. Decreased postural sway measurements occur with repeated performance of the CTSIB. Such results indicate a potential for learning the task exists and this learning effect may influence measurements (Berg, 1989). Cohen et al. (1993) demonstrated improvements in performance between the first and second attempts at the CTSIB for conditions 5 and 6 for subjects with vestibular impairments and for healthy elderly but not younger adults.

The lack of standard application of the CTSIB has resulted in a lack of normative data. While the CTSIB can be performed without expensive equipment, a device such as a computerized force platform can
be used to provide objective measurements of postural sway. One such device is the Balance Master®. A computerized force platform consists of a forceplate with subsurface sensors which detect magnitude and location of forces exerted on the surface (Balance Master® Operator’s Manual, 1991-1992). A person stands on the forceplate and a computer receives information from the forceplate regarding the location of the body weight of the person. The Balance Master® contains a software program that allows measurement of "static" balance as well as dynamic balance (a person’s ability to maintain equilibrium while moving his/her center of gravity). The Balance Master® software also allows balance exercises to be performed, monitored and recorded.

The Balance Master® measures static balance by recording a person’s shift in position of center of gravity as postural sway occurs. A trace of the sway pattern is provided on the computer screen and percentage of total sway area is computed. Therefore, the Balance Master® provides objective data quantifying the amount of postural sway which occurs during standing balance.

The attained sway value can be compared to normative values for the conditions of eyes open and eyes closed on a firm surface, which have been established for subjects aged 7-89 (Balance Master® Operator’s Manual, 1991-1992). NeuroCom® provided criterion for inclusion of subjects in normative data. All subjects included in this data performed the tests with shoes off. A safety belt was worn in case of loss of balance. Subjects were allowed to practice each task once prior to scoring the tests in order to assure that the individual’s ability to perform the test was measured as opposed to his/her ability to learn the test (Balance Master® Operator’s Manual, 1991-1992).

A limitation of the Balance Master® is its inability to accurately record hip strategy movements. The Balance Master® only records movements created by an ankle strategy which are slower than those created by a hip strategy (Balance Master® Operator’s Manual, 1991-
Measurement of strategies, if desired, must take place via observation, videography, motion analysis or palpation of the involved muscles.

Summary and Implications

Postural sway studies have revealed that elderly individuals have more postural sway than younger adults. Age related declines in the visual, vestibular, somatosensory and musculoskeletal system may result in decreased postural control and thus contribute to increased postural sway. The Clinical Test for Sensory Interaction in Balance is a test that allows systematic elimination or alteration of the inputs from the three sensory systems (visual, vestibular and somatosensory) known to influence balance.

Few studies have been performed utilizing the CTSIB. Those that have been done measure performance by timing the subject's posture maintenance. Only one study has been performed, to the authors' knowledge, using an objective measurement device for sway. No studies have been done to assess elderly adults' postural sway during the CTSIB.

A baseline of postural sway responses in a community-dwelling elderly sample may assist therapists in goal setting and treatment planning when utilizing the six sensory conditions of the CTSIB for balance retraining. Analysis of postural sway may also provide further insight into the nature of sensory organization for the elderly.

Hypothesis

This study was concerned with the postural control responses of a sample of healthy elderly women to systematic removal or alteration of input from the three sensory systems (visual, vestibular, and somatosensory). We expected that postural sway in response to the conditions of the CTSIB, as measured by the Balance Master®, would increase when intersensory conflict was present. We hypothesized that there would be statistically significant greater postural sway values for conditions 3 (firm surface with dome on head), 5 (foam surface with
eyes closed), and 6 (foam surface with dome on head) as compared to condition 1. We also, hypothesized that postural sway values would increase progressively with each successive condition (1 through 6).
CHAPTER 3

METHODOLOGY

Design

A two-factor within-subjects repeated measures design was used in this study. The changes in postural sway area (dependent variable) as a result of different standing surfaces and the changes in visual input (the two independent variables) were studied. The first independent variable, standing surface, had two levels: a firm surface and a foam surface. The second independent variable, visual input, had three levels: eyes open, eyes closed, and dome over head (conflicting visual input). A 3x2 design was created with three levels of visual input and two levels of standing surface.

The combination of variables resulted in six sensory conditions, as follows:

1. firm surface (forceplate) with eyes open.
2. firm surface (forceplate) with eyes closed.
3. firm surface (forceplate) with dome on head.
4. foam surface (placed on forceplate) with eyes open.
5. foam surface with eyes closed.
6. foam surface with dome on head.

One group was used and each subject in the group was tested under all six conditions; therefore, each subject served as her own control.

Subjects

Using a sample of convenience, healthy female subjects from the Evergreen Commons Senior Center in Holland, Michigan were selected. Each woman met the inclusion criteria based on a subjective questionnaire (Appendix C) and an objective screen of gross visual acuity. Of the 23 individuals who filled out the questionnaire, 17 met the inclusion/exclusion criteria. One subject was unable to complete
balance testing due to illness. As a result, 16 individuals completed the CTSIB test for this study. Of the six other subjects who did not complete the CTSIB, two had Meniere's disease, one was legally blind, one had frequent complaints of dizziness, and one individual did not perform the CTSIB appropriately. The range of ages of the subjects was 65 - 83 years \( (M = 72, \ SD = 5.6) \).

Volunteers were excluded from the study if they had a history of ear surgery or inner ear infections within the last six months; a fall, defined as failure to maintain an upright position during activities of daily living (Chandler, Duncan, & Studenski, 1990), within the last six months; a history of neurologic diagnoses; a history of vestibular deficits; complaints of dizziness or light-headedness within the last month; impaired community ambulation (i.e. unable to ambulate 150 feet continuously, difficulties on various ground surfaces); or had a vision deficit exceeding 20/40 (corrected vision with glasses or contacts allowed). Subjects were also excluded if an assistive device was necessary for ambulation (i.e. cane, walker, orthoses, or prostheses).

Because of the equipment used in this study, the inclusion/exclusion criteria also included body weight and height limitations. The Balance Master® platform was designed to work optimally for subjects who weigh between 40 and 300 pounds (18 - 136 kg) and stand between 30 and 80 inches (76 - 203 cm) (Balance Master® Operator’s Manual, 1991-1992).

Instrumentation

The following materials were used in this study: the Balance Master® version 3.4 and its inclusive software package, a stadiometer, piece of foam and a dome for the CTSIB, a goniometer, a gait belt, a standard straight back chair, an adult folding walker, a stopwatch, and a Snellen visual chart.

The Balance Master® is a tool used in clinical settings to provide objective measures of the basic components of balance control including
center of gravity, postural alignment, limits of stability, and rhythmic weight shifts. The Balance Master® hardware includes a force platform, consisting of two adjacent 9- x 18-inch (22.86- x 45.72-cm) footplates, on which the subject stands. The force platform is interfaced with an IBM-compatible PC/AC computer, a monitor, printer, keyboard, and controller box (Appendix B). The Balance Master® was programmed such that under "custom suite" of the assessment menu, a category of CTSIB was established to collect data for the six standing conditions that constitute a trial.

The Balance Master® forceplates rest on two force transducers which measure the electromotive force in volts and convert the vertical forces exerted on the two plates into pounds (Balance Master® Operator's Manual, 1991-1992). The total vertical force is calculated and from this the X and Y axes centers of vertical force are calculated. The center of gravity has been approximated at .5527 of the total height of a person (Balance Master® Operator's Manual, 1991-1992). Geometrically, the sway angle is calculated using the center of gravity height and the instantaneous Y axis position of total vertical forces.

A Health-O-Meter stadiometer (manufactured by Continental Scale Corporation in Bridgeview, IL) was used to obtain subjects' heights and weights. These values were then entered into the Balance Master® which allowed computerized calculation of the sway parameters (center of gravity height, limits of stability, and sway angles). The data output by the Balance Master® were percent target sway areas. Theoretical limits of stability was a precalculated area determined by the Balance Master® software package dependent on the subject's center of gravity and height (Balance Master® Manual, 1991-1992). The area covered by oscillations of the subject's center of gravity was calculated and then converted into a percentage of the theoretical limits of stability.

A universal goniometer was used to measure ankle dorsiflexion and plantarflexion. Reliability of the goniometric measurements was ± 5
degrees. Intratester reliability for the goniometer was established by performing three measurements each of bilateral dorsiflexion and plantar flexion in 23 subjects. If the three measurements were ± 5 degrees from the mean, the measurements were considered reliable.

Sun-Mate foam, manufactured by Dynamic Systems, Inc., of standard size (40.64- x 45.72- x 10.16-cm), was used in this study. The foam was of soft pressure quality and described as having a 5 lb/ft$^3$ (19.95 N/m$^2$) density and as being a 100% open cell elastomeric foam. The grid lines of the forceplate were traced onto a piece of paper which was used as a template to reproduce the grid lines onto the foam. The grid lines were reproduced on both sides of the foam.

The dome used in this study was fabricated from a Pier I Imports 18 inch (45.72 cm) hanging paper lamp with a wire frame covered by thin white paper. Construction of the dome was based on the instructions provided by Shumway-Cook and Horak (1986). The bottom 5 inches (12.75 cm) of the back half was removed to allow enough room for the dome to be placed over the head and to rest comfortably on a subject’s shoulders. Vertical lines were drawn on the inside front of the dome. Three lines were drawn 2 inches (5.08 cm) apart at the two ends and 6 inches (15.24 cm) apart in the center. An X was drawn in the center of the visual field of the dome.

Reliability

The reliability of the Balance Master® is ± .1 pound (.045 kg) of the weight of the person (Balance Master® Operator’s Manual, 1991-1992). It is unclear (D. Cooper, NeuroCom® International, Inc., personal communication, May 4, 1993) how this measurement translates into reliability of percent maximal sway area. Reliability of the stadiometer was ± 1 pound (.45 kg) and ± 1 inch (2.54 cm). Reliability of the goniometric measurements was ± 5 degrees. Reliability of the stopwatch was ± 100th of a second.
Calibration of the Balance Master® was built into the system (Balance Master® Operator’s Manual, 1991-1992). Recalibration during the study was not necessary. The stadiometer was zeroed at the beginning of data collection and was checked prior to each use. The calibration screw was used as needed to assure a zero position.

Three trials were performed to allow assessment of test-retest reliability of the CTSIB on the Balance Master®. The trials occurred on the same day with a 30 second rest between each trial.

To assure intratester reliability, each researcher was responsible for a particular pretest measurement (i.e. one researcher provided instructions for the timed-stands test, single leg stance, and ambulation in dorsiflexion; one researcher took time measurements; one researcher took height and weight measurements; and two researchers measured ankle range of motion where one researcher put the joint in position and the other researcher took the goniometric measurement).

During the CTSIB on the Balance Master®, each researcher again performed the same duties with all subjects while collecting the data (i.e. one researcher ran the program, provided instructions to the subject, and timed the trials for information if a subject lost balance and two researchers provided stand-by guard).

Procedure

Recruiting

Prior to the actual data collection, a presentation of the study and requirements of the participants was given to various exercise groups at the Evergreen Commons Senior Center. Participants were active healthy elderly women. Those interested in participating volunteered for two appointment times. Subjects completed the medical history questionnaire and performed functional tasks during the first visit and performed the CTSIB during the second visit. All aspects of the study took place at the Evergreen Commons Senior Center. All subjects who volunteered progressed through all aspects of the study secondary to the
personal interest of the subjects. Only data from subjects who met inclusion criteria were used by the investigators.

Pretest Data Collection

Pretest data collection began with completion of a subjective medical history questionnaire (Appendix C) in the presence of one researcher. The investigator clarified any questions that occurred. All individuals who were willing to participate in the investigation were then asked to read and sign an informed consent form (Appendix D).

The subjects were then asked to perform a gross visual acuity screen. A Snellen visual chart determined the gross visual acuity of the subject. The standard specifications for testing were used; the subject stood 20 feet from the visual chart and each eye was tested separately. Corrective eye wear was used by those subjects who were dependent upon these devices for functioning in the community.

Prior to the CTSIB, during the second appointment, the subjects performed functional tasks to assess strength. The data gathered was used for descriptive purposes and for possible stratification of postural sway data post hoc. Heel walking assessed anterior compartment strength of the legs. The timed-stands test (TST) quantified knee flexor and extensor strength. Single leg stance (SLS) for 15 seconds established functional gluteus medius strength. Bilateral ankle dorsiflexion and plantarflexion range of motion were also measured.

Each subject walked on their heels a distance of 5 feet (1.524 m). The subjects were allowed to wear low-heeled shoes and to use upper extremity support on the wall for balance. Each subject was given one practice trial, prior to recording the results.

The time required to complete 10 full stands from a sitting position without the use of upper extremities was recorded with a stopwatch to the nearest 100th of a second. The TST was performed using a plastic molded straight back chair 44.5 cm high and 38 cm deep. Subjects wore low-heeled shoes and performed five practice stands.
Practice allowed for correct positioning and learning of the task. The test was performed once with a 2 minute rest between the practice and the trial.

Single leg stance with both eyes open was timed for up to 15 seconds. The subject performed the task with low-heeled shoes and one investigator provided contact guard. Because balance was not the focus of this task, subjects were allowed to hold onto the investigator’s hand but could not lean or push into the investigator’s hand. Three measurements were collected for each lower extremity.

Three goniometric measurements were taken for bilateral ankle dorsiflexion and ankle plantarflexion following the procedures described by Norkin and White (1985). Two investigators were responsible for this measurement. One investigator positioned the joint and the other investigator read and recorded the measurement.

CTSIB

Prior to performing the CTSIB, the subject’s height and weight was recorded and instruction was provided regarding the testing procedure. The subject wore a gait belt and performed the test in stocking feet for 20 seconds in each condition. The stance time was 20 seconds opposed to 30 seconds as originally described by Shumway-Cook and Horak (1986) secondary to the collection methods of the Balance Master®. Three CTSIB trials were completed by each subject where one trial was defined as going through each of the six conditions without a rest. After each trial, a rest period of 30 seconds was provided.

Subjects stood quietly during conditions 1 through 6 successively. After the first three conditions the subject was asked to step off the platform and the foam was put in place for the following three conditions. One minute was allowed to change the foam at which time the subject remained standing. The six conditions were not performed randomly as previous researchers (Cohen et al., 1993) reported no
differences in postural sway between testing randomly and testing in the series previously described.

During the CTSIB test, the subject was instructed to stand as steadily as possible with her arms at her sides. If, at any time, the subject was touched by either of the investigators, took a step, or reached for the walker, the data recorded by the Balance Master® was inaccurate and the test for that condition was terminated. In these situations the investigators recorded the performance as a "fall". The Balance Master® does not record time elapsed when termination occurs during assessment, therefore this value was recorded manually (via stop watch measurement). Stance durations less than 20 seconds were not used for statistical purposes regarding postural sway area but allowed qualitative analysis of results.

To ensure the safety of the subjects during the CTSIB, a gait belt and stand by guard of two investigators were provided. A walker was also placed in front of the subjects for their use if they felt they were losing their balance. The walker was also used for assistance when placing their feet on the forceplate and foam surfaces.

Data Analysis

The means of the pretest data, which included heel walking (HW), timed-stands test (TST), single leg stance (SLS), and goniometric measurements, were used for descriptive purposes. Individual performances during the TST were also compared to normative data. Postural sway data from individuals whose times during the TST did not fall within the normal parameters were subjected to a post hoc t-test to compare their sway responses to all others.

Because the subjects served as their own controls in each of the conditions, a repeated measures analysis of variance (ANOVA, $p < .05$) was used to assess sway area differences between conditions. Data were analyzed using the statistical analysis system (SAS-PC) computer program. Variance was partitioned to include a main effect for subjects
and for each condition variable, termed treatment. These interactions represent the random or chance variations among subjects for each treatment.

Differences established by the ANOVA were then subjected to a post hoc Tukey's test. A Tukey's studentized range was used to (a) decrease the Type I error and (b) determine where significant differences were found.

T-tests were used to compare the postural sway responses between: (a) two age groups, (b) two groups with visual differences, (c) subjects whose performances during the TST were below average compared to subjects whose performances were within the normative range, and (d) subjects with less than functional range of motion in at least one ankle for both plantarflexion and dorsiflexion. A paired t-test was used to assess learning (or improved performance based on sway values) between the three trials.

Basic Assumptions

Basic assumptions of the investigators were as follows:

1. The subjects would have accurate recall when responding to the subjective medical questionnaire.

2. The subjects would use an ankle strategy with a slow body sway rate versus a hip strategy with a faster sway rate in maintaining their quiet standing position.

3. The majority of the subjects would be able to complete the CTSIB without losing balance or without falling.

Limitations of the Study

The following factors were considered limitations of this study:

1. Convenience sampling was used instead of random sampling.

2. Because the sample consisted of healthy and physically active elderly females, results may not represent the all inclusive elderly population.

3. Subjects were volunteers who met the inclusion criteria.
4. Since only quiet standing was examined, the results of this study may not be used to predict functional ability or dynamic balance capabilities.

5. The Balance Master® was only able to accurately record body sway rates below 0.3 Hz.

6. Only one foam density was used.
CHAPTER 4  
RESULTS  
Pretest Measures/Descriptive Analysis  
The majority of the subjects (87.50%) were able to perform the timed-stands test (TST) at or quicker than the normative mean for their individual ages. The normative data for the TST provided a predicted upper 5% limit of normal for all age groups and 93.75% of the subjects were within this range. The mean ($M = 17.97$, $SD = 5.09$) TST performance for the elderly women in this study is comparable to the upper 5% limit of normal for 35 year old women (Csuka & McCarty, 1985). All of the subjects were able to ambulate five feet in ankle dorsiflexion, termed heel walking (HW). All subjects performed single leg stance (SLS) on each lower extremity for 15 seconds maintaining upright posture with left upper extremity support.

Additional pretest measurements included ankle range of motion and visual acuity. Without regard to age, functional dorsiflexion (DF) is generally given as 10 degrees from neutral and functional plantarflexion is 30-50 degrees (PF) from neutral (Norkin & Levangie, 1992; McPoil & Brocato, 1990). Percentages of subjects with less than functional range of motion in at least one ankle was as follows: 56% had less than 10 degrees of DF and 12.5% had less than 30 degrees of PF.

As shown in Figure 1, the majority of the subjects had a gross visual acuity of 20/20. At times when subjects had differing acuities between their eyes, the eye with the greater visual acuity represented our interpretation of their visual acuity.

Sway Differences Between Conditions  
As stated previously, three trials of the CTSIB were performed by each subject. In trial one 50% of the subjects fell (i.e. were unable...
Figure 1. Gross visual acuity of subjects.
to maintain quiet standing for 20 seconds) in condition 5 and 18.75% fell in condition 6. In trial two 11.76% of the subjects fell in condition 5 and 0% fell in condition 6. Trial three was the only trial with complete data for all conditions (no subjects fell). The SAS-PC would not perform the desired statistical analysis in trials which had missing data points. Therefore, analysis was based on the results of the third trial and the first two trials were considered practice.

Figure 2 demonstrates the general pattern of sway responses throughout the conditions. More sway was observed while on the foam surface compared to the firm surface.

Using a repeated measures ANOVA ($F(5, 75) = 33.38, p < .01$), statistical significance was found between the conditions (Table 2). The post hoc Tukey’s equation indicated increased postural sway in conditions 5 and 6 ($\bar{M} = 1.8175$ and 1.7425 respectively, $p < .05$) as compared to conditions 1 through 4 (Table 3). Means within each Tukey grouping letter were not significantly different.

Learning Effect

The decrease in the percentage of falls with repeated performance (Figure 3) suggests a learning effect was present for the subjects in this study. With regard to the percent maximum sway area, an overall (all conditions combined) significant learning effect was found between trials one and two and between trials one and three ($p < .01$), but not between trials two and three. When comparing the trials for each condition, a significant learning effect was found between trials one and three in conditions 2, 4, and 5 ($p < .05$). Learning was also significant ($p < .01$) between trials one and two and between trials one and three in condition 6.
Figure 2. Sway responses of subjects during the CTSIB.
Table 2
Summary of Repeated Measures ANOVA

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>15</td>
<td>8.6183</td>
<td>.5745</td>
<td>1.78</td>
</tr>
<tr>
<td>Treatment</td>
<td>5</td>
<td>53.9916</td>
<td>10.7983</td>
<td>33.38*</td>
</tr>
<tr>
<td>Error</td>
<td>75</td>
<td>24.2600</td>
<td>.3235</td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>95</td>
<td>86.8698</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .01
Table 3

Summary of Tukey's Studentized Range Test

<table>
<thead>
<tr>
<th>Tukey grouping</th>
<th>Mean</th>
<th>N</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.8175</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>A</td>
<td>1.7425</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>.5469</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>.1356</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>.1169</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>.0938</td>
<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 3. Falls in conditions 5 and 6 throughout the trials.
Performance Between Age Groups

Subjects were divided into two age groups. Age group one represented individuals between 65-70 years of age (n=7) and age group two were individuals older than 70 years of age (n=9). No significant difference in overall performance between the two age groups was found. When performance between the two age groups in each of the six conditions of trial three was compared, the older age group demonstrated significantly more sway during conditions 2 ($t(14) = -2.7397, p < .05$) and 4 ($t(9.9) = -3.6446, p < .01$) than the younger group (Figure 4).

Performance with Visual Differences

Subjects were separated into two groups based on visual acuity. One group (n=3) represented individuals who were blind in one eye (less than 20/50 visual acuity). The other group of subjects (n=13) met inclusion criteria in both eyes. No significant difference in overall performance between the two groups of subjects was found. However, with respect to individual conditions, the subjects who were blind in one eye demonstrated significantly increased postural sway in condition 6 ($t(14) = 4.8663, p < .001$) compared to the other subjects (Figure 5).

Performance Based on Pretest Measurements

Subjects who performed below their normative mean during the TST and subjects who had less than functional range of motion in at least one ankle did not show any difference in postural sway performance.
Figure 4. Performance between age groups.
Figure 5. Performance between subjects with visual differences.
Postural sway was expected to increase throughout the performance of a trial from conditions 1 through 6. In comparison to condition 1, significantly increased sway during conditions 3, 5, and 6 was expected. These expectations were based on two factors. First, physiologic aging is accompanied by declining function of the three noted sensory systems (Daleiden & Lewis, 1990) and a possible decrease in efficiency of sensory integration (Anacker & Di Fabio, 1992; Woollacott et al., 1982). The elderly women, although considered healthy, may have had difficulty with resolution of sensory conflict. Secondly, the conditions of the CTSIB are ordered such that inputs from the systems are eliminated or altered with theoretical progressive complexity (Nashner, 1991; Shumway-Cook & Horak, 1986).

In this study, the healthy elderly women swayed more on the foam than on the firm surface. Sway values also increased when the subjects closed their eyes. When the dome was introduced, sway actually decreased as compared to blinded conditions on the same surface. These findings supported those of Kantner et al. (1991). Although Kantner et al. (1991) included healthy elderly subjects in their sample, the number of elderly subjects was not stated. Therefore, the healthy elderly response remained unclear.

Sway values during conditions 3 and 6 of this study were actually less than those during conditions 2 and 5 respectively. The first hypothesis that sway values would progressively increase from conditions 1 through 6 was rejected. The expectancy that postural sway would increase during condition 3 compared to condition 1 was also rejected. In this case, use of the dome on a firm surface did not result in decreased postural stability as measured by percent sway area.
Significantly increased postural sway during conditions 5 and 6 was found, which confirmed the remaining hypotheses. These results concurred with Nashner (1991) and Shumway-Cook and Horak (1986) who maintain that conditions 5 and 6 are the most difficult of the CTSIB conditions in terms of intersensory conflict.

The results from both this study and the one by Kantner et al. (1991) indicate that use of the dome was actually easier for the young and old subjects than standing with eyes closed. In this study, the dome was placed directly on the subject’s shoulders in an attempt to correlate the sway of the dome with the body instead of the head. Kantner et al. (1991) and Cohen et al. (1993) placed the dome on the subject’s head as originally described by Shumway-Cook and Horak (1986). Neither method seems to be an adequate imitation of the sway referencing which occurs during the SOT on the Equitest®.

One possible explanation for the inadequacy of the dome is that the subjects may have been able to reference their sway to the environment through the opening in the base of the dome. The three subjects who were blind in one eye swayed significantly more than the other subjects only during condition 6. These women may not have had suitable peripheral vision and thus were unable to reference to the environment through the limited opening at the base of the dome. A box-shaped dome which closes around the subject’s body may increase the efficacy of the dome for all subjects. Another criticism of the dome is that the visual reference point, the X, may be too close to the subject’s face to allow true focus. To remedy this, a dome may be constructed which is farther from the subject’s face.

While use of the dome did not prove to be more difficult than the blinded conditions, the sway values during conditions 3 and 6 were greater than during conditions 1 and 4 respectively. The difference was statistically significant for condition 6 and may imply that performance
with the dome was more difficult than standing with eyes open, especially when the somatosensory system was also challenged.

While results of this study suggest that the conditions of the CTSIB with the dome do not present increased difficulty for healthy elderly women, it should be noted that the subjects of this study were not only healthy (as defined by the inclusion/exclusion criteria) but were active. All claimed to exercise 2-5 days per week; most were active in community center activities and volunteer programs. Due to their activity levels, the women in this study may not accurately represent the average healthy elderly population but may demonstrate above average postural control for their ages.

Physical activity results in improved strength, range of motion and endurance which are all contributing factors to balance performance. In the study by Lord, Caplan, and Ward (1993) women (ages 57-75) who performed aerobic exercise one hour, two times a week for 12 months demonstrated significantly less sway during condition 5 of the CTSIB than non-exercisers. Therefore, the sway responses by the subjects in this study may illustrate the potential capabilities (rather than normal responses) of healthy elderly women in performance of the CTSIB.

Normative data is available for postural sway responses on the Balance Master® during CTSIB conditions 1 and 2 (NeuroCom® International, Inc., 1992). As a group, the subjects (ages 65-83 years) demonstrated considerably smaller sway areas than the normative values for their age group (Table 4). Comparisons to normative data were made for descriptive purposes to confirm that the subjects in this study do not represent the average elderly population. Rather, the ideal of an active, exceptionally healthy group of elderly individuals may be demonstrated by the results.

Table 5 summarizes the authors' interpretation of the results which was based primarily on the CTSIB interpretation provided by
Shumway-Cook and Horak (1986) and the SOT interpretations provided by Flores (1992) and Dickins et al. (1992).

As with other balance studies concerned with elderly balance responses (Flores, 1992; Kantner et al., 1991; Nashner, 1989), postural sway responses of the subjects in this study did not increase significantly when eyes were closed on a firm surface. Therefore, the subjects, as a group, did not demonstrate an abnormal reliance on vision for postural control when somatosensory inputs were available.

Increased sway during conditions 5 and 6 for the subjects of this study support the findings by Kantner et al. (1991). Similarly, Teasdale et al. (1992) found greater sway parameters for elderly subjects (but not young adult subjects) during an "eyes closed on foam" trial as compared to conditions which were similar to conditions 1, 2 and 4 of the CTSIB, but held for 80 seconds (vs. 20-30 seconds). Alexander (1994) reported increased sway for elderly subjects during conditions 5 and 6 of the SOT. Poorer performance on condition 5 indicated a potential for impaired function of the vestibular system with regard to postural control. The increased sway present during condition 6 may indicate a strong reliance on vision for postural stability when somatosensory input is altered.

The mean percent sway area for condition 4 was not significantly greater than the preceding conditions. However, a visible increase in sway was noted by the examiners, and confirmed by the sway values, which implied increased difficulty when foam was introduced. Through observation, the level of difficulty while on the foam for the women in this study may indicate reliance on somatosensation for balance. Contrarily, the foam may have challenged the musculoskeletal elements of the lower extremities. While statistically insignificant, the observations may be valuable when applying the principles of the CTSIB to balance evaluation and rehabilitation in the clinic (see Clinical Implications).
Table 4
Comparison of Subjects' Sway Values to Normative Data

<table>
<thead>
<tr>
<th>Study results</th>
<th>% Max Sway Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eyes open firm surface</td>
</tr>
<tr>
<td></td>
<td>.05 - .16 (M = .09, SD = .03)</td>
</tr>
</tbody>
</table>

Normative data age groups

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Study results</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-49</td>
<td>.097</td>
</tr>
<tr>
<td>50-59</td>
<td>.345</td>
</tr>
<tr>
<td>60-69</td>
<td>.126</td>
</tr>
<tr>
<td>70-79</td>
<td>.186</td>
</tr>
<tr>
<td>80-89</td>
<td>.415</td>
</tr>
<tr>
<td>80-89</td>
<td>.39</td>
</tr>
</tbody>
</table>

52
Table 5

**Interpretation of the CTSIB**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Implications of increased sway</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>*Reference for &quot;normal postural control&quot; for subject.</td>
</tr>
<tr>
<td>2</td>
<td>Increased reliance on vision.</td>
</tr>
<tr>
<td>3</td>
<td>Excessive reliance on vision even during presence of inaccurate input.</td>
</tr>
<tr>
<td>4</td>
<td>Increased reliance on somatosensation</td>
</tr>
<tr>
<td>5</td>
<td>Co-reliance on vision and somatosensation with emphasis on vision. *Since both vision and somatosensation are altered, poor performance on only condition 5 may indicate impaired vestibular function.</td>
</tr>
<tr>
<td>6</td>
<td>Excessive reliance on vision even during presence of inaccurate input. Possible inefficient use of vestibular system in maintenance of postural stability. Possible difficulty with resolution of intersensory conflict.</td>
</tr>
</tbody>
</table>
Limitations of CTSIB

The CTSIB provides a clinical version of the SOT. When compared to the SOT (Nashner, 1982), the CTSIB provides a more generalized and less sensitive analysis of postural stability during similar sensory conditions (Di Fabio, 1993). Use of the foam and the dome in the CTSIB provides generally inaccurate sensory input rather than the sway referenced input provided by the Equitest® in the SOT. Shumway-Cook & Horak (1986) caution that control of posture is complex and interpretation of the CTSIB should allow for influencing factors other than sensory integration. Such factors include strength, range of motion, motor pathways, previous experiences, and disease processes. Therefore, a direct correlation cannot be made between performance on the CTSIB and sensory integration. Failure to consider the complexity of postural control may lead to erroneous assumptions about deficits in a patient's sensory systems.

A source of variability in the CTSIB is the use of foam. A variety of foams have been used by investigators and the density is generally labelled with qualitative terminology which decreases reproducibility of studies. Shumway-Cook and Horak (1986) and Cohen et al. (1993) used a Sun-Mate foam of medium density. Lord et al. (1991) used a rubber foam. The examiners in this study found that foam is not labelled consistently which makes reproducibility difficult. For example, the Sun-Mate labels provided to the investigators by Dynamic Systems, Inc. varied from the specifics listed in previous studies. The choice of foam appeared to be similar to the foam used in Shumway-Cook and Horak (1986).

Also, foam does not sway with reference to the body as the Equitest® platform (used in the SOT) does. The compliant surface simply provides inaccurate input as to the position of the foot relative to upright and also allows movement of the foot and ankle to occur in more than one plane. Contrarily, the Equitest® platform moves only in the anterior-posterior direction. Therefore, use of the foam may challenge
the musculoskeletal system of the subject and result in a confounding variable with respect to sway performance. This variable may have a greater effect in elderly subjects with decreased strength and ankle range of motion.

Stratification of Sway Responses

Subjects were divided into groups based upon whether they had functional range of motion bilaterally or whether they had a functional deficit in at least one ankle. Dorsiflexion and plantarflexion were analyzed separately. No statistical significance was found between the amount of dorsiflexion or plantarflexion and the amount of sway in any condition.

Strength assessment prior to data collection was performed via functional tests such as single leg stance, heel walking and the timed-stands test. All subjects were able to maintain single leg stance without dropping the unsupported hip for 15 seconds on either leg. Similarly, all subjects demonstrated adequate tibialis anterior muscle strength to perform heel walking for 5 feet. Therefore, in this study, strength and range of motion limitations did not appear to be factors which influenced sway responses between the subjects. Previous studies have shown ankle strength and range of motion to influence sway; our results apply only to active subjects. Further studies with a more diverse group of subjects should incorporated functional strength of ankle musculature (dorsiflexors and plantarflexors included).

The subjects' performances on the timed-stands test were generally quicker than the normative data provided by Csuka and McCarty (1985) for their ages. Only two subjects performed slower than the normative mean for their age. A t-test compared those two subjects to the remainder of the group and no sway differences were found. The number of subjects in the "below norm" group may have been too small for such analysis.

Alexander (1994) stated that postural control continues to decline throughout the life span such that the "old" old (greater than 80 years)
demonstrate decreased postural stability than the "young" old (less than 80 years). Individuals older than 80 years did have more sway than younger elderly during conditions 4-6 on the SOT (Wolfson et al., 1992). The age distribution of the subjects in this study allowed analysis of sway responses of those aged 65-70 versus those aged 70-83 years. The older group demonstrated significantly greater sway than the younger group during conditions 2 and 4. Explanation of these results may be as follows: (a) "Old" old subjects rely more heavily on vision than "young" old, and (b) advancing age is accompanied by less efficient compensation with the introduction of a sensory challenge. However, the exact cause cannot be determined, and is beyond the scope of this study. Further studies could expand the age range and increase the number of subjects such that the "old" old age group would be 85 years of age or older.

Learning Effect

During conditions 5 and 6 several subjects lost their balance in the first trial. Fewer subjects lost their balance in trial two, and no one lost balance in trial three. Because of the observable improvement in performances during conditions 5 and 6 throughout the trials, the investigators assumed learning occurred with practice.

A significant learning effect in which sway values decreased with practice was found between trials one and three for conditions 2, 4, 5, and 6. Additionally, sway during condition 6 was significantly less in trial two than in trial one. Cohen et al. (1993) also demonstrated a learning effect during repeated performance of the CTSIB; their basis for performance was ability to maintain standing position for 30 seconds. They found significant improvements for vestibular impaired and healthy elderly subjects between trials one and two for conditions 5 and 6. Similarly, during the first trials of the SOT (Wolfson et al., 1992), elderly subjects tended to fall during conditions 5 and 6. Frequency of balance loss significantly decreased in the third SOT trial
compared to the first, demonstrating a learning effect. The presence of a learning effect in this study did not allow for the establishment of test-retest reliability of the CTSIB for healthy elderly females during one session.

Clinical Implications

The CTSIB allows evaluation of standing balance during systematic removal or alteration of sensory inputs. Identification of potential deficiencies in the sensory integration of balance is possible. Clinically, this test allows a physical therapist to evaluate a patient with generalized balance impairments and to obtain a more detailed assessment of the specific areas of postural control deficit.

A variety of methods are used to report results of the CTSIB. Descriptions of performance during the CTSIB range from stance times (20-90 seconds), weighting stance times for a score, and measuring postural sway in a variety of ways. In this study, the Balance Master® provided objective measurements of sway responses. Since computerized force platforms are not available in many clinical settings, the primary clinical application of these percent max sway values may be to obtain a better understanding of the healthy elderly postural control system and to create a model for potential capabilities of healthy elderly women.

Lord et al. (1993) questioned whether age related impairments in postural control are due solely to physiologic aging or may be secondary to inactivity and disuse. The lack of consistent methods of measurements of CTSIB performance prevent comparison of our results to those of young adult subjects in previous studies and it is unclear whether our subjects demonstrated more sway than younger adults.

Results of this study indicated that conditions 5 and 6 were the most difficult. Previous studies demonstrated similar response patterns for young and old adults. When limited to sensory integration theory (without regard to other influencing factors), interpretation of these findings suggests the vestibular system was the only sensory system
which was excessively challenged during the CTSIB. Lack of daily challenge of the vestibular system (or heavy reliance on another system) may be one explanation for the increased sway during conditions 5 and 6 demonstrated by adult subjects. However, the improvement of sway values during conditions 5 and 6 with practice suggest the vestibular system is able to adapt quickly when demands are placed on it.

Clinically, physical therapists often allow only one practice trial of the CTSIB. Our study implies that a patient may be able to maintain balance during challenging conditions if allowed adequate practice. Therefore, a clinical evaluation should consist of at least three trials to ensure adequate assessment. Additionally, the presence of learning during repeated performance of the CTSIB suggests plasticity in the postural control system. Shepard, Smith-Wheelock, Telian, and Raj (1993) state that balance retraining therapy may assist the balance system with compensation for deficits. Implications are that the CTSIB may be used as not only an evaluation tool, but a treatment tool once potentially deficient sensory systems are identified.

The use of the CTSIB as a treatment tool for improvements in balance is justified for goals of improving static balance. However, functional balance is most often dynamic. Carryover of standing postural control to dynamic control is not supported in the literature (Anacker & Di Fabio, 1992; Di Fabio, 1993; Di Fabio & Badke, 1990; Weinstein, 1989). Balance training should include static and dynamic activities to assure appropriate carryover to function.

The CTSIB may assist a therapist in identifying deficiencies in postural control which can then be addressed in both static and dynamic activities to assure carryover to function. Specific exercises to address potential sensory integration impairments for a person with increased sway on foam may include such things as practicing balance positions on foam and other uneven surfaces. Similarly, suggestions to patients can be made to assist with compensation for potential
deficiencies. For example, increased sway during condition 2 implies strong reliance on vision and may indicate a need for careful scanning of a room prior to entering, use of good lighting and maintenance of adequate strength corrective lenses. Increased sway on the foam surface as demonstrated in this study, may lead to suggestions such as: wear properly fitted shoes, and walk carefully over snow, sand, padded carpet and other uneven surface. During conditions 5 and 6, vision and somatosensation are challenged. Therefore suggestions for a patient with difficulty may include all of the above.

Limitations and Suggestions for Further Studies

A limitation of this study was the inability to generalize the results to the elderly population. The subjects were not representative of the target population for a few reasons. As previously mentioned, the subjects were physically active. The socioeconomic level of the subjects allowed for availability of a variety of resources. Health education, exercise classes, financial counseling, and a variety of other services were available for subjects. A majority of subjects reported being in previous studies that used the Balance Master®. The subjects also seemed highly motivated to improve their performance over the three trials.

The limitations of the components of the CTSIB were previously discussed in relation to the SOT and in regards to the lack of standardization of foam types and measurements of performance (see Limitations of CTSIB). Additionally, use of the Balance Master® results in some limitations of this study. The Balance Master® was only able to accurately record body sway rates below .3 Hz, which corresponds to the slow body sway rate used in an ankle strategy as opposed to the faster sway rate during a hip strategy. If subjects did not use an ankle strategy while maintaining upright posture, the percent maximal sway area calculated by the Balance Master® may have been inaccurate.
While the Balance Master® allowed objective measurement of balance responses to the CTSIB, use of the foam on the force platform may alter the sway measurements. NeuroCom® International, Inc. claims the Balance Master® is no less sensitive to sway with use of foam than without use of the foam (L. Allison, personal communication, May 13, 1993); however, no documentation of such sensitivity has been reported. The Balance Master® calculated center of gravity based on the subject's height and sway area was based on this value. The foam was 10.26 cm thick which raised the subject's actual center of gravity and may have resulted in inaccurate sway recordings.

Direct application of the values obtained in this study is not possible. Since the Balance Master® is not available in all clinics, these values may not be relevant to all therapists. Previous published studies have not used the Balance Master® to record percent maximal sway areas. Therefore, comparison of results is difficult.

A standardized method for the CTSIB has not been established. Standardization of the equipment and performance measurements via further studies is necessary. Measuring stance time during the CTSIB as originally described by Shumway-Cook and Horak (1986) is an easy quantification of performance, but is limited in its ability to qualify balance responses. The investigators in this study measured postural sway responses on the Balance Master® to contribute to available information about the quality of performance during the CTSIB for elderly women.

Since sway is described in so many different ways, the current literature only allows comparison of trends or patterns of CTSIB performances. Clinically, a trend or pattern of performance is not enough information to establish the status of a patient. That is, a patient may demonstrate a trend in amount of sway, but the baseline may be at, above or below the "normal" sway values. If studies could correlate the various measurements of sway with descriptive terms such
as minimal, moderate and maximal, the results of CTSIB balance studies would be more clinically applicable. For example, simultaneous use of a grid and plumb line with a force platform would provide two types of equivalent data for a specific postural response. In other words, body displacement measurements would be paralleled with sway areas. If the objective data from these two methods could then be categorized into qualitative terms, a standard definition of these terms could be developed. This would allow comparison of more clinically used methods of measurement with the technical data available in some of the research. A common language in reporting performance, both clinically and experimentally, would improve the ability to understand and compare findings by various investigators. Clinicians would be able to utilize the information from CTSIB studies for various types of patients.

One of the purposes of this study was to establish test-retest reliability. The learning effect identified with one session prevented conclusions from being drawn about test-retest reliability. Further studies could change the design of the study to incorporated multiple sessions of testing.

Theoretically, a gross assessment of the sensory integration process is possible through the use of the CTSIB. With the changes rapidly occurring in health care reform, functional outcomes of treatments are becoming crucial to rehabilitation. Although assessing the efficiency of the sensory systems is important, predicting functional complications secondary to the results of the CTSIB is more relevant. The functional activities were incorporated in this study to provide the following: (a) descriptive data about the subjects and (b) possible stratification during post hoc tests to correlate results of CTSIB with function. The investigators of this study were unable to statistically analyze the relationships between dynamic functional abilities and performance of the CTSIB because few subjects performed below what would be expected as normal during the pretest tasks. In
addition to the functional activities used in this study, the get up and go test (Mathias, Nayak, & Isaacs, 1986), functional reach test (Weiner, Bongiorni, Studenski, Duncan, & Kochersberger, 1993) and a timed ambulation test could be included to correlate the results of CTSIB performance with function. Also, the investigators suggest use of a larger sample of functionally independent elderly females, who are more representative of the general population, to assist in correlating results of the CTSIB with function.

Summary

The Clinical Test for Sensory Interaction in Balance (CTSIB) (Shumway-Cook & Horak, 1986) assesses the effects of altered or eliminated inputs to the visual, vestibular and somatosensory systems on postural stability. The test has been applied to healthy individuals of various ages, as well as those with balance disorders. However, the elderly response to the CTSIB has not been well documented. This study examined the postural sway responses of healthy elderly women during performance of the CTSIB.

Sway responses (increased sway during conditions 5 and 6 as compared to all other conditions) suggest possible heavy reliance on the somatosensory system and potentially impaired use of vestibular system for sensory integration. However, sway patterns throughout conditions were similar to those established for younger adults in previous studies.

The subjects were active, healthy women who may have demonstrated above average postural control for their ages. Quantitative analysis of healthy elderly subjects with various activity levels may allow physical therapists to better understand the potentials of the elderly postural control system. This understanding may then assist with evaluation, goal setting and treatment planning for elderly patients with postural control deficits.
References


APPENDIX A

Diagram of the CTSIB
VISION
NORMAL EYES CLOSED DOME

1. 
2. 
3. 

SURFACE
NORMAL
NORMAL
NORMAL

FOAM
FOAM
FOAM

4. 
5. 
6.
APPENDIX B

Description/Diagram of the Balance Master®
System Components

The picture below shows the Balance Master Hardware and includes:

(1) Dual forceplate
(2) Cart with attachable shelves
(3) IBM-compatible PC/AT computer
(4) Monitor
(5) Printer
(6) Keyboard
(7) Controller Box

PARTICIPANT QUESTIONNAIRE

NAME ____________________________________________________________

DATE _______________ AGE ________

ADDRESS __________________________________________________________

CITY _________________________ STATE _______________

ZIP __________________________

PHONE NUMBER __________________________________________________

PLEASE ANSWER THE QUESTIONS BY PUTTING THE LETTER X IN THE BOX
NEXT TO YOUR RESPONSE.

Have you fallen or nearly fallen within the last 6 months?
  [] yes
  [] no

Have you had an inner ear infection or an ear surgery within the
last 6 months?
  [] no
  [] yes

Do you have times when you feel lightheaded or dizzy?
  [] yes
  [] no

If yes, when and how often do you have the above symptoms?
____________________________________________________________________

Have you ever been tested by a doctor for vestibular deficits?
  [] yes
  [] no

Have you ever been hospitalized for a head injury or been
diagnosed as having a brain tumor?
  [] yes
  [] no

Have you ever been diagnosed as having multiple sclerosis,
Parkinson’s syndrome, stroke, or peripheral neuropathy?
  [] yes
  [] no
Do you ever use crutches, a cane, a walker, orthoses, or prostheses to help you walk?

[ ] yes
[ ] no

If yes, what do you use and when?

Are you able to walk 150 feet without stopping?

[ ] yes
[ ] no

Do you have any difficulty walking on unlevel surfaces (inclines/declines, grass, carpet, or gravel surfaces)?

[ ] yes
[ ] no

Are you currently being treated by a doctor, chiropractor, or physical therapist?

[ ] yes
[ ] no

If yes, does the treatment pertain to any of the above questions?

[ ] yes
[ ] no

Please list the medications that you are currently taking.
Questionnaire #:_____

PRELIMINARY DATA COLLECTION FORM

Age of subject: _______
Height of subject: _______
Weight of subject: _______
Gross visual acuity of subject: R _______ L _______
Does the subject have an upper extremity amputation?
    [ ] yes
    [ ] no
Does the subject pass the gross visual screen with corrected vision?
    [ ] yes
    [ ] no

Walk 5 feet in ankle dorsiflexion (seconds): ______

Timed-stands test (seconds): ______

Single leg stance with eyes open (seconds):
    Right: ______, ______, ______
    Left: ______, ______, ______

Measurement of ankle dorsiflexion ROM (degrees):
    Right: ______, ______, ______
    Left: ______, ______, ______

Measurement of ankle plantar flexion ROM (degrees):
    Right: ______, ______, ______
    Left: ______, ______, ______
APPENDIX D

Informed Consent
INFORMED CONSENT

I understand that this is a study of various aspects of the human body that work together to maintain balance in standing. The results of this study will help physical therapists understand normal aging changes in the body in regard to standing balance and also assist in standardizing a common clinical test.

I also understand that:

1. I have been selected to participate because of my current wellness in health and my age.

2. Participation in this study will involve measurement of leg strength and ankle motion, which will take approximately 20 minutes. My height and weight will be measured. I will perform 3 trials of a clinical test in which I will stand on a forceplate that measures amount of sway while standing. I will stand on this forceplate under 6 different conditions:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Stand on firm surface (forceplate) with eyes open.</td>
</tr>
<tr>
<td>2.</td>
<td>Stand on firm surface with eyes closed.</td>
</tr>
<tr>
<td>3.</td>
<td>Stand on firm surface with paper dome on head.</td>
</tr>
<tr>
<td>4.</td>
<td>Stand on foam (placed on forceplate) with eyes open.</td>
</tr>
<tr>
<td>5.</td>
<td>Stand on foam surface with eyes closed.</td>
</tr>
<tr>
<td>6.</td>
<td>Stand on foam with paper dome on head.</td>
</tr>
</tbody>
</table>

I will stand under each condition for 20 seconds, and after completion of each trial (all 6 conditions), I will be able to rest for 2 minutes. The balance test will take approximately 20 minutes. The test will be administered at a mutually convenient, predetermined time. The study will take place at Evergreen Commons Senior Center.

3. I have a potential risk of falling, but this will be minimized with a gait belt around my waist, a walker in front of the platform, and two people present to guard against my falling. My current wellness in health decreases my chance of falling.

4. The information I provide will be kept strictly confidential and the data will be coded so that identification of individual participants will not be possible.

5. I may discontinue my participation in this study at any time in the screening or testing process.

6. A summary of results will be made available to me upon my request.

[] Check here if interested in receiving summary.
I acknowledge that:

"I have been given an opportunity to ask questions regarding this research study. These questions have been answered to my satisfaction."

"In giving my consent, I understand that my participation in this study is voluntary and that I may withdraw at any time by phoning any of the investigators prior to the clinical test or by requesting termination during the clinical trial. There will be no consequences if I choose to no longer participate."

"I hereby authorize the investigators to release the information obtained in this study to scientific literature. I understand that I will not be identified by name."

"I have been given the phone number of the investigators so that I may contact any one of them if I have any questions regarding this study."

"I acknowledge that I have read and understand the above information. I agree to participate in this study."

_________________________   ________________________
Witness' Signature           Participant's Signature

_________________________   ________________________
Date                        Date
APPENDIX E

Raw Data
Table 6. Trial Three Raw Data of % Postural Sway Area

<table>
<thead>
<tr>
<th>Code</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>101A</td>
<td>.08</td>
<td>.12</td>
<td>.09</td>
<td>.4</td>
<td>2.32</td>
<td>4.47</td>
</tr>
<tr>
<td>123H</td>
<td>.08</td>
<td>.16</td>
<td>.25</td>
<td>.48</td>
<td>3.82</td>
<td>2.82</td>
</tr>
<tr>
<td>167Q</td>
<td>.08</td>
<td>.24</td>
<td>.19</td>
<td>.63</td>
<td>3.26</td>
<td>1.95</td>
</tr>
<tr>
<td>191P</td>
<td>.09</td>
<td>.11</td>
<td>.08</td>
<td>1.19</td>
<td>1.95</td>
<td>1.77</td>
</tr>
<tr>
<td>211J</td>
<td>.09</td>
<td>.14</td>
<td>.11</td>
<td>.44</td>
<td>1.23</td>
<td>1.98</td>
</tr>
<tr>
<td>321U</td>
<td>.09</td>
<td>.13</td>
<td>.08</td>
<td>.29</td>
<td>.75</td>
<td>.88</td>
</tr>
<tr>
<td>330O</td>
<td>.13</td>
<td>.08</td>
<td>.18</td>
<td>.42</td>
<td>1.34</td>
<td>1.52</td>
</tr>
<tr>
<td>334S</td>
<td>.13</td>
<td>.08</td>
<td>.08</td>
<td>.39</td>
<td>1.22</td>
<td>.78</td>
</tr>
<tr>
<td>398I</td>
<td>.11</td>
<td>.17</td>
<td>.06</td>
<td>.61</td>
<td>1.76</td>
<td>1.14</td>
</tr>
<tr>
<td>432N</td>
<td>.07</td>
<td>.06</td>
<td>.07</td>
<td>.28</td>
<td>.28</td>
<td>.91</td>
</tr>
<tr>
<td>444Y</td>
<td>.09</td>
<td>.04</td>
<td>.07</td>
<td>.40</td>
<td>.97</td>
<td>.92</td>
</tr>
<tr>
<td>601M</td>
<td>.16</td>
<td>.17</td>
<td>.11</td>
<td>.82</td>
<td>3.82</td>
<td>1.18</td>
</tr>
<tr>
<td>699C</td>
<td>.06</td>
<td>.25</td>
<td>.17</td>
<td>.56</td>
<td>2.3</td>
<td>2.54</td>
</tr>
<tr>
<td>712K</td>
<td>.10</td>
<td>.19</td>
<td>.12</td>
<td>.52</td>
<td>1.06</td>
<td>2.72</td>
</tr>
<tr>
<td>739F</td>
<td>.05</td>
<td>.07</td>
<td>.11</td>
<td>.52</td>
<td>2.00</td>
<td>1.44</td>
</tr>
<tr>
<td>999Z</td>
<td>.09</td>
<td>.16</td>
<td>.10</td>
<td>.80</td>
<td>1.00</td>
<td>.86</td>
</tr>
</tbody>
</table>