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The Effects of Elevated Shoe Heights on Static and Dynamic Balance in Healthy Younger Women

Rhett L. Randall

University of North Dakota

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THE EFFECTS OF ELEVATED SHOE HEIGHTS
ON STATIC AND DYNAMIC BALANCE
IN HEALTHY YOUNGER WOMEN

by

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An Independent Study
Submitted to the Graduate Faculty of the
Department of Physical Therapy
School of Medicine
University of North Dakota

in partial fulfillment of the requirements
for the degree of
Master of Physical Therapy

Grand Forks, North Dakota
May 2001
This Independent Study, submitted by Rhett L. Randall in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Michael Smith)
(Faculty Preceptor)

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(Thomas Moss)
(Chairperson, Physical Therapy)
PERMISSION

Title The Effects of Elevated Shoe Heights on Static and Dynamic Balance in Healthy Younger Women

Department Physical Therapy

Degree Master of Physical Therapy

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# TABLE OF CONTENTS

LIST OF TABLES ........................................................................................................ vii

LIST OF FIGURES ..................................................................................................... viii

ACKNOWLEDGEMENTS ........................................................................................... ix

ABSTRACT ................................................................................................................ x

CHAPTER

I  INTRODUCTION ........................................................................................................ 1

  Purpose .................................................................................................................. 3

  Clinical Application ............................................................................................... 4

II REVIEW OF THE LITERATURE .............................................................................. 5

  Research Studies .................................................................................................. 6

  Postural Control .................................................................................................. 9

  Balance Measures ............................................................................................... 11

  Reliability Studies .............................................................................................. 11

III METHODOLOGY .................................................................................................. 14

  Subjects ............................................................................................................... 14

  Instrumentation ................................................................................................ 15

    Limits of Stability Test .................................................................................... 17

    Bilateral Stance Test ....................................................................................... 18

    Functional Reach Test ................................................................................... 19
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bilateral Stance Test Intrarater Reliability Using ICC and r-value</td>
<td>25</td>
</tr>
<tr>
<td>2. Limits of Stability Test Intrarater Reliability Using ICC and r-value</td>
<td>25</td>
</tr>
<tr>
<td>3. Functional Reach Test Intrarater Reliability Using ICC and r-value</td>
<td>25</td>
</tr>
<tr>
<td>4. ICC Value Interpretation</td>
<td>26</td>
</tr>
<tr>
<td>5. Correlation Coefficient r-value Interpretation</td>
<td>26</td>
</tr>
<tr>
<td>6. NBM® Tests and FRT Descriptives</td>
<td>29</td>
</tr>
<tr>
<td>7. Wilcoxon and Paired t test Descriptives</td>
<td>31</td>
</tr>
<tr>
<td>8. Relationship of Shoe Conditions to Performance on LOS Test, Bilateral Stance Test, and FRT Using Pearson’s Correlation Coefficient</td>
<td>33</td>
</tr>
<tr>
<td>9. Relationship of Shoe Conditions to Performance on LOS Test, Bilateral Stance Test and FRT Using Spearman’s Correlation Coefficient</td>
<td>34</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>NeuroCom® Balance Master</td>
<td>16</td>
</tr>
<tr>
<td>2.</td>
<td>Elevated shoe measurements taken in centimeters</td>
<td>20</td>
</tr>
<tr>
<td>3.</td>
<td>NBM® foot placement used</td>
<td>21</td>
</tr>
<tr>
<td>4.</td>
<td>Eight directions of limits of stability</td>
<td>22</td>
</tr>
<tr>
<td>5.</td>
<td>Scatterplot of FRT scores and maximal excursion forward on NBM®</td>
<td>35</td>
</tr>
</tbody>
</table>
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ABSTRACT

The purpose of this study was to determine the effects of elevated shoe heights on static and dynamic balance in healthy young women. The balance of 30 female volunteer subjects with ages ranging from 20 to 26 years (mean age = 22.3 years) was tested. Dynamic balance was tested using the limits of stability (LOS) test on the NeuroCom® Balance Master (NBM®), version 6.1 as well as the Functional Reach Test (FRT). Each subject's static balance was tested using the bilateral stance test on the NBM®. Subjects participated in a one time testing session which consisted of the performance of the three balance tests in a random order with elevated-soled shoes on (minimum heel height of 4.0 cm) and barefoot.

Significant differences in dynamic stability were noted in the LOS test and in the FRT. The results of the two dynamic tests suggest that balance may be impaired with the wearing of shoes with elevated soles. The bilateral stance test for static stability found that subjects exhibited increased postural sway when barefoot as compared to with elevated shoes on. The results of this static test suggest that stationary balance may be somewhat more stable with elevated shoe wear.

The findings of the LOS test and FRT are in agreement with much of the previous high-heeled shoe literature, however, the bilateral stance test for postural sway is not in agreement with some of the previous research. Nonetheless, it is apparent that elevated
shoe heights can produce dynamic balance deficits and therefore clinicians should always carefully inspect and assess a client’s footwear as part of the evaluation procedure.
CHAPTER I
INTRODUCTION

For thousands of years humans have worn shoes. It has always been recognized that shoes provide protective covering for the feet as well as support.¹ In more recent times, shoes have evolved in every way imaginable to reflect the personality of its wearer. Changes in fashion have altered heel height, sole width, and lateral support, which sometimes appear to provide less protection from extrinsic factors. A current trend in the year 2000 with younger women has been towards shoes with an elevated sole. As individuals wear these fashionably high shoes at home, to work, to school, even dance clubs and other recreational activities, the possibility of loss of balance and potential injury increases. Lack of support and alterations in the center of mass from its normal location can all lead to an increased risk of falling.

Falls are multifactoral in nature and include the interaction of intrinsic and extrinsic factors.² Intrinsic causes can come from many different areas throughout the body. They can include neurological, musculoskeletal, and other medical abnormalities. Extrinsic causes can include such factors as slick floors, stairs, poor lighting, pavement cracks, and footwear.³ Depending on the individual, these factors can affect a person's balance in various ways, because one's reaction to the environmental influence determines how the body will accommodate. Extrinsic factors, especially footwear, are fairly easy to alter in order to create the safest environment.
Many studies involving the elderly have been done to assess how shoe design affects both balance and gait.\textsuperscript{4-6} Analysis of heel height, sole thickness, collar height, and many other factors have all been done, primarily on older women. Considering that the age group with the highest incidence of falls and related injuries such as hip and arm fractures are the elderly, such studies are important. However, of equal importance is assessment of shoe safety in younger women. Considering the high activity levels and fast movements of the younger population, shoe safety concerns should also be researched in this population. Ankle sprains, strains, and other injuries can severely limit productivity as work, at home, and in the social and recreational genre. Such injuries can demand high levels of financing from insurance companies, workman's compensation, and personal income.

Styles such as the platform shoe or elevated sandals and boots have become exceedingly popular not only in the United States but in other countries as well. \textit{Alice Magazine} reported recently that the Japan Consumer Information Center issued a public warning about the dangers of platform shoes.\textsuperscript{7} This follows after a recent string of accidents leading to everything from sprained ankles, scuffed knees, and broken bones to fatal traffic accidents and fractured skulls from falls. A recent Japanese poll found that 23\% of platform wearers had fallen while wearing their shoes, with almost half of those women suffering an injury. Another survey in Japan found 40\% of women in their 20's and 25\% of women in their 30's owned at least one pair of platform shoes.\textsuperscript{8}

Balance testing has been growing as a quantitative way to measure personal stability and safety. Biofeedback systems utilizing force platforms such as the NeuroCom\textsuperscript{\textregistered} Balance Master (NBM\textsuperscript{\textregistered}) have been implemented in evaluation and
treatment of various orthopedic and neurological disorders. Such a device has also been used in various research studies to assess and analyze balance performance under different conditions.\textsuperscript{9,10} This paper presents research on how varying shoe sole heights may affect balance in younger women by using the NeuroCom\textsuperscript{®} Balance Master and the Functional Reach Test for analysis.

Purpose

The purpose of this study was to determine if significant changes occur in static steadiness and dynamic stability when the same individual is assessed barefoot and while wearing elevated shoes on the NeuroCom\textsuperscript{®} Balance Master and the Functional Reach Test (FRT). The research questions that will be addressed are: 1) Is there a significant difference in measures of static steadiness when the same individual is assessed barefoot and wearing elevated shoes? 2) Is there a significant difference in measures of dynamic stability when the same individual is assessed barefoot and wearing elevated shoes?

The following three hypothesis have been made by the researcher: 1) There will be significantly greater forward Functional Reach Test scores for the barefoot condition when compared to the elevated shoe condition. 2) An increased center of gravity sway will be noticed with wearing of elevated shoes as compared to barefoot. 3) The wearing of elevated shoes will show decreased results on the limits of stability test determined on the NeuroCom\textsuperscript{®} Balance Master in all testing parameters when compared to the barefoot condition.
Clinical Application

Balance is an essential component to carrying out all activities of daily living. Extrinsic factors such as footwear may significantly affect balance and put individuals at risk for injury. This study has the potential for many benefits to both individual participants and society. Through assessment using the NeuroCom® Balance Master and Functional Reach Test, the participants will learn about the relative safety of their own dress/casual shoes and also desired shoe characteristics to look for when purchasing future shoes. Data results may help provide physical therapists and other health professionals with evidence based research to assist in proper shoe recommendations for clients and/or aid in activity selection involving dynamic balance while wearing higher soled shoes. This could in turn help decrease the risk of injuries occurring secondary to loss of balance created by inappropriate footwear. Finally, this study can be used as a basis for future research involving a larger sample size and/or different shoe types.
CHAPTER II

REVIEW OF THE LITERATURE

Very little research has been done to study the effects elevated shoe heights have on static or dynamic balance in younger healthy women. Limited still is research on how shoe heights affect balance using a force platform biofeedback system to analyze, such as the NeuroCom® Balance Master. A number of studies have assessed how footwear affects posture and balance, however the main focus of such research has been on the elderly. Most studies have analyzed shoes termed high-heeled, generally meaning shoes with a large heel height and a smaller sole at forefoot contact. These shoes generally have a small sole surface area unlike the platform type shoes. Although high-heels are structurally different than platforms and other high-soled shoes, they both maintain many similarities. The high-soled shoes analyzed in this study, either were level from the heel to toe, or had a minimal angle between the heel and forefoot. In this paper, the terms high-soled shoes and elevated shoes will be used synonymously.

In the following review of the literature, a number of studies will be examined which analyze the effects high-heeled shoes have on balance and gait. To describe what components are involved in balance, postural control and stability will be explained in detail. In addition, reliability research on the NBM® and the Functional Reach Test will be examined.
Research Studies

For centuries, heel elevation has been incorporated into footwear, usually being dictated more by fashion than practicality and functional considerations. High-heels first became popular in the early 1600s, and still are a powerful feature of a women’s wardrobe.\textsuperscript{1,5} In today’s society, many women wear high-soled shoes in both professional and social settings. Due to this fashionable trend, various researchers have raised questions as to how high-heeled shoes affect a person’s posture, balance, gait, and even general energy expenditure.

A study by Lord and Bashford,\textsuperscript{12} was conducted using thirty women aged 60 to 89 years. The subjects underwent assessments of static and dynamic balance under four conditions: 1) barefoot, 2) in standard low-heeled shoes, 3) in high-heeled shoes (3cm) with raised collars, and 4) in their own shoes. It was found that in the static stability tests, subjects performed best while barefoot, intermediate in the low-heeled shoes and their own shoes, and worst in the high-heeled shoes. The dynamic range test showed subjects performed best in low-heeled shoes, intermediate while barefoot, and worst in their own and high-heeled shoes. The researchers came to the conclusion that high-heeled shoes constituted a needless hazard for balance in older women. This study supported other biomechanical studies which have stated that high-heeled shoes have detrimental effects on walking patterns.\textsuperscript{13,14}

Snow and Williams\textsuperscript{15} investigated the effects high-heeled shoes have on the center of mass position, posture, three-dimensional kinematics, rearfoot motion, and ground reaction forces. Three different heel heights (1.91, 3.81, 7.62 cm) were worn by each of 11 women recruited from the local university community. It was found that with
an increase in heel height came an increase in forefoot loading. This occurs secondary to increased plantarflexed position of the ankle with high-heeled wearing. As this occurs, it in turn changes the insertion angles of muscles and the relative position of bones within a joint.\textsuperscript{5,16} This increased forefoot loading was also presumably caused by significant anterior displacement of the total body center of mass (COM) with an increase in heel height. Since approximately 50\% of the total body mass is contained in the trunk, trunk positions have a large influence on the position of the COM. In this study, as an increase in heel height was noted, the trunk angle became significantly more flexed while refraining from displaying other significant postural adaptations. The researchers came to the conclusion that the increased trunk angle without postural adaptations may have led to the COM anterior displacement with increasing heel height during standing. These findings of the anterior displacement of the body's COM with increased heel height has been supported by other literature.\textsuperscript{16}

Opila et al\textsuperscript{17} researched the location of the body's line of gravity with respect to anatomic landmarks in 19 healthy college students. Their findings showed that lumbar flattening rather than an increase in lordosis is found with high-heel wearing, leading to possible balance changes. Other studies have also analyzed postural adjustments with high-heel wearing. Certain researchers have reported that the ankle joint moves anteriorly from a position posterior to the line of gravity, with increasing heel height.\textsuperscript{18} With increased heel height, instead of the COM moving anterior, the pelvis and trunk moved posterior to a stationary line of gravity. Still others have reported no change with increased heel height in the horizontal position of the COM.\textsuperscript{19} With conflicting results
and theories, the influence which high-heeled shoes have on alterations in posture and on the placement of total body COM is still variable.

A study by Arnadottir and Mercer, assessed thirty-five women, aged 65 to 93 from assisted living facilities and retirement communities. Each subject performed a static and dynamic balance test including the Functional Reach Test (FRT), the Timed Up & Go Test (TUG), and the 10-Meter Walk Test (TMW). The FRT is a measure of the distance an individual can reach forward without moving the feet or demonstrating loss of balance. The TUG test measures the time taken to stand up from a chair, walk 3m at a comfortable and safe pace, turn around, walk back to the chair, and sit down. The TMW is a measure of self-selected walking speed for 10 meters. This study was performed to determine whether footwear affected performance on such balance tests in older women. Each subject wore walking shoes and dress shoes (elevated heel heights) during testing as well as performing barefoot. The results showed that subjects performed better on the FRT when barefooted or wearing walking shoes compared with when dress shoes were worn. During the TUG and TMW tests, the subjects moved faster in walking shoes, slower barefoot, and slowest wearing dress shoes. The researchers came to the conclusion that footwear selection may improve performance of balance and gait tasks in older women.

Merrifield and Murray et al found shorter stride lengths when subjects were instructed to walk in high-heeled shoes. Mathews and Wooten measured oxygen consumption in 10 female subjects walking in high heels, saddles, loafers, and barefoot. It was found that subjects used significantly more oxygen while wearing high-heels.
Also, no significant change in the subjects' center of gravity was noted as they stood in each pair of shoes, indicating the existence of anatomic compensation.

Besides heel height, other features of shoe designs affect the wearer. Research by Edelstein\textsuperscript{24} showed the importance of a broad base of support as seen in lower-heeled shoes. He emphasizes how high-heels reduce stability and add stress to the metatarsal heads and forefoot as the foot slides forward. Snijders\textsuperscript{25} analyzed the angle made between forefoot contact and the heel height as an indicator of stability. An angle between 10° and 14° relative to the ground is recommended, with greater instability caused by larger angles. Heel composition has also been the subject of numerous studies.\textsuperscript{26,27} It is generally found that a more rigid surface provides greater proprioception and thus stability.

A number of other studies have been conducted to assess the influence footwear has on balance and gait in various individuals.\textsuperscript{5,26,28-32} Most tend to agree that footwear properties have a significant influence on balance and safety. To further understand how safety can be compromised by inadequate footwear, it is important to fully comprehend what balance is and how it is controlled. The following sections will explain in detail postural control, static balance and dynamic balance.

Postural Control

Postural control is defined as the ability to maintain the body's center-of-gravity over the base of support during quiet standing as well as movement.\textsuperscript{10} It is the control of the body's position in space for the dual purposes of stability and orientation.\textsuperscript{33} Maintaining a relationship between the body's segments, and between the body and the environment for a task is termed postural orientation. Postural stability refers to the
ability of the body to maintain its position, specifically the center of mass, within specific boundaries of space. Postural stability is a complex process involving the coordinated actions of biomechanical, motor, sensory and central nervous system components. This information is used not only to assess the position and motion of the body in space, but to also generate forces for controlling body positions. Musculoskeletal components, such as joint range of motion, spinal flexibility, and biomechanical relationships among body segments is required. Neural components include visual, vestibular, and somatosensory systems, sensory strategies that organize these multiple inputs, as well as neuromuscular response synergies. Another very important contribution to postural control are higher level neural processes which are the basis for adaptive and anticipatory aspects of postural control.

The specific organization of the postural systems is determined by the environment in which it is being performed as well as by the functional task. Every task that humans perform requires the ability to control our body's position in space. Depending on the task and environment, the orientation and stability component will vary. When individuals wear shoes with elevated soles, their postural control will vary depending on their experiences and body systems, as well as being impacted by the environment they are in. Maintaining postural control during stance requires the center of body mass be kept within stability limits, usually defined by the length of the feet and the distance between them. If this is not done, a fall will occur, unless the base of support is changed by taking a step or using another type of movement strategy, such as the ankle or hip strategy. The ankle strategy is a subtle movement of the body in which restoration of the COM to a position of stability is attained through body
movements centered primarily about the ankle joint. The hip strategy controls motion of the COM by producing large and rapid motion at the hip joint.

Balance Measures

Force platform systems such as the NeuroCom® Balance Master have advantages in objectively quantifying body sway and measuring the location of an individual center-of-pressure as it relates to the base of support. Various parameters have been established as researchers record and continue to study human balance. Researchers can utilize biofeedback on a force platform system to analyze postural steadiness as measured by postural sway. Information on postural steadiness can be found by examining directional displacement of COM as well as the total sway area in a static position.

Dynamic stability refers to movement within the limits of stability (LOS) in which the COM falls outside the base-of-support. This can be analyzed on the NBM® by having individuals weight shift to successive targets located on the computer screen within a specified amount of time, within 100% of their LOS.

Other tests such as the Functional Reach Test, can be used to quickly quantify dynamic balance without using an expensive computer system. The FRT is easy to administer and provides reliable feedback as to an individuals forward reaching distance.

Reliability Studies

Research has demonstrated, that both the NBM®, and the FRT are reliable tests for balance assessment in various conditions. The following sections describe reliability studies regarding both styles of testing.

The NeuroCom® Balance Master was selected for this study because it provides continuous feedback of the position of the center-of-gravity in relation to the theoretical
limits of stability (LOS) as a source of performance information during static standing and during leaning in various directions. A study done by Clark et al\textsuperscript{9} set out to establish the reliability of the LOS test on the NeuroCom\textsuperscript{®} Balance Master and to determine the relative variance contributions from identified sources of measurement error. Examples of error sources may include manual test coding errors, the use of multiple testers, misunderstood test instructions by the patient, as well as inaccurate calibration of the equipment. Knowledge of these various sources of measurement error is therefore important for establishing reliability. The researchers found the 75\% and 100\% LOS test are reliable tests of dynamic balance when administered to healthy older adults with no recent history of falls. Estimated generalizability coefficients for 2 and 3 days of testing ranged from .69 to .91. The dynamic balance measures were generally consistent across multiple evaluations.

Other researchers have also established reliability measures on the NBM\textsuperscript{®}. Henderson and colleagues\textsuperscript{40} estimated the test-retest reliability of the LOS test when performed on two occasions 1 week apart in a sample of both older healthy adults and younger adults. The ability to shift the center of gravity (COG) quickly and accurately through space demonstrated moderate to high test-retest reliability.

Listen and colleagues\textsuperscript{41} researched the reliability of dynamic balance tests available on the NeuroCom\textsuperscript{®} Balance Master. The limits of stability test was administered to a sample of hemiparetic patients in a random order on three separate occasions at 1-week intervals. The variables, movement time and path sway were found to be strongly reliable (ICC (2,1) = .88 and .84, respectively).
The Functional Reach Test is another measure of dynamic balance having a background of researched reliability. The FRT is a balance measure that demonstrates excellent test characteristics by combining current dynamic postural control theory with a practical measurement system.\textsuperscript{42} In the standing position, it represents the maximal distance an individual can reach forward beyond arm's length while maintaining a fixed base of support. This test originated because of clinical observation that reaching tasks simulate age-sensitive learning tasks used to assess postural control. Reaching adds a functional dimension to leaning, tying it to real world application.

In a study by Duncan et al,\textsuperscript{43} involving one-hundred twenty-eight healthy individuals age 21-87, the criterion validity of the Functional Reach Test was established using the center of pressure excursion (COPE) as the comparison standard. Inter-observer reliability as well as test-retest reliability were also established in this study. The FRT was found to be more precise and reliable than COPE as well as being age-sensitive. Another study using the FRT with 217 elderly male veterans (aged 70-104 years) showed that the test cannot only provide highly reliable measurements of balance, but can be used to predict the risk of falling.\textsuperscript{44}

As research has demonstrated, both the NeuroCom\textsuperscript{®} Balance Master and the Functional Reach Test have been shown to be reliable tests for balance assessment in various conditions. In this paper, the researchers will use these two testing methods to assess balance in younger healthy women. The following chapter describes the methods and materials used for analysis.
CHAPTER III
METHODOLOGY

The final approval for this study was obtained from the University of North Dakota (UND) Institutional Review Board for the use of human subjects. A copy of the Human Subjects Review form is located in Appendix A. During recruitment, all individuals were informed that their participation was strictly voluntary. The components of the study were explained to those interested in participating, with each subject giving informed written consent. A copy of this consent form is located in Appendix B. To identify possible health or safety concerns, as well as to gather individual shoe information from participants, a health background and shoe history questionnaire was given to each individual before inclusion. This questionnaire was utilized to obtain information including: medications, past injuries/vestibular problems, vision, exercise level, shoe size, frequency of wear, activity level in shoes, orthotic use, as well as others. A copy of this questionnaire is located in Appendix C.

Subjects

In order to test the hypotheses associated with this study, 31 healthy women within the age range of 20-39 years were recruited from two physical therapy classes within the UND student population. It was determined prior to testing that subjects must meet the following inclusion criteria prior to participation in this study.

1. No current or past medical diagnosis or history affecting balance.
2. Currently taking no medications affecting the central nervous system (CNS) or medications known to affect balance/coordination.

3. No symptoms of dizziness or lightheadedness.

4. Have no symptoms suggestive of vestibular or neurologic disorders.

5. No psychological disorders including depression.

6. No history of two or more unexplained falls within the past 6 months.

7. Normal vision with or without glasses.

8. Will own a pair of dress/casual shoes with a heel height of at least 4 cm (1.6 inches).

9. Each subject will have worn these elevated shoes at a frequency of at least once a week.

Once all components of the criteria were met, and a signed consent form was received, each individual was tested on the NeuroCom® Balance Master and Functional Reach Test in a randomized order.

Instrumentation

The NeuroCom® Balance Master (NeuroCom® International, Inc, 9570 SE Lawnfield Road, Clackamas, OR 97015-9611, Telephone (800) 767-6744) was used in this study to assess the limits of stability and to assess postural sway using the bilateral stance test. The machine is composed of two 9-inch by 60-inch force platforms resting on four load cells which transfer information from the platform system to a connected computer.45 A picture of the NBM® in use can be seen in Figure 1. This computerized system is integrated with a software program that interprets various data obtained during a balance assessment. This provides quantitative data and provides an objective measure
of balance and balance-related activities to the researcher and subject by giving continuing visual feedback and statistical information regarding performance. Performance information is available on computerized printouts which can be depicted as numerical charts, graphs, and picture representations of the assessment with tracing of the center-of-gravity movement. An example of a computer results sheet can be seen in Appendix D.

Figure 1. NeuroCom® Balance Master.
Limits of Stability Test

The limits of stability test, quantifies several movement characteristics associated with the subjects ability to sway voluntarily to various locations in space and maintain stability at these positions for a brief period of time. This test is used to assess reaction time, movement velocity, endpoint excursion, directional control, and maximum excursion. The subjects are required to lean in eight directions, as far as possible without losing their balance or taking a step. These directions include: forward, forward-right, right, right-back, back, back-left, and left-forward. Scores for each direction (i.e., back, back-right, and back-left) are combined in a weighted fashion to obtain an overall value for that direction (i.e., back). For example:

\[(0.8)(\text{left-back}) + (0.8)(\text{right-back}) + (1)(\text{back}) \]

\[2.6\]

During the testing, the location of the subjects COG is displayed on the computer screen as a man-like cursor which provides visual feedback. By weight-shifting, the subject is required to lean as quickly and accurately as possible so that the cursor coincides with targets that are also displayed on the screen. Refer to the NeuroCom® Balance Master manual for further information. The following list describes the five components which the LOS tests:

1. Reaction time—time in seconds between the cue to move and the initiation of movement.

2. Movement velocity—the average speed of COG movement, expressed in degrees per second, between 5% and 95% of the distance to the primary endpoint.
3. Endpoint Excursion—on the primary attempt to reach the target, it is the distance traveled by the COG. This is expressed in % LOS and is considered to be the point at which the initial movement toward the target ceases, and subsequent corrective movement begins.

4. Maximal Excursion—the furthest distance traveled by the COG during the trial.

5. Directional Control—the amount of movement in the intended direction (toward the target) compared to the amount of extraneous movement (away from the target). This is calculated as a percentage in the following manner:

\[
\frac{(\text{amount of intended movement}) - (\text{amount of extraneous movement})}{\text{amount of intended movement}}
\]

For example, if a subject’s movement is directly toward the target in a straight line, then the amount of extraneous movement would equal zero, and the perfect directional control score would be 100%.

**Bilateral Stance Test**

A bilateral stance test on a firm surface was also used in this study and involved static standing in a predetermined area on the force plates, depending on the subjects' height. This test was used to quantify postural sway velocity and determine COG position with the subject standing quietly on the force plate with eyes open. The relative absence of COG sway is indicated as stability, while greater sway indicates less stability.
The average COG sway was computed in the computer and quantified for data interpretation.

**Functional Reach Test**

The Functional Reach Test, as first described by Duncan et al., was utilized as a second test of dynamic balance. This test is used to assess the maximal distance an individual can reach forward beyond arm’s length while maintaining a fixed base of support in the standing position. The testing equipment consisted of a 48 inch leveled measuring stick mounted on the wall at the shoulder height of the subject. Tape was placed on the ground as a reference point for each subject to start from. The distance reached in centimeters was recorded and the mean of three trials was computed.

**Assessment Procedure**

Subjects reported to the research room on the second floor of the UND Physical Therapy Department for assessment on the NBM® and FRT. Before assessment, individuals randomly selected the order of tests (i.e., bilateral stance, LOS, FRT) to be performed and whether to begin testing with their elevated shoes on or off. Once the order of tests and initial shoe condition were determined, all three tests were performed. One researcher was responsible for the bilateral stance and LOS testing on the NBM®, while another researcher was responsible for testing of the Functional Reach Test. Before assessment on the NBM®, individuals were assigned an identification number and their date of birth and height were entered in the file. All tests were administered at the subject’s pace in order to provide adequate warm-up and rest between trials. One researcher was also assigned the task of measuring the dimensions of all elevated shoes either before or after testing for consistency of measurements. Shoe dimensions
measured included: length of heel, width of heel, sole thickness beneath the first metatarsal height (i.e. forefoot height), and vertical height at back of heel. Figure 2 represents measurements taken. See Appendix E for pictures of the different elevated shoe designs.

![Figure 2. Elevated shoe measurements, taken in centimeters.](image)

**Limits of Stability Test**

Prior to testing, each subject was introduced to the force platform system. This included a general description of the apparatus and how performance would be measured, balance strategies utilized to maintain balance, subject expectations, and a warm-up session. Subject data was entered into the file consisting of an identification number, date of birth, and height. Each subject was instructed in and positioned for proper foot placement on the force plates as per NBM® protocol. Figure 3 shows the correct foot placement used. See the NeuroCom® Balance Master manual for specific details.45
Figure 3. NBM® foot placement used.

During testing, the subject was instructed to maintain the foot position while being able to splay the forefoot and lift the toes to maintain balance. The balls of the feet and heels had to remain in contact with the force plate at all times or testing would be repeated.

Prior to testing, each subject performed a warm-up on the NBM® which consisted of weight shifting to 100% LOS. The subject was instructed to lean in all eight directions (Figure 4) in the same order as the testing would be administered. Each target was to be reached as quickly and accurately as possible as soon as the green “GO” indicator appeared on the bottom of the screen. This position was then held until the cursor disappeared, followed by movement back to the center of the screen. A complete set of verbal instructions administered to each subject prior to testing can be found in Appendix F. Subjects were allowed to bend at the knees and hips and use their arms for balance, as long as their feet maintained contact with the force plate in the manner described above. Each subject was allowed to warm-up for as long as desired in order to feel as though able to adequately and comfortably perform the test. Following completion of one entire
warm-up target set, the subject then performed the testing procedure. An adequate practice session is important since Hamman et al.\textsuperscript{46} determined that there is a high "learning curve" associated with using the NBM\textsuperscript{®}. In their study which examined the training effects during repeated training sessions using the NBM\textsuperscript{®}, they observed statistically significant improvements in normal, healthy subjects' test results after repeated training sessions.

![Diagram of eight directions of limits of stability](image)

Figure 4. Eight directions of limits of stability.

**Bilateral Stance Test**

The bilateral stance test on a firm surface used in this study involved static standing in a predetermined area on the force plates of the NBM\textsuperscript{®}. Each subject stood for 3 trials with each trial lasting 10 seconds. Subjects were told to stand as upright and as steady as possible during testing. A complete set of instructions given to each subject prior to testing can be found in Appendix F.
Functional Reach Test

The Functional Reach Test was also used to assess dynamic stability. Each subject was asked to stand with the distal ends of each great toe (or front edge of shoes) at the edge of the tape-line and with their feet shoulder-width apart. Subjects were also asked to stand with their dominant arm as close to the wall as possible (i.e., ~ 3 inches) without touching the wall. The same standing position was used for all trials. Subjects were told to make a fist with their dominant hand and raise their arm forward to a 90° angle so that it was parallel to the measuring stick mounted on the wall. From this position, a starting measurement was taken at the third metacarpal of the subject’s dominant hand. When assuming the starting position, subjects were instructed not to protract or retract their scapula; their position was then inspected to confirm a correct starting position. The subject was then asked to “reach as far forward as possible with your arm without losing your balance or taking a step.” Guidelines given to subjects prior to reaching were to: keep the reaching arm parallel with the measuring stick mounted on the wall, avoid touching the wall while reaching, not twist the upper body while reaching, and not to lift their heels off of the floor at any time. The final reaching position was recorded in the same fashion as the starting position. The distance reached in centimeters was recorded and the mean of three trials was computed. If during any trial, the base of support was moved (e.g., step taken), or, any of the guidelines were violated the trial was discarded and repeated. A complete listing of the verbal instructions given to subjects can be found in Appendix G. A spotter was present during all testing as the task was performed. Prior to testing, each subject received two practice
trials and all questions regarding the testing were answered. Each subject performed the test with shoes on and barefoot.

Pilot Study

A pilot study on the NBM® was performed in order to establish intrarater (test-retest) reliability for one of the testers. A separate pilot study was also performed using the same subjects on the Functional Reach Test in order to establish intrarater reliability of another tester. Ten subjects ranging in age from 20-50 years were assessed using the bilateral stance test, limits of stability test, and the Functional Reach Test in the same manner as described in the assessment procedures, including the amount of practice and rest each individual was given. The one exception was that all testing in the pilot study was conducted with subjects' shoes off. The NBM® procedure manual was followed, and both researchers were present during the assessment of the subjects. To establish intrarater reliability, the same procedure was followed a second time, approximately one to two days later. Two subjects were released from the pilot study due to lack of effort during the second assessment, giving a remaining total eight subjects. The SPSS Version 10.0 (SPSS, Inc., Chicago, IL) was used to calculate intrarater reliability for all tests.

Intrarater Reliability

An intraclass correlation coefficient (ICC) was calculated from a repeated measures of analysis of variance (ANOVA) in order to assess test-retest reliability for each rater using both the NBM® and FRT, testing the subject on different days. One researcher tested subjects on the NBM®, testing bilateral stance COG sway and limits of stability, while another researcher tested the same subjects on the FRT. Intrarater reliability results for bilateral stance test are reported in Table 1, while the intrarater
reliability results for the limits of stability test and FRT are reported in Table 2 and Table 3 respectively.

Table 1. Bilateral Stance Test Intrarater Reliability Using ICC and r-value.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rater 1 ICC Value</th>
<th>Rater 1 r-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes Open COG Sway Velocity</td>
<td>.8097</td>
<td>.7251</td>
</tr>
</tbody>
</table>

Table 2. Limits of Stability Test Intrarater Reliability Using ICC and r-value.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rater 1 ICC Value</th>
<th>Rater 1 r-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time Composite</td>
<td>.5042</td>
<td>.3452</td>
</tr>
<tr>
<td>Movement Velocity Composite</td>
<td>.9057</td>
<td>.8321</td>
</tr>
<tr>
<td>Maximum Excursion Composite</td>
<td>.7538</td>
<td>.6359</td>
</tr>
<tr>
<td>Directional Control Composite</td>
<td>.8299</td>
<td>.7146</td>
</tr>
</tbody>
</table>

Table 3. Functional Reach Test Intrarater Reliability Using ICC and r-value.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rater 2 ICC Value</th>
<th>Rater 2 r-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional Reach Test Mean</td>
<td>.9744</td>
<td>.9501</td>
</tr>
</tbody>
</table>

**ICC and r-value Interpretation**

When calculating the intraclass correlation coefficient, there are no real standard values set for acceptable reliability. Values range between 0.00 and 1.00, with those numbers falling closer to 1.00 determining stronger reliability scores. As a general guideline, values above .75 are indicative of good reliability, while those below .75 represent poor to moderate reliability. It is generally considered that reliability should exceed .90 to ensure reasonable validity for clinical measurements. Table 4 represents an ICC value interpretation for intrarater reliability.
The correlation coefficient \( r \) allows researchers to state mathematically the relationship that exists between two variables. The \( r \)-value may range from +1.00 through 0.00 to -1.00. An \( r \)-value of +1.00 indicates a perfect positive relationship, 0.00 indicates no relationship, and -1.00 indicates a perfect negative relationship. Table 5 represents common interpretation of the correlation coefficient \( r \). For further interpretation, both the ICC value and \( r \)-value were used in pilot study analysis. Results show ICC values ranging from good to very high with the exception of poor reaction time results. Interpretation of \( r \)-values show results ranging from moderate to very high with the exception of poor reaction time.

Table 4. ICC Value Interpretation.

<table>
<thead>
<tr>
<th>ICC Value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>.90-.1.00</td>
<td>Very high</td>
</tr>
<tr>
<td>.75-.90</td>
<td>Good</td>
</tr>
<tr>
<td>&lt; .75</td>
<td>Poor to Moderate</td>
</tr>
</tbody>
</table>

Table 5. Correlation Coefficient \( r \)-value Interpretation.

<table>
<thead>
<tr>
<th>( r ) Value</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>.90-.1.00</td>
<td>Very High</td>
</tr>
<tr>
<td>.70-.89</td>
<td>High</td>
</tr>
<tr>
<td>.50-.69</td>
<td>Moderate</td>
</tr>
<tr>
<td>.26-.49</td>
<td>Low</td>
</tr>
<tr>
<td>0.00-.25</td>
<td>Little, If Any</td>
</tr>
</tbody>
</table>

Data Analysis

The data gathered for all subjects on the limits of stability test, bilateral stance test, and Functional Reach Test were entered into the SPSS Version 10.0 software.
system. With this program, descriptive statistics including mean and standard deviation were calculated. Calculations were also done to determine values for the paired $t$ test and Wilcoxon test. Comparisons between results were run using the Pearson correlation and Spearman correlation for further analysis.

**Reporting of Results**

Upon completion of this study, a copy of the results of this independent study was given to the University of North Dakota Department of Physical Therapy. This study was completed to fulfill the requirements of the University of North Dakota School of Medicine and Health Sciences Physical Therapy Program.
CHAPTER IV

RESULTS

The results consisted of the limits of stability test scores and bilateral stance test scores from the NBM®, as well as the Functional Reach Test scores. The data obtained from these assessments were analyzed using descriptive statistics to determine if any of the variables displayed significant results when comparing the shoes on condition to the barefoot condition. Comparisons were also made between test results and health and shoe questionnaire data collected prior to testing.

Subject Profile

Thirty female subjects, 20 to 26 years of age (mean age = 22.3 years), participated in this study. No subjects were excluded and all data was used. All subjects participated in a random one time testing session on the NBM® and FRT, both with elevated-soled shoes on and barefoot.

Descriptive Statistics

Descriptive statistics including mean and standard deviation were calculated from the data gathered during the one time testing session. For a listing of values from all tests, see Table 6. Only the components of testing found to be reliable during the initial pilot study were included in the data analysis as described in Chapter II.

Analytical Statistics

Analytical statistics were used to determine if a significant difference in static and dynamic balance existed between tests when comparing shoes on and barefoot.
Table 6. NBM® Tests and FRT Descriptives

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Limits of Stability test:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction Time (seconds)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction Time-right (1)</td>
<td>30</td>
<td>.54</td>
<td>.13</td>
</tr>
<tr>
<td>Reaction Time-right (2)</td>
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<td>.58</td>
<td>.18</td>
</tr>
<tr>
<td>Reaction Time-back (1)</td>
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<td>.57</td>
<td>.24</td>
</tr>
<tr>
<td>Reaction Time-back (2)</td>
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<td>.55</td>
<td>.20</td>
</tr>
<tr>
<td>Movement Velocity (degrees/sec)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Movement Velocity-forward (1)</td>
<td>30</td>
<td>8.49</td>
<td>2.17</td>
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<tr>
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</tr>
<tr>
<td>Movement Velocity-right (1)</td>
<td>30</td>
<td>9.09</td>
<td>2.86</td>
</tr>
<tr>
<td>Movement Velocity-right (2)</td>
<td>30</td>
<td>8.29</td>
<td>2.87</td>
</tr>
<tr>
<td>Movement Velocity-back (1)</td>
<td>30</td>
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<td>1.15</td>
</tr>
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<td>Movement Velocity-back (2)</td>
<td>30</td>
<td>3.87</td>
<td>1.32</td>
</tr>
<tr>
<td>Movement Velocity-left (1)</td>
<td>30</td>
<td>10.55</td>
<td>3.36</td>
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<td>Movement Velocity-left (2)</td>
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<td>9.78</td>
<td>3.07</td>
</tr>
<tr>
<td>Endpoint Excursion (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endpoint Excursion-right (1)</td>
<td>30</td>
<td>81.43</td>
<td>12.16</td>
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<tr>
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<tr>
<td>Endpoint Excursion-back (1)</td>
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<td>43.90</td>
<td>10.55</td>
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<tr>
<td>Endpoint Excursion-back (2)</td>
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<td>47.70</td>
<td>15.88</td>
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<tr>
<td>Maximal Excursion (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal Excursion-forward (1)</td>
<td>30</td>
<td>112.30</td>
<td>9.28</td>
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<tr>
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<td>88.07</td>
<td>11.85</td>
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<tr>
<td>Maximal Excursion-back (1)</td>
<td>30</td>
<td>54.13</td>
<td>9.19</td>
</tr>
<tr>
<td>Maximal Excursion-back (2)</td>
<td>30</td>
<td>62.97</td>
<td>13.86</td>
</tr>
<tr>
<td>Maximal Excursion-left (1)</td>
<td>30</td>
<td>100.47</td>
<td>4.78</td>
</tr>
<tr>
<td>Maximal Excursion-left (2)</td>
<td>30</td>
<td>97.87</td>
<td>6.25</td>
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<tr>
<td>Directional Control (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Directional Control-forward (1)</td>
<td>30</td>
<td>90.63</td>
<td>4.69</td>
</tr>
<tr>
<td>Directional Control-forward (2)</td>
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<td>89.13</td>
<td>4.64</td>
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<td>Directional Control-back (1)</td>
<td>30</td>
<td>49.10</td>
<td>27.52</td>
</tr>
<tr>
<td>Directional Control-back (2)</td>
<td>30</td>
<td>54.00</td>
<td>22.11</td>
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<tr>
<td><strong>Bilateral Stance Test:</strong> (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm Surface-eyes open (1)</td>
<td>30</td>
<td>.27</td>
<td>.15</td>
</tr>
<tr>
<td>Firm Surface-eyes open (2)</td>
<td>30</td>
<td>.20</td>
<td>.11</td>
</tr>
<tr>
<td><strong>Functional Reach Test:</strong> (cm)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Functional Reach Test (1)</td>
<td>30</td>
<td>42.56</td>
<td>5.04</td>
</tr>
<tr>
<td>Functional Reach Test (2)</td>
<td>30</td>
<td>38.43</td>
<td>5.56</td>
</tr>
</tbody>
</table>

Key: (1) – shoes off
(2) – shoes on
conditions. The nonparametric Wilcoxon test and parametric paired samples $t$ test were both used in the data assessment. Results obtained from these two tests are listed in Table 7. An alpha level of .05 was chosen to determine significance.

The FRT scores and NBM® variables for the LOS and bilateral stance tests which were determined to be reliable during the initial pilot study were included in the data analysis. As Table 7 demonstrates, the following variables showed a significant change ($p < .05$) between testing with shoes on and barefoot: movement velocity-back, maximal excursion-forward, maximal excursion-right, maximal excursion-back, maximal excursion-left, bilateral stance on firm surface-eyes open, and the FRT. For the LOS test, movement velocity back was 0.68 degrees/second greater with shoes on compared to barefoot. This means that subjects moved to the back target during LOS testing slower with their shoes on than when barefoot. Also for the LOS test, maximal excursion forward was 11.27% greater barefooted compared to with shoes on, maximal excursion right was 5.53% greater barefooted compared to with shoes on, maximal excursion back was 8.84% greater with shoes on compared to barefooted, and maximal excursion left was 2.6% greater barefooted compared to with shoes on. Maximal excursion is defined as the furthest distance traveled by the subject’s center of gravity (COG) during a trial of the LOS test. Therefore, subjects’ were able to move farther forward, to the right, and to the left when barefoot compared to with shoes on and farther back with their shoes on compared to when barefoot.

For the bilateral stance test on the NBM®, subjects average COG position was 7% greater when barefoot compared to with shoes on. This means that subjects’ tended to sway to a greater percentage of their theoretical LOS while barefoot compared to while
Table 7. Wilcoxon and Paired t test Descriptives.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Wilcoxon</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits of Stability:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 1 Reaction Time-right (1) – (2)</td>
<td>-1.46</td>
<td>.14</td>
<td>29</td>
<td>-1.51</td>
<td>.14</td>
<td></td>
</tr>
<tr>
<td>Pair 2 Reaction Time-back (1) – (2)</td>
<td>-1.19</td>
<td>.85</td>
<td>29</td>
<td>.36</td>
<td>.73</td>
<td></td>
</tr>
<tr>
<td>Pair 3 Movement Velocity-forward (1) – (2)</td>
<td>-3.30</td>
<td>.77</td>
<td>29</td>
<td>.63</td>
<td>.53</td>
<td></td>
</tr>
<tr>
<td>Pair 4 Movement Velocity-right (1) – (2)</td>
<td>-1.49</td>
<td>.14</td>
<td>29</td>
<td>1.45</td>
<td>.16</td>
<td></td>
</tr>
<tr>
<td>Pair 5 Movement Velocity-back (1) – (2)</td>
<td>-2.42</td>
<td>.02*</td>
<td>29</td>
<td>-2.73</td>
<td>.01*</td>
<td></td>
</tr>
<tr>
<td>Pair 6 Movement Velocity-left (1) – (2)</td>
<td>-1.75</td>
<td>.08</td>
<td>29</td>
<td>1.34</td>
<td>.19</td>
<td></td>
</tr>
<tr>
<td>Pair 7 Endpoint Excursion-right (1) – (2)</td>
<td>-1.89</td>
<td>.06</td>
<td>29</td>
<td>2.03</td>
<td>.05</td>
<td></td>
</tr>
<tr>
<td>Pair 8 Endpoint Excursion-back (1) – (2)</td>
<td>-1.49</td>
<td>.14</td>
<td>29</td>
<td>-1.61</td>
<td>.12</td>
<td></td>
</tr>
<tr>
<td>Pair 9 Maximal Excursion-forward (1) – (2)</td>
<td>-4.39</td>
<td>.00*</td>
<td>29</td>
<td>5.71</td>
<td>.00*</td>
<td></td>
</tr>
<tr>
<td>Pair 10 Maximal Excursion-right (1) – (2)</td>
<td>-3.09</td>
<td>.00*</td>
<td>29</td>
<td>3.58</td>
<td>.00*</td>
<td></td>
</tr>
<tr>
<td>Pair 11 Maximal Excursion-back (1) – (2)</td>
<td>-3.91</td>
<td>.00*</td>
<td>29</td>
<td>-4.52</td>
<td>.00*</td>
<td></td>
</tr>
<tr>
<td>Pair 12 Maximal Excursion-left (1) – (2)</td>
<td>-2.26</td>
<td>.02*</td>
<td>29</td>
<td>2.57</td>
<td>.02</td>
<td></td>
</tr>
<tr>
<td>Pair 13 Directional Control-forward (1) – (2)</td>
<td>-1.33</td>
<td>.19</td>
<td>29</td>
<td>1.65</td>
<td>.11</td>
<td></td>
</tr>
<tr>
<td>Pair 14 Directional Control-back (1) – (2)</td>
<td>-1.94</td>
<td>.35</td>
<td>29</td>
<td>-1.07</td>
<td>.30</td>
<td></td>
</tr>
<tr>
<td>Bilateral Stance Test:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 15 Firm Surface-eyes open (1) – (2)</td>
<td>-3.01</td>
<td>.00*</td>
<td>29</td>
<td>3.46</td>
<td>.00*</td>
<td></td>
</tr>
<tr>
<td>Functional Reach Test:</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 16 Functional Reach Test (1) – (2)</td>
<td>-4.33</td>
<td>.00*</td>
<td>29</td>
<td>-6.95</td>
<td>.00*</td>
<td></td>
</tr>
</tbody>
</table>

Key: (1) – shoes off  
(2) – shoes on  
* Significant difference between test conditions at α ≤ .05

wearing their shoes. Finally, for the FRT subjects’ reached an average of 4.13 cm farther when barefoot compared to with shoes on. This means that subjects were able to reach farther, controlling the movement of their COG over a fixed base of support, when barefoot compared to while wearing their shoes.

Upon determination of the significant variables/scores for all tests, the variables in the shoes on condition were correlated to information obtained from the health and shoe questionnaires. Specifically, the frequency of shoe wear per week, heel height, heel area, and whether or not subjects felt safe while wearing their elevated shoes were chosen for comparison. Pearson and Spearman correlations were utilized to determine if any
significant relationships existed. See Tables 8 and 9, respectively for specific data regarding these correlations. An alpha level of .05 was used to determine significance.

A significant relationship was found between maximal excursion forward and subjective stability in shoes \((p = .046, r = -.366)\) and between FRT scores and frequency of shoe wear per week \((p = .047, r = .366)\) using the Pearson correlation. This means that about 14% (i.e. \(r^2 = -.366^2\)) of the time a woman’s maximal excursion forward score on the LOS test can be predicted by whether or not she feels stable in her elevated-soled shoes. A woman’s FRT score can also be predicted by the number of times she wears her shoes per week the same percentage of the time. The Spearman correlation also showed a significant relationship \((p < .05)\) between FRT scores and frequency of shoe wear per week \((p = .029, r_s = .399)\), which reinforces the findings by the Pearson correlation. In addition, using the Spearman test, a significant correlation was found between the bilateral stance test and frequency of shoe wear per week \((p = .040, r_s = -.377)\). This means that about 14% of the time a woman’s bilateral stance test score can be predicted by the number of times she wears her elevated-soled shoes per week.

Based on the apparently close functional relationship of the NBmaximal excursion-forward test and the Functional Reach Test, a correlation was run between the two to assess any significant relationships. A Pearson correlation and a Spearman correlation were both run. The findings showed no significant correlation between the two tests \((N = 30, \text{Pearson}: \ p = .548, r = .114; \ \text{Spearman’s}: \ p = .914, r_s = .021)\). Figure 5 represents a scatterplot diagram showing how the testing scores varied in relation to each other.
Table 8. Relationship of Shoe Conditions to Performance on LOS Test, Bilateral Stance Test and FRT using Pearson's Correlation Coefficient

<table>
<thead>
<tr>
<th>Variable</th>
<th>Movement Velocity back</th>
<th>Maximal Excursion forward</th>
<th>Maximal Excursion right</th>
<th>Maximal Excursion back</th>
<th>Maximal Excursion left</th>
<th>Functional Reach Test</th>
<th>Bilateral Stance Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoe Frequency / wk</td>
<td>r -.186</td>
<td>-.156</td>
<td>.115</td>
<td>.016</td>
<td>.020</td>
<td>.366</td>
<td>-2.90</td>
</tr>
<tr>
<td></td>
<td>p .326</td>
<td>.411</td>
<td>.546</td>
<td>.932</td>
<td>.917</td>
<td>.047 *</td>
<td>.121</td>
</tr>
<tr>
<td>Heel Height</td>
<td>r -.322</td>
<td>-.108</td>
<td>-.165</td>
<td>-.095</td>
<td>.133</td>
<td>.218</td>
<td>-.059</td>
</tr>
<tr>
<td></td>
<td>p .083</td>
<td>-.570</td>
<td>-.385</td>
<td>.618</td>
<td>.484</td>
<td>.248</td>
<td>.757</td>
</tr>
<tr>
<td>Heel Area</td>
<td>r -.196</td>
<td>-.200</td>
<td>-.132</td>
<td>.112</td>
<td>-.094</td>
<td>.129</td>
<td>-.075</td>
</tr>
<tr>
<td></td>
<td>p .299</td>
<td>.289</td>
<td>.485</td>
<td>.557</td>
<td>.620</td>
<td>.496</td>
<td>.695</td>
</tr>
<tr>
<td>Subjective Stability in Shoes</td>
<td>r -.048</td>
<td>-.366</td>
<td>-.143</td>
<td>-.012</td>
<td>-.251</td>
<td>-.197</td>
<td>.011</td>
</tr>
<tr>
<td></td>
<td>p -8.00</td>
<td>.046 *</td>
<td>.451</td>
<td>.948</td>
<td>.180</td>
<td>.298</td>
<td>.952</td>
</tr>
</tbody>
</table>

* Significant correlation at $\alpha \leq .05$
Table 9. Relationship of Shoe Conditions to Performance on LOS Test, Bilateral Test, FRT, Spearman’s Correlation Coefficient.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Movement Velocity-back</th>
<th>Maximal Excursion-forward</th>
<th>Maximal Excursion-right</th>
<th>Maximal Excursion-back</th>
<th>Maximal Excursion-left</th>
<th>Functional Reach Test</th>
<th>Bilateral Stance Test</th>
</tr>
</thead>
</table>

* Significant correlation at $\alpha \leq .05$
Figure 5. Scatterplot of Functional Reach Test scores and maximal excursion forward on NBM®.
CHAPTER V
DISCUSSION

In analyzing the results of this study, it was found that a significant difference in measures of static steadiness and dynamic stability existed when the same individual was assessed barefoot and when wearing high-soled shoes. With performance of the FRT and the LOS test on the NBM®, subjects demonstrated significantly better results \( (p < .05) \) when barefoot as compared to when wearing high-soled shoes. With performance of the bilateral stance test on a firm surface, subjects showed significantly greater results \( (p < .5) \) when wearing high-soled shoes as opposed to going barefoot.

It is important to consider if the researcher’s three initial hypotheses were determined to be correct when analyzing all the results of this study. The first hypothesis stated that there will be significantly greater forward FRT scores for the barefoot condition when compared to the elevated shoes condition. This hypothesis proved to be supported by the research. Both the Wilcoxon test \( (p = .003) \) and the paired \( t \) test \( (p = .002) \) supported these results.

A correlation was also found between the frequency of elevated shoe wear per week and the FRT scores with high-soled shoes on (Tables 8 and 9). It can be suggested from these results that with an increased wear schedule of elevated shoes per week, there can be an expected increase in Functional Reach Test scores with elevated shoes on. This suggests that with frequent wearing, anterior reaching with elevated shoes on may be
more stable than in someone who does not wear elevated shoes frequently. As significant as this sounds, with full analysis of these results, it was determined that only 14% of the time, shoe wear frequency per week can predict the FRT scores. On a 100% scale, this number is very small and not a good representation of a true correlation.

The second hypothesis stated that an increased center of gravity sway will be noticed with wearing of elevated shoes as compared to barefoot. It was found that subjects' average COG position was 7% greater when barefoot compared to with elevated shoes on. This means that subjects tended to sway to a greater percentage of their theoretical LOS while barefoot compared to while wearing their elevated shoes. In analyzing these results, the reliability of the bilateral stance test needs to be considered. Test-retest reliability studies done by NeuroCom® using 162 subjects found poor reliability (R = .52) for the bilateral stance test on a firm surface with eyes open. Interpreted, this may mean that the 7% greater sway noted by the researchers of this elevated shoe study are not significant simply because of reliability issues.

During the initial pilot study of this project, the test-retest reliability was determined highly reliable. Even with high reliability, the results of the bilateral stance test did go against the expected hypothesis. The results also go against the postural sway findings of Lord and Bashford who analyzed the effects of high-heeled shoes on static and dynamic balance in women aged 60 to 89, measured by a “swaymeter.” This device consisted of a rod attached to the subject by a firm belt at waist level. They found significantly better performance in postural sway, coordinated stability tests, and maximal balance range while wearing flat shoes, or going barefoot compared to while wearing high-heeled shoes. It is unclear why an increased sway was noted in the barefoot
condition of this elevated shoe study. Shoe soles may somehow provide stability and increased proprioception as they conform to the bottom of the foot with increased wear.

In this study, the percentage of COG position was assessed, however, the location of the COG with elevated shoes on was not analyzed statistically. It was undetermined whether a greater anterior or posterior COG movement was occurring with elevated shoe wear. This information may have been important in analyzing why an increased COG position was noted in the barefoot condition.

The third hypothesis stated that the wearing of elevated shoes will show decreased results on the limits of stability test in all testing parameters when compared to the barefoot condition. Out of the 14 components of dynamic stability on the LOS test, 5 were found significant. With the exception of movement velocity-back, the other significant LOS test components were maximal excursion in all directions: forward, right, back, and left. This suggests that with wearing of elevated shoes, an individual will be more likely to be limited in maximal reaching ability in all directions as compared to barefoot maximal reaching. This may be important for occupations involving a lot of leaning or reaching tasks as well as certain household and recreational activities.

The findings of this study complement other research regarding the effects of high-heeled shoes on kinetic and kinematic movement components such as that of Lord and Bashford. Arnadottir and Mercer studied elderly women and found that performance was significantly greater on the FRT when barefoot or walking shoes were worn as compared to women who wore dress shoes (high-heeled shoes). An average 15% decline in FRT scores was reported regarding the change from the barefoot condition to the dress shoe condition. This is comparable to the average 10% decline in
FRT scores found in this study regarding the change from barefoot to elevated shoe conditions. Whereas many of the previous studies have come to the conclusion that wearing of high-heeled shoes constitutes a needless balance risk in elderly women, this study has concluded that the wearing of shoes with elevated soles also constitutes a balance risk in younger women, especially with maximal reaching tasks.

Limitations

Although this study adds to the findings on the effect of shoe heights on stability in younger women, the researchers acknowledge that certain limitations exist. The following are the main limitations which have been recognized:

1. The selection of subjects.
2. Variation in different shoe styles and heights among subjects.
3. Attempting to make comparisons between high-heeled shoes and elevated shoes.
4. The high learning curve associated with the LOS test.
5. Possible calibration problems with the NBM®.
6. Researcher error and inexperience.

A sample of convenience was chosen with all subjects tested being members of the physical therapy professional program at the University of North Dakota. This sample population may not be a good representation of the general population. Many physical therapy students participate in health and fitness activities on a regular basis, generally more than students of other respective professions. According to the questionnaire, participants exercised an average of 3-4 times per week. With an increase
in certain physical activities, can come an increase in dynamic balance. For this reason, a sample population from different professions would have been ideal.

Variation existed among subjects in shoe styles and shoe heights, with all shoes meeting the research criteria. Since no standard shoe was used, many variables can exist that were not accounted for. Different shoes may have greater foot support than others, providing more stability and comfort. The type of lacing or fastening varied which may also affect the subjects’ balance psychologically as well as physically. If the shoe support is not sufficient enough for the subject to feel safe during COG displacement, then they will be less likely to go to their maximal limits of stability. With varied sole heights among subjects, it is hard to determine how much of a balance difference existed between the smallest shoe heel height at 4.4 cm and the greatest height at 8.7 cm. Variation in heel area could also have been a significant factor affecting balance performance. Heel areas ranged from 15.75 cm² to 64.00 cm² with an average heel area of 48.65 cm². A Pearson correlation was run between heel surface area and the variables found significant on the NBM® and FRT. The results showed no significant correlation, suggesting that heel surface area did not influence the static and dynamic balance measures used for assessment. Even with these limitations, advantages of using the subjects’ own shoes existed which included comfort, correct shoe size, and familiarization with the particular shoe.

Limitations should also be acknowledged when attempting to make comparisons between high-heeled shoes and the elevated shoes used in this study. Previous research has shown that high-heels may be a balance hazard for many women, particularly the elderly. Generally the high-heels assessed have a narrow support base at the heel, which
decreases stability. They tend to have an increased angle between the heel and toe, causing a plantarflexion moment at the ankle, which can further decrease stability. The lateral support of high-heels are also generally not very stable allowing a potential increased ankle inversion/eversion movement to occur. The elevated shoes assessed in this study are different in several key descriptors from high-heeled shoes, which makes a true comparison difficult. Elevated shoes, generally have a wide base of support with a significantly increased heel surface area. With an increased surface area can come increased stability, as compared to the small surface area of high-heeled shoes. The angle between the heel and toe was significantly less in the elevated shoes, creating a decreased plantarflexion moment at the ankle. With the exception of the sandal style elevated shoes, most elevated shoes had some type of lateral support providing some stability, although minimal. With many differences in basic structure and support, making comparisons between high-heeled shoes and elevated shoes can be difficult.

Research has shown that a high learning curve exists on the NBM®, particularly on the limits of stability test. For future reference, it is recommended that subjects be allowed to explore movements of the cursor on the screen for a lengthened time period prior to actually being administered the test. An extended practice session, prior to running subjects may have allowed more significant reliability on the limits of stability test.

During the limits of stability testing procedure, it appeared from observation of the computer screen that many subjects had a difficult time displacing their COG in the right direction. It was undetermined whether this observation was a calibration problem leading to alteration of research data or simply a normal finding during testing.
Whenever a study is conducted, the possibility of research error exists. Potential
errors during this study may have included improper measurements during the FRT, mal-
alignment or improper foot placement on the NB$\text{M}^\circledast$ platform, as well as incorrect data
entry. Inexperience of the researchers in areas of balance assessment and the use of the
NeuroCom$^\circledast$ Balance Master may have affected the results as well. During the initial
pilot study, the FRT was found reliable, however the LOS test on the NB$\text{M}^\circledast$ had
decreased reliability. Even though five areas were determined significant, the level of
reliability varied from moderate to high. These areas of lower reliability may have been
caused by researcher error, or limited subject practice. Although maximal precautions
were undertaken to protect against these potential problems, unknown error may exist.

Recommendations

For future studies involving elevated shoes, a few recommendations should be
made. First, utilization of more functional tests available on the NB$\text{M}^\circledast$. Tests
recommended are the step/quick turn, step up/over a curb, and the rhythmic weight shift
test. The limits of stability test and bilateral stance test performed in this study may
quantitatively assess balance but are limited in their carryover effects to functional
movement.

Another recommendation should include the performance of the FRT with the
lateral reaching component added. In daily activity, people do not just reach in one
direction. Leaning out to the side and/or grasping objects across the body are a common
task. By having subjects maximally reach to their side, another dynamic measure of
balance can be obtained. Including a lateral reaching component to the FRT, will allow
more comparisons to be made to the NB$\text{M}^\circledast$ as well. The LOS test assesses medial and
lateral leaning components as well as anterior/posterior components. Correlations may be able to be drawn between these two tests.

Use only one style and height of shoe. This can have its advantages and disadvantages as described in the limitations section above. Another method may be to have more specific parameters when including shoes. For example, only include shoes that lace up, which would exclude a number of sandal or clog style shoes. Also assessed could be the adjusted heel height (heel height - forefoot height). A specific parameter could be placed in the inclusion criteria to help standardize shoes.

Use of a larger pilot study group. With a larger sample size, error and results by chance tend to decrease, while the testing reliability may increase as more variables are included. With a larger sample size, the researchers of this study may have been able to use more components attached with the LOS test. It is also recommended, that reliability of all components of testing be achieved with the pilot study prior to any testing of subjects.

Conclusion

Balance is an essential component to carrying out all activities of daily living, and is largely affected by extrinsic factors such as footwear. A number of studies have assessed how footwear affects posture and balance, however the main focus of such research has been on the elderly with high-heeled dress shoes. The purpose of this study was to determine if significant changes in balance could be observed in younger, healthy women when assessed barefoot and while wearing elevated shoes.

After assessment on the NeuroCom® Balance Master and Functional Reach Test, it was determined that significant changes in static and dynamic balance were found.
Significant differences in dynamic stability were noted in the LOS test and in the Functional Reach Test. The results of the two dynamic tests suggest that balance may be impaired with wearing of shoes with elevated soles. The bilateral stance test for static stability found an increased postural sway when subjects were barefoot as compared to with elevated shoes on. The results of this static test suggest that stationary balance may be somewhat more stable with elevated shoe wear. With these findings, it must be understood that the tests used may not be an ideal representation of functional movement and are limited in their carryover analysis. With attention paid to the limitations, this study can be used as a preliminary model that can serve as a vantage point upon which to build future research. It is apparent from this study, that elevated shoe heights can produce dynamic balance deficits and therefore clinicians should always carefully inspect and assess a clients footwear as part of the evaluation procedure.
Balance is an essential component in carrying out all activities of daily living. The maintenance of balance is a complex process which involves the interplay between the central nervous system and musculoskeletal system. Many factors contribute to an individual's ability to safely maintain balance. Some of these are intrinsic factors such as neurological, vestibular, or orthopedic deficits, while others are extrinsic factors such as one's surrounding environment or a person's footwear. Footwear, and its effect on balance, particularly in the elderly population, has been a topic of interest to researchers who have looked at ways of improving fall risk management. In particular, much research has been conducted regarding varying heel heights and its effect on balance in the elderly. However, limited research as been done to look at the impact of elevated shoe heights on the balance of a young, normal population. It appears that a growing fashion trend among younger women is towards the wearing of
dress/casual shoes with higher overall sole heights during both everyday activities and social events. With increased shoe heights may come deficits in static and/or dynamic balance. The purpose of this study is to determine what effect elevated shoe heights have on the balance of young women as assessed by the NeuroCom® Balance Master and the Functional Reach Test. This study will hopefully help provide some insight as to the relative safety of higher soled shoes which have become much more prevalent in recent years and to assist physical therapists in making proper shoe recommendations to clients, especially those that may be challenged by balance deficits or low back pain.

PLEASE NOTE: Only information pertinent to your request to utilize human subjects in your project or activity should be included on this form. Where appropriate attach sections from your proposal (if seeking outside funding).

2. PROTOCOL: (Describe procedures to which humans will be subjected. Use additional pages if necessary. Attach any surveys, tests, questionnaires, interview questions, examples of interview questions (if qualitative research), etc., the subjects will be asked to complete.)

Subjects:

Subjects will consist of at least 20 healthy volunteers from the University of North Dakota student and/or faculty population. Recruitment will be carried out by the researchers and done by word of mouth. A questionnaire administered before participation will be used to obtain health and shoe information that may influence the subjects balance and subsequent participation in the study. Subjects will be selected on the basis of meeting the following inclusion criteria: 1) each subject will be within the range of 20-39 years of age, 2) each subject will have no current or past medical diagnosis or history affecting balance, 3) each subject will be taking no medications affecting the central nervous system (CNS) or medications known to affect balance/coordination, 4) each subject will have no symptoms of dizziness or lightheadedness, 5) each subject will have no symptoms suggestive of vestibular or neurologic disorders, 6) each subject will have no psychological disorders including depression, 7) each subject will have no history of two or more unexplained falls within the past 6 months, 8) each subject will have normal vision with or without glasses, 9) each subject will own a pair of dress/casual shoes with a heel height of at least 4 cm, and 10) each subject will have worn these elevated shoes at a frequency of at least once a week. No volunteers in this age group will be excluded from this study unless there is a safety or health concern. Informed consent for this study will be obtained via a signed consent form (attached) before any testing procedures are performed.

Instrumentation:

The NeuroCom® Balance Master system will be used in this study. It is a clinically acceptable and safe machine commonly used in physical therapy to assess balance. The NeuroCom® Balance Master system operates on two 9-inch by 60-inch forceplates that determine the amount of force being exerted by each foot. The total force information is transferred to the computer system where calculations are performed to determine the test subjects’ center of gravity and postural sway. The computer screen is equipped with a cursor to provide visual feedback on the location of the subjects center of gravity. The computerized measurements and feedback systems are what make the system unique and beneficial to both the subject and researcher. The Functional Reach Test will also be used in this study. Intra-reliability for testing using the NeuroCom® Balance Master and Functional Reach Test will be established prior to the start of the study through an instrumentation class which each member of the research team is currently enrolled in. Validity of the NeuroCom® Balance Master has been established through its ability to generate computerized printouts of objective, quantifiable data. Validity of the Functional Reach Test has also been established.
through numerous clinical studies. Published literature supports the scientific efficacy and clinical use of both the NeuroCom® Balance Master and Functional Reach Test and acknowledges both as reliable and valid tools for assessing balance.

Procedure:

All testing will be conducted in the research room at the UND Physical Therapy Department. Each subject will be assessed once in random order. The tests to be assessed will be drawn randomly without replacement one at a time from a hat. Each subject will then perform a warm-up of each test prior to performing the recorded test, in the order they were drawn. The warm-up will allow the subjects to familiarize themselves with the NeuroCom® Balance Master and Functional Reach Test. It will allow the subjects to assess how to control their center of gravity and postural sway. The high learning curve associated with the NeuroCom® Balance Master requires the subject to perform a trial assessment before any results are recorded. Standardized testing procedures as described in the NeuroCom® Balance Master manual will be followed by the researchers for the following tests:

1) Bilateral Stance with shoes on and off (an indicator of static balance skills)

This testing procedure requires the subject to stand as still as possible on both feet for 10 seconds with shoes on and shoes off.

2) Limits of Stability Test with shoes on and off (an indicator of dynamic balance skills)

This test requires the subject to shift their weight and lean in all directions including: forward, backward, sideways, and diagonally. During this test, the subject will be required to maintain their balance while keeping their feet planted on the force platform.

In addition, the Functional Reach Test will be conducted with shoes on and off (as an indicator of dynamic balance skills). This test is measured with the subject in a standing position. The subject reaches forward with his/her dominant hand along a ruler placed on the wall. The subject is instructed to reach as far forward as possible without taking a step or losing balance. Each subject will perform 2 practice trials and then 3 measured trials in order to minimize possible learning effects.

For all testing, appropriate dress/casual shoes will be defined as having a firm sole and a heel height of at least 4 cm (1.6 in.). The heel height will be established by measuring the vertical distance from the floor to the insole at the front of the heel. Other shoe characteristics such as the flare of the sole and firmness of the sole will be qualitatively judged and documented.

Testing procedures will take approximately 20-45 minutes with members of the research team present at all times to ensure the complete safety of all participants.

Data Analysis and Reporting:

Statistical analysis of the data will consist of descriptive and analytical statistics. A related samples t-test or the most appropriate method of statistical analysis will be used. The individual subjects’ results will remain confidential, and the data will be identified in a manner that maintains subject confidentiality. All data, questionnaires, and consent forms will be kept in a confidential file at the Department of Physical Therapy (room 1518), University of North Dakota and will be kept for a three-year period, at the end of which the documents will be shredded.
3. BENEFITS: (Describe the benefits to the individual or society.)

This study has the potential for many benefits to both individual participants and society. Through assessment using the NeuroCom® Balance Master and the Functional Reach Test, each participant will learn about the relative safety of their own dress/casual shoes and also desired shoe characteristics to look for when purchasing future shoes. Participants will also become aware of their relative balance when not wearing any type of footwear. Data results will help provide physical therapists and other health professionals with evidence based research to assist in proper shoe recommendations for clients and/or aid in activity selection involving dynamic balance while wearing higher soled shoes. This could in turn help prevent or decrease the risk of injuries occurring secondary to loss of balance created by inappropriate footwear. Finally, results could be utilized by shoe manufacturers in developing safer shoes for the consumer.

4. RISKS: (Describe the risks to the subject and precautions that will be taken to minimize them. The concept of risk goes beyond physical risk and includes risks to the subject's dignity and self-respect, as well as psychological, emotional or behavioral risk. If data are collected which could prove harmful or embarrassing to the subject if associated with him or her, then describe the methods to be used to insure the confidentiality of data obtained, debriefing procedures, storage of data for the required three years, final disposition of data, etc.)

The risks associated with this study are minimal, but those that exist will be controlled. The physical risks include possible loss of balance during the assessment on the NeuroCom® Balance Master and during the Functional Reach Test. The risk of falling, however, will be minimized by having at least one member of the research team spotting subjects during all testing procedures. In addition, verbal instructions and demonstrations will be given to subjects prior to and during balance assessment.

Participants dignity, self-respect, and privacy will be protected by the research team by 1) testing all subjects in a private, controlled environment, 2) giving subjects complete instructions regarding their role in the research project, 3) scheduling individual testing sessions to promote privacy, 4) informing the subjects that all information pertaining to their history and performance will be disclosed only with a number and that no names will be used, and 5) informing the subjects that this is a voluntary exercise and they may withdraw at any time from the testing without fear of retribution or prejudice.
CONSENT FORM: Attach a copy of the CONSENT FORM to be signed by the subject (if applicable) and/or any statement to be read to the subject should be attached to this form. If no CONSENT FORM is to be used, document the procedures to be used to assure that infringement upon the subject's rights will not occur.

Describe where signed consent forms will be kept for the required 3 years, including plans for final disposition or destruction.

Informed consent will be obtained through the attached consent form. Each subject will be required to sign the form if they agree with the terms that are presented. Upon agreement, they will be included in the study.

All consent forms, questionnaires, and data reports will be kept in a locked confidential file located in the Physical Therapy office (room 1518) of the University of North Dakota School of Medicine and Health Sciences. Data and information obtained from the study will be kept for 3 years following the completion of the study. At the end of this three year period the documents containing this information will be disposed of with the use of a shredder. Please see attached consent form.

8. For FULL IRB REVIEW forward a signed original and fifteen (15) copies of this completed form, including fifteen (15) copies of the proposed consent form, questionnaires, examples of interview questions, etc. and any supporting documentation to the address below. An original and 19 copies are required for clinical medical projects. In cases where the proposed work is part of a proposal to a potential funding source, one copy of the completed proposal to the funding agency should be attached to the completed Human Subjects Review Form if the proposal is non-clinical; 7 copies if the proposal is clinical medical.

Office of Research & Program Development
University of North Dakota
Grand Forks, North Dakota 58202-7134

On campus, mail to: Office of Research & Program Development, Box 7134, or drop it off at Room 105 Twamley Hall.

For EXEMPT or EXPEDITED REVIEW forward a signed original, including a copy of the consent form, questionnaires, examples of interview questions, etc. and any supporting documentation to one of the addresses above. In cases where the proposed work is part of a proposal to a potential funding source, one copy of the completed proposal to the funding agency should be attached to the completed Human Subjects Review Form.

The policies and procedures on Use of Human Subjects of the University of North Dakota apply to all activities involving use of Human Subjects performed by personnel conducting such activities under the auspices of the University. No activities are to be initiated without prior review and approval as prescribed by the University's policies and procedures governing the use of human subjects.

SIGNATURES:

Principal Investigator

Project Director or Student Adviser

Training or Center Grant Director

Date

Date

Date

(Revised 4/1998)
APPENDIX B
Consent Form

Title: The Effects of Elevated Shoe Heights on Static and Dynamic Balance in Healthy Younger Women

You are invited to participate in an independent study conducted by students of the UND physical therapy program (Kip Ouchi & Rhett Randall) in collaboration with faculty member Meridee Danks. Your participation in this study would be greatly appreciated and it should be noted that it is strictly voluntary.

The purpose of this study is to determine what effects elevated shoe heights have on the balance of young women as assessed by the NeuroCom® Balance Master and Functional Reach Test. The NeuroCom® Balance Master is a clinically acceptable machine commonly used to assess balance in physical therapy. Subjects for this study must be healthy individuals between the ages of 20-39. All volunteers in this age group must meet the following inclusion criteria: 1) No current or past medical diagnosis or injury affecting balance, 2) No medications affecting the central nervous system or known to affect balance/coordination, 3) No symptoms of dizziness or lightheadedness, 4) No symptoms suggestive of vestibular or neurologic disorders, 5) No psychological disorders including depression, 6) No history of two or more unexplained falls within the past 6 months, 7) Normal vision with or without glasses, 8) Must own a pair of dress/casual shoes with a heel height of at least 4 cm (1.6 in.), and 9) Must wear your elevated shoes at least once a week. You will be asked to fill out a brief health and shoe questionnaire prior to the start of the study in order to protect you from injury and help us interpret our results. We do ask that you bring shoes with a heel height of at least 4 cm and be prepared to be tested in these shoes as well as barefoot when participating in the study.

You will only be asked to participate in a one time testing session lasting 20-45 minutes. You will be asked to report to the research room on the second floor of the UND Physical Therapy Department at your scheduled testing time. This session will include assessment on the NeuroCom® Balance Master, tested with both dress/casual shoes on and barefoot, as well as a Functional Reach Test. Balance Master tests will include: 1) standing as still as possible on both feet for a fixed period of time, tested both with shoes on and barefoot, and 2) leaning forward, backward, sideways, and diagonally without moving your feet, tested both with shoes on and barefoot. The Functional Reach Test will include standing without moving your feet while reaching forward with your dominant hand along a measuring device placed on the wall.

Although the process of balance testing involves some risk of falling and injury, the researchers of this study feel the risk of injury is minimal. In order to reduce this risk of falling, an assistant will be provided to safeguard you from possible loss of balance during the assessment. If you should choose to participate in this study, you will benefit from exposure to the research process and the knowledge that you have been an active participant in helping to improve the field of physical therapy. You may also benefit from learning a little more about the relative safety of your dress/casual shoes.
The results of this study will remain confidential and your data will be identified by a number known only to the investigators. These results will be kept in a locked confidential file in the UND Physical Therapy Department for three years following the completion of the study. After this period of time, the results will be destroyed. If you decide to participate, you are free to withdraw your participation at any time for any reason. You may stop the experiment at any time if you are experiencing pain, discomfort, fatigue, or any other symptoms that may be detrimental to your health. Your decision not to participate in this study will not affect your future relationship with the University of North Dakota or the Physical Therapy Department. If it is determined that you have health issues that put you at risk for injury or you do not meet the inclusion criteria, you may be excluded from the study. However, again, you will not be penalized in any way.

The investigators are available to answer any questions you might have concerning this study now or in the future. Questions may be answered by contacting Kip at (701) 746-0722 or Rhett at (701) 777-9599. A copy of this consent form will be available to all participants in the study upon request. If you would like to contact Meridee she can be reached at (701) 777-3861.

In the unlikely event that this research project results in physical injury or medical treatment including first-aid, emergency treatment, or any follow-up care, the investigators along with the University of North Dakota are not responsible for any such injury or treatment. The payment for any such treatment must be provided by you and your third party payer, if applicable.

I have read all the above, all my questions have been answered, and I willingly agree to participate in this study explained to me by Kip Ouchi and Rhett Randall.

_____________________________  ________________
Participant's Signature          Date

_____________________________  ________________
Witness (not Investigator)       Date
APPENDIX C
Health Background Questionnaire

1. Are you currently taking any medications? (e.g. allergy medications, cold medications, etc.) Please list all over-the-counter and/or prescription medications in order for us to determine if these may affect your balance.

2. Do you have any current or past medical diagnoses or injuries occurring within the last year that could affect your balance? If so, please list them and their associated dates. (include fractures, orthopedic conditions, sprains, etc.)

3. Do you have any symptoms (e.g. dizziness, lightheadedness) associated with a vestibular disorder? If yes, please explain your symptoms.

4. Have you experienced any episodes of two or more unexplained falls within the past 6 months? If so, please list.

5. Do you have normal vision (either with or without glasses/contacts)?

6. What is your height and weight?

7. What is your date of birth? (month/day/year)

8. Please circle which is your dominant hand? Right Left
9. How many times a week do you exercise? (please circle)
   0 days  1-2 days  3-4 days  5+ days/week

What type of physical activities are you involved in?

Shoe information

1. What is your shoe size?

2. How often do you wear your high-soled shoes? (i.e. days per week)
   Please note that shoes must have a heel height of at least 1.6 inches.

3. Are your high-soled shoes seasonal?

4. Do you notice any changes in your activity level when wearing your high-soled shoes? If so, please explain.

5. Are your high-soled shoes comfortable to wear?

6. Do you feel your balance is impaired in any way while wearing your high-soled shoes? If so, please explain.

7. Do you wear orthotics of any type in your shoes? If so, for what condition?
APPENDIX D
Computer Results Example

University of North Dakota
School of Medicine & Health Sciences
501 N Columbia Rd
Grand Forks, ND 58202-9037

Name: 277, 277
ID: ATID00401
DOB: 7/26/1978
Referral Source: Grand Forks
School of Medicine & Health Sciences North Dakota.

Diagnosis: HBM40LQBM
Operator: Randall Rhett L
Test Date: 5/5/2000
Test Time: 12:47:34 PM

Height: 5'4"
Comments: elevated shoe height study

LIMITS OF STABILITY TEST

<table>
<thead>
<tr>
<th>Transition</th>
<th>RT (sec)</th>
<th>MVL (deg/sec)</th>
<th>EPE (%)</th>
<th>MXE (%)</th>
<th>DCL (%)</th>
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</thead>
<tbody>
<tr>
<td>1 (F)</td>
<td>0.51</td>
<td>6.2</td>
<td>103</td>
<td>103</td>
<td>88</td>
</tr>
<tr>
<td>2 (RF)</td>
<td>0.61</td>
<td>11.7</td>
<td>108</td>
<td>110</td>
<td>83</td>
</tr>
<tr>
<td>3 (R)</td>
<td>0.46</td>
<td>6.2</td>
<td>112</td>
<td>112</td>
<td>92</td>
</tr>
<tr>
<td>4 (RB)</td>
<td>0.41</td>
<td>10.0</td>
<td>99</td>
<td>99</td>
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</tr>
<tr>
<td>5 (B)</td>
<td>0.67</td>
<td>2.6</td>
<td>65</td>
<td>65</td>
<td>87</td>
</tr>
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<td>6 (LB)</td>
<td>0.54</td>
<td>5.0</td>
<td>89</td>
<td>89</td>
<td>58</td>
</tr>
<tr>
<td>7 (L)</td>
<td>0.42</td>
<td>10.9</td>
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<td>93</td>
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<tr>
<td>8 (LF)</td>
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<td>89</td>
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</tbody>
</table>

Data Range Note: NeuroCom Data Range: 20-39
Post Test Comments:
shoes off

### LIMITS OF STABILITY TEST

<table>
<thead>
<tr>
<th>Transition</th>
<th>RT (sec)</th>
<th>MVL (deg/sec)</th>
<th>EPE (%)</th>
<th>MXE (%)</th>
<th>DCL (%)</th>
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</thead>
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<td>61</td>
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<td>66</td>
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</tr>
<tr>
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<td>93</td>
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<tr>
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<td>14.6</td>
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<td>67</td>
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</tbody>
</table>

#### Data Range Note: NeuroCom Data Range: 20–39

Post Test Comments:

- shoes on
MODIFIED CLINICAL TEST FOR SENSORY INTERACTION ON BALANCE (CTSIB)

1. Firm—Eyes Open (FIRM-EO)
   - Trial 1
   - Trial 2
   - Trial 3

2. Firm—Eyes Closed (FIRM-EC)
   - Trial 1
   - Trial 2
   - Trial 3

3. Foam—Eyes Open (FOAM-EO)
   - Trial 1
   - Trial 2
   - Trial 3

4. Foam—Eyes Closed (FOAM-EC)
   - Trial 1
   - Trial 2
   - Trial 3

**Data Range Note:** NeuroCom Data Range: 20–39

Post Test Comments:
- shoes off

MODIFIED CLINICAL TEST FOR SENSORY INTERACTION ON BALANCE (CTSIB)

1. Firm—Eyes Open (FIRM-EO)
2. Firm—Eyes Closed (FIRM-EC)
3. Foam—Eyes Open (FOAM-EO)
4. Foam—Eyes Closed (FOAM-EC)

Data Range Note: NeuroCom Data Range: 20–39

Post Test Comments:
  shoes on
APPENDIX E
Examples of Elevated Shoes
APPENDIX F
NeuroCom® Balance Master Verbal Instructions

Limits of stability test:

- When we start the testing, I want you to stand with both of your feet planted on the Balance Master.
- It is O.K. to lift your toes, bend at the knees, move your arms, and move your hips, as long as the base of your feet stays planted and does not move.
- When we start, I want you to keep the little man figure in the center square as steady as you can until a green GO appears at the bottom of the screen.
- You should then lean to try and move the man figure to the highlighted target with the blue circle, as quickly and accurately as possible.
- Hold it there as long as the blue circle remains, which will be for 8 seconds.
- Don’t worry if you can’t get all the way to the target, just get as close as you can.
- Once the cursor disappears, return to the center square and we’ll start the next trial.

Bilateral stance test:

- I want you to stand with both of your feet planted on the Balance Master.
- Stand as upright and steady as you can with your eyes open looking straight ahead.
- Please do not talk or move during the testing.
- The test will last for ten seconds and we will do three trials
- Ready, set, and GO.
Functional Reach Test Verbal Instructions:

- Please stand with your dominant arm closest to the wall and as close to the wall as possible (i.e. ~3 inches) without touching the wall.
- Please stand with your toes (or front edge of shoes) at the edge of the line of tape on the floor with your feet at shoulder’s width apart.
- Stand up nice and tall and raise your arm (i.e. dominant arm) to 90° so that your arm is parallel with the measuring stick mounted on the wall.
- Please make a fist with your hand (i.e. dominant arm) and reach as far forward as possible without losing your balance or taking a step.
- Do not lift your heels off of the floor or twist your body when reaching, but you may bend at the hip.
- Try to keep your reaching arm parallel with the measuring stick mounted on the wall, but do not touch the wall.
REFERENCES


70


