THE EFFECT OF PREFABRICATED FOOT ORTHOTICS ON FUNCTIONAL AND POSTURAL STABILITY IN OLDER ADULTS

A THESIS SUBMITTED TO THE BALL STATE UNIVERSITY GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

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BY

JACQUELINE E. HEATH

ADVISOR: D. CLARK DICKIN, PH.D.

BIOMECHANICS LABORATORY

BALL STATE UNIVERSITY

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COMMITTEE APPROVAL:

____________________________________________  __________________
Committee Chairperson (Dr. D. Clark Dickin)  Date

____________________________________________  __________________
Committee Member (Dr. Henry Wang)  Date

____________________________________________  __________________
Committee Member (Dr. Dorice Hankemeier)  Date

DEPARTMENTAL APPROVAL:

____________________________________________  __________________
Graduate Coordinator  Date

GRADUATE OFFICE CHECK:

____________________________________________  __________________
Dean of Graduate School  Date

BALL STATE UNIVERSITY
MUNCIE, INDIANA
MAY 2013
Decloration

The work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and the material has not been submitted, either in whole or in part, for a degree at this or any other university.

Jacqueline E. Heath

P.I.
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Table of Contents

THE EFFECT OF PREFABRICATED FOOT ORTHOTICS ON FUNCTIONAL AND POSTURAL STABILITY IN OLDER ADULTS ................................................................. i
A Special Thanks to ........................................................................................................ iv
Table of Contents ........................................................................................................... v

Chapter 1: Development of the Problem ...................................................................... 1
  Introduction .................................................................................................................. 1
  Purpose ......................................................................................................................... 7
  Assumptions ............................................................................................................... 8
  Delimitations .............................................................................................................. 8
  Limitations .................................................................................................................. 9

Chapter 2: Literature Review ......................................................................................... 10
  Introduction ............................................................................................................... 10
  Foot Ailments in the United States ........................................................................... 10
  Foot Orthotics ........................................................................................................... 11
    Purpose ..................................................................................................................... 11
    Effects on foot ailments ......................................................................................... 12
    Types of Foot Orthotics ......................................................................................... 13
  Human Balance and Stability .................................................................................... 18
    What is balance? ....................................................................................................... 18
    Balance maintenance ............................................................................................... 18
  Factors affecting balance performance ..................................................................... 20
  Foot Orthotics’ Effect on Balance Performance ....................................................... 21
    Ankle Sprains ......................................................................................................... 22
    Functional Ankle Instability .................................................................................... 23
    Abnormal Foot Structure ....................................................................................... 26
    Healthy Individuals ................................................................................................ 28
    Textured Orthotics ................................................................................................. 31
    Older Adults ............................................................................................................ 33
    Sensation deficits ..................................................................................................... 33
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postural stability.</td>
<td>34</td>
</tr>
<tr>
<td>Fall risk</td>
<td>35</td>
</tr>
<tr>
<td>Falls in the Elderly</td>
<td>36</td>
</tr>
<tr>
<td>Incidence and consequences</td>
<td>36</td>
</tr>
<tr>
<td>Medical costs</td>
<td>37</td>
</tr>
<tr>
<td>The Role of Foot Orthotics on Balance in the Elderly</td>
<td>39</td>
</tr>
<tr>
<td>Gait Stability</td>
<td>42</td>
</tr>
<tr>
<td>Plantar pressure measurement systems</td>
<td>43</td>
</tr>
<tr>
<td>Pressure redistribution using orthotics</td>
<td>45</td>
</tr>
<tr>
<td>Conclusion</td>
<td>48</td>
</tr>
<tr>
<td>Chapter 3: Manuscript</td>
<td>49</td>
</tr>
<tr>
<td>Abstract</td>
<td>50</td>
</tr>
<tr>
<td>Introduction</td>
<td>52</td>
</tr>
<tr>
<td>Methodology</td>
<td>57</td>
</tr>
<tr>
<td>Participants</td>
<td>57</td>
</tr>
<tr>
<td>Equipment</td>
<td>57</td>
</tr>
<tr>
<td>Functional stability assessments protocol</td>
<td>58</td>
</tr>
<tr>
<td>Limits of Stability assessment protocol</td>
<td>58</td>
</tr>
<tr>
<td>Postural stability assessment protocol</td>
<td>59</td>
</tr>
<tr>
<td>Gait stability assessment protocol</td>
<td>60</td>
</tr>
<tr>
<td>Testing</td>
<td>60</td>
</tr>
<tr>
<td>Measures of Interest</td>
<td>61</td>
</tr>
<tr>
<td>Statistical Design</td>
<td>63</td>
</tr>
<tr>
<td>Results</td>
<td>63</td>
</tr>
<tr>
<td>Clinical Tests of Balance: The TUG Test and FAB Scale</td>
<td>64</td>
</tr>
<tr>
<td>Postural Stability: The SOT</td>
<td>64</td>
</tr>
<tr>
<td>Limits of Stability: LOS Test</td>
<td>66</td>
</tr>
<tr>
<td>Gait Stability from Plantar Pressure Measures</td>
<td>66</td>
</tr>
<tr>
<td>Discussion</td>
<td>67</td>
</tr>
<tr>
<td>Functional Mobility and Stability</td>
<td>67</td>
</tr>
</tbody>
</table>
Chapter 1: Development of the Problem

Introduction

Accidental falls comprise a serious problem for older adults in the United States, where one in three older adults aged 65 and older experience falls each year (O'Loughlin, Robitaille et al. 1993; Hornbrook, Stevens et al. 1994). Approximately 20% to 30% of these fallers suffer moderate to severe injuries such as hip fractures or head trauma, and more than 90% of hip fractures occur as a result of falling (Black, Maki et al. 1993). Fall injuries are the leading cause of both nonfatal injuries and unintentional injuries that cause death in older adults, accounting for over 20,400 deaths in 2009 (Kochanek, Jiaquan et al. 2011). In 2010, 2.35 million older adults were treated in emergency departments for fall injuries and of these, more than 662,000 were hospitalized (CDC 2012).

Apart from physical consequences, falls have severe consequences on psychological well-being and quality of life as well. About 43% of those who experience
fall injuries at home that require hospital admission are discharged to a nursing home (Alexander, Rivara et al. 1992). Further, a history of falls develops fear and anxiety for both the faller and their family that naturally leads to a self-imposed reduction in activity level, independence and often social isolation and depressive symptoms (Gregg, Pereira et al. 2000). These result in reduced physical fitness and mobility, which in turn increase the risk of future falls (Kiel, O'Sullivan et al. 1991).

These physical and psychological consequences are even more ominous when coupled with the rapidly rising rate of fatal and nonfatal fall occurrence. From 1993 to 2003, there was a substantial increase of 55.3% in US death rates due to falls in adults aged 65 and older. It was also estimated that in Ohio, for example, fall-related emergency room visits and hospitalizations increased from 2002 to 2009 by 61% and 51%, respectively (2012). The sheer magnitude of fall occurrences and related medical issues takes a significant toll on medical costs. Costs directly related to falls in 2000 were over $19 billion, which is equivalent to over $28 billion in 2010 dollars (Stevens, Corso et al. 2006). If fall incidences continue to rise, medical costs due to falls is projected to escalate dramatically as the baby boom cohort trickles into the 65+ age group: it has been projected that by 2020, the total cost of fall injuries will reach an astonishing $85 billion (England, Hodson et al. 1996). Direct costs account for as little as 8% of total costs related to falls, as they only include costs directly related to treatment and not non-medical expenditures such as loss of work and reduced quality of life ("Falls Among Older Adults," 2012). As the consequences of falls are many and incidence rates
are already high and expected to increase, the need for further research in fall prevention is becoming much more critical.

The correlation between fall risk and poor postural stability in older adults is well documented (Overstall, Exton-Smith et al. 1977; Tinetti, Speechley et al. 1988). Individuals having suffered multiple falls perform more poorly on balance and functional tests, exhibiting 20-30% greater postural instability in comparison to non-fallers when standing on various surfaces in various stances (Menz and Lord 2001; Melzer, Benjuya et al. 2004). Although not statistically significant, substantial differences in stability limits between these elderly groups are also observed in the antero-posterior and medio-lateral direction.

Balance maintenance is directly related to the visual, somatosensory, and vestibular sensory information available to the central nervous system (CNS) regarding the location of the body’s center of gravity (COG) (Nashner 1989). Older adults suffer reduced quality and quantity of sensory information which is a major contributor to decreased postural stability. Specifically, loss of cutaneous pressure sensation is a normal result of aging and has been linked to postural instability in the elderly (Tanaka, Noriyasu et al. 1996). Foot orthotics are one intervention that have been shown to improve postural stability and could play an effective role in improving postural stability for older adults (Gross, Mercer et al. 2012).

Foot orthotics are used to optimize lower extremity function by supporting and realigning the foot into a more mechanically stable position (Wu 1990). Realigning the foot and increasing the surface area contact between the foot and the ground allows for
joint mechanoreceptors in the talocrural and subtalar joints to detect important sensory
information (Guskiewicz and Perrin 1996). This increases stimulation of the
neurosensorv system at the feet, thereby enhancing the afferent somatosensory feedback
available to the CNS crucial for postural control. Many studies documenting improved
postural stability with the use of foot orthotics attribute the improvements to an improved
quality and quantity of somatosensory information available to the CNS (Hamlyn,
Docherty et al. 2012).

Orthotics have been shown to improve postural stability in a number of
populations suffering conditions that decrease their postural control. Individuals
suffering ankle sprain and ankle instability have poorer postural stability than healthy
individuals, however, custom-made orthotics have been found to decrease their postural
sway (Orteza, Vogelbach et al. 1992; Guskiewicz and Perrin 1996). Improvements for
those with ankle sprains were suspected to be due to increased support to, and
realignment of, the injured subtalar and talocrural joints, allowing for proper joint
mechanics and increased joint mechanoreceptor function. Individuals with ankle
instability exhibit improved performance with customized orthotics on the Star Excursion
Balance Test, which quantifies functional stability, and enhanced scores on the
Cumberland Ankle Instability Tool, a self-reported measure of functional deficits
resulting from instability (Sesma, Mattacola et al. 2008). Prefabricated foot orthotics also
decrease postural sway both immediately following and after a two-week acclimation
period, as quantified by using center of pressure (COP) data (Hamlyn, Docherty et al.
2012).
Foot structure abnormalities, such as cavus and planus feet, are associated with varying sensory input to the balance system and decreased postural stability (Hertel, Gay et al. 2002). However, foot orthotics again offer a mechanism by which sensory input and postural stability can be restored. COP velocity during single leg stance with and without visual input significantly decreased over a 6-week period for those with more than 7° forefoot varus. For individuals with rearfoot malalignment, decreased postural sway in single- and double-limbed stance has been reported over a six-week period as well (Mattacola, Dwyer et al. 2007).

For the investigations considering individuals with foot injury or abnormalities, it appears that the effect of orthotics is to restore the balance performance deficit created by these conditions (Orteza, Vogelbach et al. 1992). For older adults, it is possible that the postural stability deficits induced by loss of somatosensory information at the foot may be able to be restored with the application of foot orthotics. However, despite recent literature regarding the effects of foot orthotics on various populations, there has been little research investigating the role of orthotics in the elderly. One study found improvements on balance for older adults using semi-customized arch supports, as quantified by the Berg Balance Scale (BBS), the Timed-Up-and-Go (TUG) test, and self-reported benefits of the supports (Mulford 2008). These results were observed immediately and persisted over the six-week period. A different investigation examined the effect of extensively customized orthotics on static and dynamic postural stability measurements in adults having previously experienced one or more unexplained falls (Gross, Mercer et al. 2012). Static stability was quantified by the single-leg and tandem
stance tests and dynamic stability by the tandem gait and alternating step tests. Significant improvements were observed for all tests immediately following the application of foot orthotics, but no differences were found between performance after the initial application and after two weeks of orthotic use. These results indicate that customized orthotics have prominent and immediate effects on both static and dynamic balance, possibly making up for the balance deficit caused by loss of plantar sensation. However, there did not appear to be continued improvements or reductions in stability after the initial insertion of the orthotic. One possible reason for the lack of evidence for continued improvement with longer-term use is the low level of difficulty and precision in the balance tests used in previous studies. Future studies may identify more longitudinal improvements with continued orthotic use by assessing balance with higher precision during more dynamic tasks and through the manipulation of sensory information to help isolate potentially elevated functioning via orthotics that increase contact area and improving overall foot alignment.

The majority of studies assessing balance and posture has used static or clinical balance assessments but has not thoroughly addressed more dynamic tasks of postural control. Dynamic stability is key to safe locomotion, especially for the elderly (Lemaire, Biswas et al. 2006). Biomechanical gait and static postural stability measures are predominately based on analysis of COP from a force platform to obtain postural sway measures, but useful information regarding plantar pressure distribution can also be obtained via in-shoe pressure sensors. These pressure sensors assess the dynamic pressure gradient across the surface of the foot. Research has demonstrated that using
both customized and prefabricated foot orthotics effectively redistribute plantar pressures by maximizing contact area, resulting in reduced local peak pressures (Tsung, Zhang, Mak, & Wong, 2004). In older adults, peak pressure at the heel is significantly reduced with orthotics by redistributing the pressure to the midfoot and forefoot by increasing the contact area in these sections (Bonanno, Landorf et al. 2011). In this study, the prefabricated orthotic was most effective at reducing pressure at the rearfoot when compared to other shoe inserts such as heel cups, pads and lifts.

Taken together, both prefabricated and customized foot orthotics have exhibited positive effects on increasing static and dynamic postural stability and redistributing plantar pressure (Tsung, Zhang et al. 2004; Gross, Mercer et al. 2012). However, there is a stark difference in cost between the two types, with modest prices of $10-$90 for prefabricated orthotics and $225-$500 for customized orthotics, warranting a comparison of the effects of the two types. Prefabricated orthotics are much more attainable with regard to overall cost and accessibility, posing a much more realistic method to increase stability for individuals suffering poor postural stability. In several studies, no significant differences were found between prefabricated and customized orthotics (Landorf, Keenan et al. 2006; Baldassin, Gomes et al. 2009). However, the use of customized orthotics may be justified under certain circumstances where individual structural modifications are necessary.

Purpose

In addition to the present research available regarding the effects of foot orthotics on balance, more research is needed to better identify and understand the benefits of foot
orthotics in the elderly. The purpose of this study was to explore the potential benefits of prefabricated foot orthotics on measures of postural sway, region of stability, dynamic functional mobility and stability and redistribution of plantar pressure. Significant results would contribute to the evidence that prefabricated foot orthotics may be an economical and effective method to reduce fall risk in the elderly.

**Assumptions**

The implications of the results of this study are based on a few assumptions. It was assumed that improved performance on the functional tests, SOT and LOS tests correlate to improved postural stability and by extension, a reduced risk of falling. It was also assumed that all participants put forth equal effort on all tests and answer all questions honestly. In the case of significant results, concluding that prefabricated orthotics improve balance was based on the assumption that PowerStep orthotics are an accurate representation of general prefabricated foot orthotics.

**Delimitations**

Several factors were controlled by this study in order to isolate the application of foot orthotics as the variable resulting in a change in balance performance. These delimitations included age, the health of the participants and the type of orthotic chosen. Significant results can then only directly apply to the healthy older adult population using PowerStep orthotics and would have to be generalized to the overall older adult population for other similar prefabricated orthotics.
Limitations

Some other limitations of this study that might have benefitted from additional control and may have affected the results were a possible learning effect throughout testing and sampling by convenience and volunteerism. The length of time of balance testing may have led to fatigue as well. Testing was randomized, however, which helped to minimized the potential for the learning effect and fatigue to influence results. It was also limited to moderate or greater test-retest reliability (ICC = 0.69 to 0.91) that has been reported for the LOS test (Newstead, Hinman et al. 2005). For the average of three trials of the six SOT conditions, test-retest reliability ranges from only fair to decent (ICC = 0.26 to 0.68), however, these figures were found for the composite score, which will not be used (Ford-Smith, Wyman et al. 1995). Additionally, there may be limited external validity of the BalanceMaster, in that performance on the BalanceMaster tests do not correlate perfectly to functional dynamic stability that contributes to the maintenance of balance and reduced fall risk. However, it is a common and precise measurement of postural stability, particularly in altered sensory environments and is often considered the gold standard for testing of this nature. The FAB and TUG functional tests were included as well to provide direct measurement of functional stability. These tests were chosen largely due to their high reliability, with a Cronbach’s alpha value of 0.805 and ICC > 0.95 for the FAB and TUG tests, respectively (Ng and Hui-Chan 2005; Klein, Fiedler et al. 2011).
Chapter 2: Literature Review

Introduction

The philosophy of evidence-based practice in medicine has become rooted in the health care system since the early 1990’s to ensure safe and quality care to patients suffering health issues (Uden, Boesch et al. 2011). Evidence-based practice involves integrating the best scientific research evidence and clinical expertise available in order to administer the best health care possible. There is a deficit, however, of scientific research in certain areas of podiatry which has prevented evidence-based practice from taking root in the treatment of foot disorders and ailments.

Foot Ailments in the United States

Foot disorders and foot pain are common public health concerns in the United States. The National Center for Health Statistics conducted a survey in 1990 on which 24% of the 119,631 respondents reported suffering at least one foot ailment (Greenberg and Davis 1993). Flat feet or fallen arches, toe and joint deformities, nerve damage and
Foot injuries were among the many reported foot ailments. In this survey, older adults reported more issues with foot ailments than the younger population: more than twice the rate of foot ailments was reported by those 65 years and older than those between 18 and 44 years. Further, one in every three elderly persons (65+ years) reported suffering some type of foot problem. Other studies claim that up to 80% of older people are affected by foot ailments, with the most common problem being hallux valgus (Benvenuti, Ferrucci et al. 1995; Menz and Lord 2001). Regardless of the specific cause of pain, one third of those over 70 years classify their foot pain as disabling (Menz, Tiedemann et al. 2006).

Despite the high prevalence of foot problems, only 35% of people who report problems consider the condition serious enough to get medical attention and of these, only half actually seek treatment (Greenberg and Davis 1993). For older people, many foot problems go unreported because they consider foot pain an inevitable consequence of aging rather than a medical condition requiring treatment (Williamson, Stokoe et al. 1964; Munro and Steele 1998; Menz and Lord 2001). For individuals who do seek medical attention for foot pain, podiatrists may prescribe a variety of treatments (Pelto 2012). They may decide to pad and tape the foot, prescribe medication, administer injections, or in extreme cases, perform surgery. Additionally, one of the more common treatments for foot ailments is the daily use of orthotics.

**Foot Orthotics**

**Purpose.** Foot orthotics are purposed for restoring correct foot function through treating various lower extremity pathologies and foot ailments (Landsman, Defronzo et al. 2009). Based on current knowledge, foot orthotics can be defined as devices used to
optimize lower extremity function by supporting and aligning the foot and preventing and correcting foot deformities in order to prevent and treat injury, pain and disability (Wu 1990). In simpler terms, the overall physiological effect of foot orthotics is to realign the joints and bones of the foot to a more mechanically stable position (Orteza, Vogelbach et al. 1992; Guskiewicz and Perrin 1996). They achieve this by increasing structural support at both the medial and lateral aspects of the foot. Realigning the foot in this manner may place the ligaments of the talocru ral joint in a more optimal position for joint mechanoreceptors to detect important sensory information. By realigning the foot and increasing the surface area contact between the ground and the sole of the foot, orthotics increase stimulation of the neurosensory system at the feet and therefore enhance the afferent somatosensory input available to the CNS (Guskiewicz and Perrin 1996). In addition, foot orthotics can act as a cushion between the ground and the foot to attenuate forces on the lower extremity.

**Effects on foot ailments.** One review examined literature regarding the use of foot orthoses to treat various foot conditions (Hawke, Burns et al. 2008). They summarized that foot orthotics have been shown to be effective for the treatment rearfoot disorders such as plantar fasciitis, posterior tibial tendon dysfunction, Achilles tendon disorders, ankle sprains, and equinus disorders, as well as for treating pes cavus, rheumatoid arthritis, and hallux valgus (Sobel, Levitz et al. 1999; Hawke, Burns et al. 2008). Many of these deformities cause pain and imbalance that can potentially be prevented and corrected by the prescription of orthotics. Foot orthotics can provide relief to sensitive or painful areas on the plantar surface of the foot such as with hallux valgus and callouses customizing support to the areas of pain and sensitivity (McPoil 2009).
They also re-distribute the forces acting on the foot and control the amount and rate of foot motion, which is important for patients with plantar fasciitis, arch pain, medial tibial stress syndrome, and over-pronated feet. For patients with limited foot mobility, orthotics can increase the surface area of contact between the ground and plantar surface of the foot. Because orthotics can act as a cushion for the foot, they have also been used to prevent the development lower-extremity overuse injuries by decreasing the peak force exerted on the feet during impact.

**Types of Foot Orthotics.** Several different types of orthotics are available based on the desired clinical application. They can be prescribed to redistribute pressure and relieve pain on the plantar surface of the foot, increase the surface area of contact between the ground and plantar surface, provide support to the arches and to control foot motion (McPoil 2009). For example, individuals with pronated feet are frequently prescribed foot orthotics with posting to control foot motion in the frontal plane. For patients seeking pressure relief, custom-molded orthotics are often prescribed to provide relief to specific points on the plantar surface of the foot. Diabetic individuals often develop ulcers at the metatarsal heads, and orthotics can be designed to remove an area of the insole underneath the metatarsal heads to relieve excess pressure at those points. However, because feet and foot ailments are so diverse, various types of orthoses exist for the desired treatment effect.

**Design.** Foot orthoses designs vary based on material, customization or prefabrication techniques, and types of posting or wedging added to the orthotic.

**Materials.** Orthotics can be classified as either accommodative or functional (2009). Accommodative orthotics are designed to support the foot but not to realign the
foot and its joints during ambulation, whereas functional orthotics are used to realign the foot in order to treat mechanical pathologies that are structural or functional in nature. Materials used for fabrication of these orthotics can be rigid, semi-rigid, or soft. Soft orthotics are made from compressible materials such as silicone or foam and are commonly used by people missing protective fatty tissue on the foot. They help to absorb shock, increase balance, and take pressure off sore spots of the foot (Isaacs 1985). They can also be used to relieve pressure from painful or injured areas of the plantar surface of the foot by cushioning or padding the foot with the soft material (Ibrahim 2007).

Functional orthotics are rigid and generally made of plastic, carbon fiber, leather or fiberglass (2009; Pelto 2012). They are designed to control function or lower extremity joint motion during gait for those with abnormal foot position or movement and to prevent the application of injury-causing forces to the bones, joints, tendons and ligaments of the lower extremity. The subtalar joint and the talocrural joint are two joints directly below the ankle whose function orthotics help to control by providing additional support to the foot at certain points, such as the medial and longitudinal arch (Isaacs 1985). Specifically, rigid orthotics are typically used to control excessive pronation and reduce forefoot loading by providing rigid support to the medial arch (Chalmers, Busby et al. 2000), whereas soft orthotics are generally prescribed for rigid foot ailments such as pes cavus and used to reduce general foot pain (Jackson, Binning et al. 2004).

Semi-rigid orthotics are a combination of soft materials reinforced by rigid materials (Pelto 2012). They are another type of functional orthotic but only partially control abnormal foot motion and position (2009). They mostly benefit athletes who
need additional structural support, but also shock absorption during high impact activity (Pelto 2012).

**Structural Modifications.** Modifications can be made to the specific structural design of an orthotic to serve a variety of purposes. Pressure at certain painful areas of the foot can be reduced by adding posts or wedges to redistribute the body weight to asymptomatic areas of the foot. For example, hallux valgus leads to the formation of a bunion when the first metatarsal deviates medially and the first toe deviates laterally to the second (Charrett 2009). Biomechanically speaking, excessive pronation and diminishing of the medial arch of the foot are two key causes to the development of hallux valgus and bunions. Therefore, custom orthotics designed for relief from bunions provide support for the longitudinal and anterior transverse arches and include a pronation wedge at the heel to limit hindfoot valgus. These modifications bring the entire affected foot into proper alignment to reduce excess pressure at the first metatarsal joint. Similarly, foot orthotics are frequently prescribed to a person with excessive pronation to control excessive subtalar and tarsal joint motion during gait by adding posting to the medial aspect of the foot (Nawoczenski, Cook et al. 1995). In fact, it has been shown that posting in orthoses reduces foot eversion and ankle eversion moments by placing the foot in a more inverted position during the stance phase of gait (Mundermann, Nigg et al. 2003). As such, medial posting may be more beneficial to individuals with pronated feet, which is linked with excessive eversion (Messier and Pittala 1988). Other possible modifications include, but are not limited to, cushioning or elevating the heel with wedges, sole wedges to promote supination or pronation and metatarsal pads (Pelto 2012). Heel lifts can also be added to adjust for bilateral differences in leg length.
Prefabricated versus custom-made. Prefabricated orthotics are mass-produced for a typical foot shape and size and for general foot problems (Pelto 2012). Some of the modifications described above, such as medial and lateral postings, are available in generic prefabricated orthotics, which also come without modifications. However, specially designed custom-made orthotics can be designed with modifications specifically for the wearer’s uniquely shaped foot. In this case, the designer fabricates a device from a three-dimensional representation of their foot and can add specializations specifically for the person’s desired outcome (2009). While prefabricated orthoses can be purchased at relatively modest prices of around $10-$90, custom orthotics are usually considerably more expensive due to individualized fitting, costing anywhere between $225 and $500 per pair (Landorf, Keenan et al. 2006; Pelto 2012). This stark difference in cost has warranted comparison of the effects of prefabricated and custom-made orthotics in both the short- and long-term (Landorf, Keenan et al. 2006; Baldassin, Gomes et al. 2009). In several studies, the effectiveness of prefabricated and customized orthotics have been compared (Orteza, Vogelbach et al. 1992; Landorf, Keenan et al. 2006; Baldassin, Gomes et al. 2009). Landorf et al. (2006) compared the long-term effectiveness (12-months) of soft sham orthotics, prefabricated orthotics with firm foam, and semi-rigid custom-made orthotics on pain in those with plantar fasciitis. The results showed that the prefabricated and custom-made orthotics were more effective in reducing pain than were the sham orthoses. However, those effects were small and no substantial difference was found between fabricated and customized orthoses for the treatment of plantar fasciitis. Baldassin et al. (2009) also evaluated the effectiveness of prefabricated and customized orthotics on pain in patients with plantar fasciitis and likewise found
similar effectiveness between prefabricated and customized orthotics for decreasing pain after eight weeks of orthotic use. On the other hand, Orteza, Vogelbach & Demegar (1992) found that unmolded orthotics did not help to improve ankle pain nor postural stability scores in people with acute inversion ankle sprains, but that molded orthotics did help to improve both stability and pain. Therefore, the variability in the effectiveness of prefabricated and custom-made orthotics is likely based on the intended purpose as well as those who are using them.

Other studies have compared the effectiveness of prefabricated and customized foot orthotics on variables other than pain (Mattacola, Dwyer et al. 2007; Hamlyn, Docherty et al. 2012). In one such study on subjects having sustained ankle sprains, none of the five types of orthotics tested, including four prefabricated and one customized orthotic, were effective in reducing sway length and COG velocity measures of postural stability (Hertel, Denegar et al. 2001). In a very similar investigation of healthy subjects, no significant differences in postural stability measures were found between the customized orthotic and the four prefabricated orthotics (Hertel, Denegar et al. 2001). However, it is important to note that in both of these instances the customized orthotic did not have individualized posting, which could have accounted for differences found in the study by Orteza et al. (1992). After performing a systematic review on the effectiveness of foot orthoses in lower limb overuse conditions, Richter, Austin & Reinking (2011) concluded that there was no significant difference between the ability of prefabricated and customized orthotics to prevent the occurrence of lower limb overuse conditions.
In light of these findings, the elevated cost of customized orthotics compared to prefabricated orthotics and the easy accessibility of prefabricated orthotics, a risk-benefit analysis is needed to justify the prescription of custom-made orthotics over prefabricated orthotics. Custom-made orthotics clearly offer the benefits of individualized shaping of the orthotic to meet a patient’s specific needs, but depending on the desired outcome, prefabricated orthotics may be just as effective as the more expensive customized orthotics. Additional research should be conducted to compare the effectiveness of different types of orthotics for different applications.

**Human Balance and Stability**

In the past decade, several studies have been performed to determine the effects of foot orthotics on balance and postural control. In order to understand the effects of orthotics on postural control, however, it is important to understand balance, how it is maintained, and what factors affect our ability to balance.

**What is balance?** Balance describes a person’s ability to maintain an upright stance (Hertel 2002). Postural control is used to maintain balance by keeping the body’s COG within some support base (Nashner 1989). The base of support is the area in which your body interacts with the support surface beneath it, and while the COG stays within its base of support, the body is able to maintain balance. For example, while standing, the base of support is the area between the feet. When the COG moves outside the base of support, a fall will occur unless the base of support is shifted to maintain the location of the COG within its limits, such as by taking a step.

**Balance maintenance.** The body maintains balance through the CNS obtaining sensory information regarding the location of the body’s COG in space. It integrates
information from vision, the vestibular system and somatosensation. Visual input relays information to the CNS regarding movement of the body in relation to its surroundings. The vestibular system of the inner ear features three semicircular canals containing fluid that are sensitive to angular acceleration of the head (Lee 2011). These canals are mutually orthogonal, enabling the detection of rotation in all three cardinal planes. The vestibular system also features two otolith organs that are sensitive to linear acceleration in the transverse and sagittal planes. Sensory receptors in the muscles and joints provide the CNS with somatosensory information regarding the movement and location of their corresponding body parts (Nashner 1989). Lastly, pressure receptors in the soles of the feet provide information regarding the support surface on which the person is standing.

The brain uses a combination of these three sensory systems to determine the location of the body’s COG and detect shifts toward the limits of its base of support in order to generate the appropriate, corrective musculoskeletal response (Nashner 1989). However, it cannot simply rely on each sensory component equally at all times since one or more sensory source may be absent or may relay inaccurate information regarding the body’s actual orientation in space. For example, one’s visual input while standing between two cars moving forward would suggest that their COG is shifting backwards, when in reality it is their visual surroundings that are moving forward. A properly functioning CNS is able to select the orientationally accurate sensory information and discard the rest. However, any absent or inaccurate sensory information, whether visual, vestibular or somatosensory, will decrease the performance of the CNS in relation to balance and postural stability.
Factors affecting balance performance. As previously stated, there are several factors that contribute to one’s ability to maintain balance, including sensory information from the visual, vestibular and somatosensory systems. Several studies have provided research evidence that foot-sole sensation is important in shaping appropriate postural responses via the somatosensory information sent to the CNS (Perry, McIlroy et al. 2000; Perry, Santos et al. 2001; Meyer, Oddsson et al. 2004). Reduction of plantar cutaneous sensitivity induced via anesthesia to the plantar surface of the foot was shown to reduce torque production in ankle inversion and ipsilateral flexion of the trunk and increase torque from hip abduction as a corrective response to lateral perturbation (Meyer, Oddsson et al. 2004). This indicated a shift from the ankle strategy (i.e. postural corrections generated by the musculoskeletal system through rotations about the ankle) to the hip strategy (postural corrections generated through rotations about the hip) in response to postural perturbation. Small postural perturbations predominantly lead to a response with the ankle strategy, while larger perturbations warrant the use of the hip strategy (Runge, Shupert et al. 1999). The loss of plantar sensation induced through anesthesia by Meyer, et al. then caused a response appropriate for larger perturbations and thus an overreaction to the magnitude of perturbation. Therefore, it was concluded that plantar cutaneous sensitivity is necessary for normal, efficient postural responses.

Loss of cutaneous touch and pressure sensation is a normal result of aging and has been scientifically shown to be a contributing factor to postural instability in the elderly (Tanaka, Noriyasu et al. 1996). The loss of cutaneous sensation on the plantar surface of the foot has been correlated not only with impaired balance control, but also with an
increased risk of falling (Lord, Ward et al. 1994; Lord, Menz et al. 2003; Meyer, Oddsson et al. 2004).

Interventions with the potential to increase somatosensory information to the plantar surface of the foot could play an important role in increasing postural stability for those with increased tactile stimulation thresholds of the foot. One such intervention shown to have positive effects on postural stability is the application of foot orthotics. Many studies having reported improved postural stability with the use of foot orthotics attribute the improvement to increased tactile stimulation of the plantar surface of the foot (Priplata, Niemi et al. 2003; Sesma, Mattacola et al. 2008; Hamlyn, Docherty et al. 2012).

**Foot Orthotics’ Effect on Balance Performance.**

Many studies have been performed in the past decade to determine the effects of foot orthotics on balance and postural sway in a number of populations, producing varying results (Orteza, Vogelbach et al. 1992; Hertel, Denegar et al. 2001; Percy and Menz 2001; Mattacola, Dwyer et al. 2007; Gross, Mercer et al. 2012; Hamlyn, Docherty et al. 2012). The mixed results from these studies are likely due to a myriad of factors, including different sample populations, a varied type of orthotics used for intervention, and the length of time the effects were observed. Some of the populations studied have included healthy subjects, older adults and patients suffering acute and chronic ankle sprains, functional ankle instability and excessive forefoot varus or rearfoot malalignment. Additionally, studies have included the use of several different types of foot orthotics, ranging from custom-made or various types of prefabricated orthoses to
posted or non-posted orthotics. Despite the differences in population and orthotic types, however, several trends can be identified.

**Ankle Sprains.** Individuals suffering ankle sprains have shown poorer postural control when compared to healthy individuals (Orteza, Vogelbach et al. 1992; Guskiewicz and Perrin 1996; Hertel, Denegar et al. 2001). Two studies examining the effect of custom-made orthotics in select populations having suffered inversion ankle sprains found that orthotics improved certain balance scores for the injured subjects, but not the uninjured (Orteza, Vogelbach et al. 1992; Guskiewicz and Perrin 1996). Orteza et al. (1992) suggests that if structural support is the reason for the effectiveness of orthotics on balance, then they should affect the uninjured as well. However, because significant improvements were only seen in the injured, they concluded that orthotics appear to only restore the balance performance deficit created by ankle injury.

An inversion ankle injury commonly causes sprain of the anterior talofibular ligament, which functions to limit adduction of the talus that is involved in closed chain pronation of the subtalar joint (Root, Weed et al. 1977). Therefore, excessive pronation may lead to increased stress of the injured anterior talofibular ligament. Joint mechanoreceptors in ligaments are usually damaged with injury to the ligaments, which causes decreased proprioceptive feedback to the CNS (Freeman, Dean et al. 1965). Orteza et al. (1992) suspected then that custom-made foot orthotics use may promote increased postural stability by controlling the subtalar joint and therefore decreasing stress to the ligaments to permit better somatosensory feedback. Guskiewicz and Perrin (1994) also suspected that the improvement they found in postural stability was due to increased support to the subtalar and talocrural joints, allowing optimal alignment during
weight-bearing for normal mechanics and for joint mechanoreceptors to better detect postural changes. They speculated that the custom orthotics also increased tactile stimulation of the plantar surface of the foot, thereby increasing somatosensory afferent feedback necessary for postural control.

In another study on individuals with ankle injury, Hertel, Denegar & Buckley (2001) investigated the effects of five types of rearfoot orthotics on postural stability for four weeks after injury. Unlike Orteza et al. (1992) and Guskiewicz and Perrin (1994), they were unable to identify changes in postural stability with the use of any of the five types of orthotics prescribed to the subjects, which included four prefabricated orthotics and one custom-molded orthotic. They suspected that the lack of significant results could be due to no adjustments being made for the individual malalignments of the subjects’ feet. In the other studies, the orthotics used were molded with individualized posting for each subject. In this study, the prefabricated orthotics used were of course not posted specifically for each individual, and the custom-made orthotic was molded to the subjects’ feet but no individualized posting was included in the fabrication. Therefore, the orthotics used by Hertel et al. (2001) may not have provided similar subtalar support as provided in previous studies.

**Functional Ankle Instability.** Functional ankle instability often follows ankle injuries such as the lateral sprain (Ferran and Maffulli 2006) and has been shown to affect basic balance tasks (Arnold, De La Motte et al. 2009). As a result of ankle instability, both static and dynamic postural stability is disrupted (Olmsted, Carcia et al. 2002; Gribble, Hertel et al. 2004; Hertel, Braham et al. 2006). Patients with ankle instability are more prone to the feeling of “giving way” in comparison to those without instability.
(Freeman, Dean et al. 1965) which is consistent with the theory that orthotics improve postural control by controlling subtalar joint motion. Two studies assessing the effect of orthotic intervention on postural stability in people suffering functional ankle instability had comparable results (Sesma, Mattacola et al. 2008; Hamlyn, Docherty et al. 2012). Findings from one study showed that custom-made orthotics are effective in improving dynamic balance over a four-week period (Sesma, Mattacola et al. 2008). This was concluded from findings that performance on the Star Excursion Balance Test (SEBT) was significantly improved with orthotic use. However, performance on the Limits of Stability (LOS) test was not. The SEBT is a functional test used to measure dynamic balance in order to indicate concerns with ability to complete activities of daily living. Like Olmsted and Hertel (2004) who found that orthotics increased dynamic stability on the SEBT with orthotic intervention for patients with cavus feet, Sesma et al. (2008) proposed that the medial support provided by the orthotics enhanced plantar cutaneous sensation and somatosensory feedback. When the subject displaced their COG to reach in the lateral direction, the support on the medial aspect of the foot provided by the orthotic helped to stabilize the foot, provide sensory afferent feedback and also diffuse the plantar pressure. This was used to explain the increased reach distances found in all directions on the SEBT (Sesma, Mattacola et al. 2008). The study also reported improvements on the Cumberland Ankle Instability Tool (CAIT), which is a self-reported function deficit test used to measure severity of ankle instability. Over the four-week testing period, significant improvement of over 20% was observed with use of orthotics for the involved ankle, but no significant difference was found for the uninvolved ankle.
Therefore, these results of these two tests indicate that foot orthotics work to increase stability in the injured limbs of subjects suffering chronic ankle instability.

The LOS test on the SMART Balance Master System\textsuperscript{®} is used to quantify the distance one is able to displace their COG in each of eight directions (antero-posterior, mediolateral, and diagonal directions) and the control the possess over movement in those directions. Lack of significant increases in LOS with orthotic use was attributed to the balance system not being challenged significantly enough to detect changes in balance performance (Sesma, Mattacola et al. 2008). It was thought that because the LOS test is a bilateral stance task that the subjects’ uninjured limb was able to compensate for balance deficits in the limb with ankle instability. It was then suggested that the LOS test may not be an effective test for patients with unilateral ankle instability.

In one other of the few studies regarding the effects of orthotic intervention for individuals with ankle instability, Hamlyn, Docherty & Klossner (2012) tested forty patients with functional ankle instability. Prefabricated foot orthotics were issued to them and their postural stability was tested before and after two weeks of orthotic use. Postural stability was measured using COP area, which was found to decrease both immediately following the application of foot orthotics and after a two week acclimation period. Therefore, they claimed that for those with functional ankle instability, not only customized orthotics, but prefabricated orthotics can also improve postural stability.

Similar to other studies that assessed the effectiveness of orthotics for the treatment of ankle sprain or instability (Orteza, Vogelbach et al. 1992; Guskiewicz and Perrin 1996; Sesma, Mattacola et al. 2008). Hamlyn et al. (2012) attributed the observed improvements in postural control to dispersed pressure throughout the foot via increasing
support to the arches and increased surface area contact of the foot. Improvements were also attributed to increased tactile stimulation of the foot. These mechanisms are speculated to improve somatosensory feedback of the COG position, improving the information sent to the CNS to be used for postural control.

Abnormal Foot Structure. Foot structure has recently been investigated as another potential source for postural instability (Hertel, Gay et al. 2002; Cobb, Tis et al. 2004; Cobb, Tis et al. 2006). Three common foot postures have been identified, which include cavus and planus feet, which are associated with excessive rearfoot varus and valgus, respectively, and rectus feet, which are not associated with either forefoot or rearfoot malalignment (Root, Orien et al. 1977). Since the interface between the plantar surface of the foot and the ground vary as a function of foot shape, it is likely that ground reaction forces differ as a result. These differences in direction and magnitude of ground reaction forces on the foot may lead to different sensory input to the balance system and thus diversity in levels of postural control. The outcomes of these studies on foot structure suggest that problems like excessive forefoot varus (Hertel, Gay et al. 2002) and cavus feet (Cobb, Tis et al. 2004; Cobb, Tis et al. 2006) may be associated with decreased measures of postural stability. Two studies have assessed the effect of custom-made foot orthotics on groups with normal and abnormal foot structure over a period of six weeks (Cobb, Tis et al. 2006; Mattacola, Dwyer et al. 2007). Cobb et al. (2006) compared COP velocity during single leg stance with eyes open and closed between groups of individuals with greater than and less than 7º forefoot varus. The findings showed that though postural stability in individuals with $\geq 7^\circ$ forefoot varus did not initially increase with the application of foot orthotics, it did significantly improve over the six-week
acclimation period. Interestingly, postural stability improved for both the orthotic and no-orthotic conditions for this group over time. However, the group with <7º forefoot varus did not show improvements over time for either condition, which suggests that these significant improvements were due to the foot orthotic intervention, but only for those with ≥7º forefoot varus.

Mattacola et al. (2007) also studied postural stability over a period of six weeks, but in a population of individuals with and without rearfoot malalignment. Alignment was measured as the angle between the calcaneus and lower leg when placed in subtalar neutral during standing and in prone, as well as in a relaxed standing. Malalignment was defined as those with greater than 5º varus or valgus in all three of the measurements for both limbs. If these measurements were less than 5º for each limb, the individual was placed in the control group. Postural stability was evaluated by sway velocity during single-leg stance and equilibrium score during double-limb stance in an altered sensory environment for both malaligned and control groups. All stability tests were performed in shoes both with and without custom fitted semi-rigid orthotics manufactured to correct for any malalignments or abnormalities. Improvements during single-leg stance were identified with use of customized foot orthotics compared to without orthotics for both groups. However, no significant improvements were observed over time. On the other hand, measures of bilateral postural stability on the Sensory Organization Test (SOT) with a sway referenced support and eyes closed did not improve initially for the malaligned group, but were improved over time. The SOT is a test on the Smart Balance Master®, which is used to alter sensory information by using a sway referenced support surface and sway referenced surroundings. This improvement observed coincides with
the results of another study on subjects with excessively pronated feet which showed that medio-lateral sway decreased after four weeks of wearing rigid, prefabricated foot orthotics with a medial wedge (Rome and Brown 2004).

Both of the studies by Cobb et al. (2006) and Mattacola, et al. (2007) suggest that foot orthotic intervention may have a beneficial effect on postural stability for those with abnormal foot structure. However, Cobb et al. only identified differences in postural stability with orthotic intervention over time, not initially. Mattacola et al. (2007) identified the opposite for single-leg stance: significant differences initially, but not over the course of six weeks. This difference may have been due to different instrumentation used to test COG velocity during single leg stance or the construction of the semi-rigid custom-made orthotics. The orthotics used by Cobb et al. (2006) did not provide forefoot or rearfoot posting, while those used by Mattacola et al. (2007) were made to correct any malalignments or abnormalities. Additionally, the criteria for malalignments in these studies differed as well. Mattacola et al. (2007) included those with $\geq 5^\circ$ calcaneal varus or valgus in the malaligned group, whereas Cobb et al. (2006) included only those with $\geq 7^\circ$ forefoot varus. Both studies did, however, indicate that foot orthotic intervention has less of an effect, if any at all, on postural stability in individuals in the control group, with more normally aligned feet.

**Healthy Individuals.** Most studies in the literature have reported the effect of orthotic intervention on individuals suffering foot pathologies such as ankle sprain, ankle instability, or foot malalignments, which have mostly shown that orthotics enhance postural stability. Other studies have focused determining if these same improvements
are exhibited in healthy individuals as well (Stude and Brink 1997; Hertel, Denegar et al. 2001; Bateni 2012). These studies have produced varied findings.

Hertel, Denegar, Buckley, Sharkey and Wayne (2001) investigated the effects of five different types of orthotics on healthy subjects free from any type of foot malalignment. Two of the orthotics were laterally posted, two were neutral, and one was medially posted. Since these orthotics were designed for differently aligned feet and were not assigned to individuals with the alignment they were designed for, the effect on healthy subjects may not have been observed or statistically significant. However, improved postural control was found in the frontal plane for differently posted rear-foot orthotics, but not in the sagittal plane. Specifically, the medially posted orthotic was found to decrease medio-lateral COP length and velocity in comparison to the other orthotic conditions, including the shoe-only condition. No differences were found between the orthotics in the antero-posterior direction. This study differed from other studies in that the effect of different types of orthotics on postural stability were compared, rather than just comparing the effect of orthotics on postural stability compared to not using orthotics. Due to several statistical tests being done to compare conditions, the Bonferroni correction necessary may have led to insignificant findings that may have been significant if just one orthotic type had been compared to the shoe-only condition. In that case, the effects of orthotics themselves, not just the type, may have been more evident.

The findings of Stude & Brink (1997) also suggested that orthotics are effective for enhancing balance in healthy individuals. Stabilization was measured before and after nine holes of simulated golf and reassessed in a similar manner after six weeks of
daily custom-made, flexible orthotic wear. The purpose of measuring stabilization before and after nine holes of simulated golf was to generate a fatigue factor that golfers typically experience on the golf course. The objective measurement to quantify stabilization was stabilization index, or the mean oscillations per unit time, as observed in single and double leg stance with (to measure balance) and without (to measure proprioception) visual input. Results showed that, though the effect of fatigue was minimal, the between balance and proprioception after nine holes of golf was significantly decreased after six weeks of daily orthotic wear. This signifies that customized orthotics may be effective for reducing the effects of fatigue, even in healthy golf players.

Contrary to these findings, several other studies have shown that healthy, uninjured subjects do not experience increased postural stability with the use of foot orthotics. Percy and Menz (2001) measured postural sway in asymptomatic professional soccer players in four underfoot conditions, including barefoot, soccer shoes only, soccer shoes with soft insoles, and soccer shoes with hard orthoses. No differences between any of these conditions were found for postural stability in any direction under any of the testing conditions (bipedal stance, tandem stance, and unipedal stance). There are several explanations for these null results. The subjects’ degree of stability may have been too high to detect subtle changes in stability, and a bigger sample size may have resulted in significant differences. Additionally, the instrumentation for postural control measurement was different than in other studies that tracked the location of the COG. In this study, body movements were tracked by two opto-electronic displacement devices to obtain root mean squared and range values for antero-posterior and medio-lateral sway at
waist level. This instrumentation may not have been precise enough to measure postural changes in the healthy subjects tested.

In addition to these reports, the several of the studies already discussed compared the effects of orthotics on the injured or malaligned individuals to a control group without injury or malalignment. Mattacola et al. (2007) showed that both unilateral and bilateral postural stability improved with use of orthotic for both the malaligned and normally-aligned participants. Findings of Orteza et al. (1992), Guskiewicz and Perrin (1996), Cobb et al. (2006) and Hamlyn et al. (2012) discussed previously showed that neither the use of custom-made foot orthotics nor prefabricated foot orthotics did not change balance performance in uninjured subjects. These findings suggest that healthy individuals without foot problems such as ankle injury, functional ankle instability or abnormal foot structure are not subject to the decreased postural stability that is correlated with these foot problems.

The lack of consistent improvements observed in postural stability with orthotic intervention in these studies could be explained by a smaller margin for improvement in postural stability for healthy subjects. If an individual’s postural stability is not negatively affected by some foot pathology or injury, the lack of a deficit in stability gives orthotics less space on which to improve stability.

Textured Orthotics. As already discussed, the plantar surface of the foot is the interface between the ground and the body, and thus plays an important role in postural control. Cutaneous stimulation provides afferent information to the CNS, contributing substantially to the determination of the body’s COG location. Several studies have examined the contribution of this afferent information to postural control through
methods such as local anesthesia, ischemic blocking and hyperstimulation through vibration. Other studies have examined the effect of various textures of foot orthotics on postural stability with the expectation that textured insoles would increase the level of cutaneous tactile stimulation. Corbin, Hart, McKeon, Ingersoll and Hertel (2007) compared COP velocity and area while wearing textured and without wearing textured insoles during unilateral and bilateral stance with eyes opened and eyes closed trials. Postural control improved in the bilateral stance when subjects wore textured insoles compared to not wearing the textured insoles. Center of pressure area and velocity both increased significantly when not wearing textured insoles with the eyes closed compared to eyes opened, however, no significant difference was seen when wearing textured insoles. Texturing of insoles appears to provide surrogate afferent somatosensory input that compensates for the loss of visual feedback, having shown improvement in COP measures of postural control improved in the bilateral stance. However, such results were not observed during unilateral stance.

Conversely, three different types of textured orthotics did not show any significant improvement in postural stability in another similar study on middle aged women (Wilson, Rome et al. 2008). Subjects were assigned to one of four groups: a control group wearing shoes with a standard insole, and three intervention groups wearing the same shoes with a plain and smooth surfaced orthotic, a dimpled surfaced orthotic, or an orthotic with a raised grid pattern. No significant differences in medio-lateral or antero-posterior postural stability were found between orthotic conditions at baseline or after four weeks of orthotic intervention. This demonstrated that foot orthotics with differently textured surfaces pose no improvements or detrimental effects
on postural stability. The lack of significance in this case compared to the significant findings of Corbin et al. (2007) may be explained by the dependent variable. Wilson et al. (2008) measured the minimum and maximum ranges of COP whereas Corbin et al. (2007) measured COP velocity and area, which may be a more telling measure of postural sway during the collection period. Additionally, older adults have shown increased muscle activity in the lower limbs which could arise as a result of loss of somatosensory processing and lead to increased reliance on motor strategies to maintain posture rather than afferent feedback (Wilson, Rome et al. 2008). In fact, it has been demonstrated that somatosensory loss can result in increased hip strategy for postural correction rather than ankle strategy (Horak, Nashner et al. 1990). This also may have contributed to not observing significant reductions in COP excursions in the study by Wilson et al. (2008), since the average age of subjects was more than twenty years greater than in the study by Corbin et al. (2007). Although findings of other studies with texture on the surface of the insole are equivocal, there is some evidence to suggest that a textured surface may lead to improvements in postural stability by increasing the tactile stimulation of the plantar surface of the foot (Wilson, Rome et al. 2008).

**Older Adults**

**Sensation deficits.** A deficit in sensory information decreases the ability of the CNS to integrate the sensory information to make appropriate postural responses in order to minimize postural sway and loss of balance. The functions of the main sensory systems related to postural control, namely the visual, vestibular, and somatosensory systems, have been shown to decline with advancing age (Wickremaratchi and Llewelyn
Particularly, one of the more pervasive effects of aging is the loss of cutaneous sensation on the sole of the foot (Maki, Perry et al. 1999). This sensory loss decreases the amount of feedback the CNS receives for balance maintenance. Kenshalo et al. (1986) showed that older subjects between 55-84 years were significantly less sensitive to cutaneous stimulation on the plantar foot than younger subjects between 19-31 years. This loss of cutaneous sensation on the soles of the feet has been shown to correlate with impaired postural stability and increased risk of falling (Lord, Clark et al. 1991; Lord, Ward et al. 1994; Maki, Perry et al. 1999; Lord, Menz et al. 2003). It can be inferred that this correlation is due to a decreased quantity and/or quality of feedback information regarding the proximity of the COG to the limits of the base of support sent to the CNS. Without this sensory information, the ability of the CNS to initiate appropriate musculoskeletal responses critical for maintaining balance and avoiding falls is greatly decreased.

**Postural stability.** Since there is an elevated prevalence of foot problems in the elderly compared to younger populations (Greenberg and Davis 1993; Menz and Lord 2001), the consequences of foot pathologies are likely to be greater in the elderly population as well. Foot problems other than loss of cutaneous sensation on the sole of the foot are also associated with impaired balance and functional ability. In a cross-sectional study involving 135 community-dwelling older people, Menz and Lord (2001b) did not identify differences in postural sway between older people with and without foot deformities, but did identify differences between the groups in other coordinated stability and functional tests. Statistical analyses revealed that foot problems experienced by elderly individuals were an indicator of poor performance on functional ability tests.
including a leaning balance test, stair ascent and decent, an alternating step-up test, and timed 6-meter walk. These tests rely on the ability to be stable while transferring weight from one foot to the other. Since foot deformities could impair that ability, these findings could be anticipated (Menz and Lord 2001).

**Fall risk.** As foot problems are correlated with decreased postural stability, they have likewise been correlated with increased fall risk (Tinetti, Speechley et al. 1988). In the same study by Menz and Lord (2001a), it was found that community-dwelling older individuals having suffered multiple falls had a higher prevalence of foot problems than those never suffering a fall or previously suffering only one fall. These authors later identified that when compared to non-fallers, fallers exhibit reduced ankle flexibility, more serious hallux valgus deformity, reduced tactile sensitivity, decreased plantar-flexor strength, and were more likely to have disabling foot pain (Menz, Morris et al. 2006). Because it is unlikely that falls lead to the development of foot problems, the presence of foot problems appeared to be a good predictor of fall risk.

The correlation between impaired postural stability and increased fall risk has been well documented, regardless of the presence of foot problems (Overstall, Exton-Smith et al. 1977; Tinetti, Speechley et al. 1988). In the study by Menz and Lord (2001a), individuals having suffered multiple falls also performed more poorly on balance and functional tests. Significantly higher COP path length and velocity, elliptical area, and medio-lateral sway have been observed for elderly fallers in comparison to elderly non-fallers (Melzer, Benjuya et al. 2004). When assuming several different stances, including a narrow stance, standing on foam, and standing with eyes closed, fallers exhibited between 20-30% greater instability. Substantial differences, though not
significant, in stability limits between these elderly groups were also observed: in the antero-posterior and medio-lateral direction for narrow stance, the average range of COG displacements were 2.1 cm and 1.7 cm greater for fallers than non-fallers, and 1.5 cm and 0.3 cm greater in a wide stance. Given that the incidence of falls is not likely the cause for postural instability, it follows that the existence of postural instability, regardless of cause, is a good indicator of the risk of falling.

**Falls in the Elderly**

**Incidence and consequences.** Accidental falls comprise a serious problem for older adults in the United States. One in three older adults (aged 65 and older) experience falls each year (O'Loughlin, Robitaille et al. 1993; Hornbrook, Stevens et al. 1994). Of these, approximately 20% to 30% will suffer moderate to severe injuries such as hip fractures and head trauma (see Alexander, Rivara et al. 1992). More than 90% of hip fractures occur as a result of falls (Black, Maki et al. 1993). What is more, about 25% of those who suffer hip fracture will die within 6 months of the injury (Weigelt 1997). For older adults, unintentional fall injuries are the leading cause of death from unintentional injury, accounting for over 20,400 deaths in 2009, and are also the leading cause of nonfatal injuries (Kochanek, Jiaquan et al. 2011). In 2010, 2.35 million older adults were treated in emergency departments for fall injuries and of these, more than 662,000 were either transferred or hospitalized (CDC 2012). Further, about 43% of those whom experience fall injuries at home and require hospital admission are discharged to a nursing home (Alexander, Rivara et al. 1992). There, the fall incidence rates climb even higher (Luukinen, Koski et al. 1995). In approximately 41% of nursing home
admissions, either the older adult or a family member identified frequent falls as one reason for seeking admission (Isaacs 1985).

Not only are the physical consequences of falls severe, but even in the absence of injury, the effects of falls on the quality of life may be even more grave. Much of this is due to psychological consequences. A history of falls develops a fear of falling that naturally leads to a self-imposed reduction in activity level and often social isolation and depressive symptoms (Gregg, Pereira et al. 2000). This results in reduced physical fitness and mobility, which in turn increases risk of future falls (Kiel, O'Sullivan et al. 1991). Both older adults who have fallen and their families often respond to fall occurrences with anxiety and fear. The family may add to a person’s self-imposed reduction in activity level by being overprotective, restricting the person’s independence and activity.

**Medical costs.** The sheer magnitude of fall incidences and related medical issues also takes a significant toll on medical costs. Costs directly related to falls in 2000 were over $19 billion, which is equivalent to over $28 billion in 2010 dollars (Stevens, Corso et al. 2006). If the fall injury rates continue, medical costs due to falls are expected to increase dramatically since the baby boom cohort approaches retirement age around year 2020. It has been projected that by 2020, the total cost of fall injuries will reach an astonishing $85 billion (Englander, Hodson et al. 1996). Direct costs are those which patients and insurance companies pay to treat fall related injuries, such as hospital and nursing home care, rehabilitation and pharmaceuticals. However, direct medical costs constitute only a small fraction of the total financial burden associated with falls and fall related injuries. These cost estimates do not include lost wages and housework, non-
medical expenditures such as wheelchair ramps, insurance claims processing costs, reduced quality of life, etc. A study done in the state of Ohio estimated that direct medical costs account for only about 8% of total costs related to falls among adults over age 65, whereas 89% were costs on quality of life (2012).

The extensive physical, psychological and financial consequences of accidental falls are devastating. But what makes these consequences even more severe is that there has been a significant increase in the rate of fatal falls in older adults over the past couple decades. From 1993 to 2003, there was a substantial increase of 55.3% in US death rates due to falls in adults aged 65 and older. It was also estimated that, in Ohio for example, that fall-related emergency room visits and hospitalizations increased from 2002 to 2009 by 61% and 51%, respectively (2012). There is ample public attention and government regulation regarding driving safety, and appropriately so. However, similar attention and effort should be given to fall prevention in older adults. For adults over the age of 65, deaths due to accidental falls were over three times as frequent as deaths caused by motor vehicle accidents in 2009 (Kochanek, Jiaquan et al. 2011). What is even more shocking is that when comparing the statistics of deaths per 100,000 in each age group, the sum of deaths due to motor vehicle accidents in all age groups was merely 50.0% of the deaths due to falls in adults over the age of 65. The extent of the public health concerns resulting from accidental falls will continue to expand as the number of older people will increase dramatically over the next decade as the baby-boomer population trickles into this 65+ age group. As the consequences of falls are many and the incidence rates of falls and deaths due to falls are great and expected to increase, the need for further research in fall prevention becomes much more critical.
The Role of Foot Orthotics on Balance in the Elderly

Although there have been numerous investigations on the impact of foot orthotics on balance and posture in certain population, such as individuals suffering ailments that affect balance ability, like ankle injury, functional ankle instability and abnormal foot structure, there is a paucity of research investigating the role of orthotics in the elderly. However, a few recent studies have considered this role (Mulford 2008; Gross, Mercer et al. 2012). One such example included 67 adults between the ages of 60 and 87 years to explore the effect of semi-customized arch supports on the Berg Balance Scale (BBS), the Time Up and Go (TUG) test, pain, and self-reported benefits of the supports (Mulford 2008). Measurements were taken before being fitted with arch supports, immediately after being fitted, and after six weeks of wearing the arch supports. Results showed significant improvements in the areas of balance (BBS), functional mobility (TUG), pain and self-reported benefits. Balance and functional mobility immediately improved with the application of arch supports and continued to improve at the six-week retest. Foot, knee, hip and back pain decreased from the pretest to the six-week retest and some of the self-reported benefits of arch supports included activities of daily living and exercise activity ability. Though these researchers identified improvements in the elderly population, they did not test a control group not wearing orthotics to compare measurements to in order to ensure that the increases observed were indeed due to the orthotic intervention.

Gross, Mercer and Lin (2012) performed another investigation focusing on older adults and the effects of foot orthotics on balance. These authors examined the effect of custom-made foot orthotic intervention on static and dynamic postural stability
measurements in adults over the age of 65 years who exhibited poor balance on a 1-leg stance test and who reported at least one unexplained fall during the preceding year. The fabrication of the custom-made orthotics was extensive, including molding to the subjects’ feet, arch support, forefoot and rearfoot posts, and heel lift. Static stability was measured with the 1-leg stance test on each leg and the tandem stance test with one foot in front of the other. Dynamic stability was measured with the tandem gait test and the alternating step test. Each of these tests was performed twice before the insertion of orthotics, immediately after the insertion, and two weeks after orthotic intervention.

Statistically significant improvements were seen on the single-leg stance test and tandem stance test both immediately after intervention and following two weeks of orthotic use. More steps were taken in the tandem gait test after two weeks of intervention, and for the alternating step test both immediately and after two weeks. No significant differences were found between any measurements at the time immediately following orthotic intervention and after two weeks of orthotic use. Therefore, although the prominent effects of orthotic use can be immediate, there does not appear to be further improvements or losses in stability after the initial insertion of the orthotic.

This study provided preliminary evidence that foot orthotic intervention has an immediate effect on static and dynamic measurements of functional stability in older adults, but has a number of limitations (Gross, Mercer et al. 2012). Though preliminary balance tests were performed before orthotic intervention, follow up testing did not include testing again without orthotics. This is beneficial in order to compare changes in performance after the intervention period to a baseline, and to see if intervention improved balance even when not wearing the orthotics. Additionally, the orthotics tested
were expensive customized orthotics, a less economical option when compared with prefabricated. Lastly, the sample population included older adults with poor postural stability and a history of falls, so findings cannot be applied to the general older adult population that is at risk of falls.

Two other interesting studies have been conducted using different types of balance-enhancing orthotics to determine their effects on balance in the elderly. These devices were designed to address the diminished somatosensory feedback existent in older adults. One of these types of balance-enhancing orthotics included a raised ridge around its perimeter in order to do so (Perry, Radtke et al. 2008). The ridge was located at the perimeter of the orthotic to enhance stimulation of the cutaneous mechanoreceptors on the periphery of the foot. Since loss of balance occurs when the COG deviates from the borders of the base of support, enhanced somatosensory stimulation, which is intended to occur only when the COG nears the limits of the base of support, in these instances was suspected to lead to enhanced balance. In fact, research on healthy older adults aged 65-75 years with moderate insensitivity of the soles (compared to young adults) has shown that balance evaluated via lateral stability during gait increased when participants wore these insoles compared to wearing conventional insoles. Furthermore, the magnitude of the effect on balance was not significantly diminished after 12 weeks of wearing the insole throughout the day. This indicated that the CNS did not acclimate to the increased cutaneous stimulation induced by the ridge on the periphery but continued to use the elevated stimulation for postural control. These findings provide evidence that increased tactile stimulation of the plantar surface of feet can act to increase balance.
Another interesting technique investigated to enhance plantar-surface somatosensation feedback is the use of a vibrating insole. Input noise can enhance sensory (Liu, Lipsitz et al. 2002) and motor function in a process called stochastic resonance. Noise is typically thought to impede signal detection and system performance, so this effect seems counterintuitive. However, the results of this study showed that the application of noise through these vibrating insoles actually resulted in a decrease in seven of the eight postural sway parameters measured. The insoles were gel-based and vibrated at an intensity just below the unique sensory threshold of each individual foot so that the stimulus was subsensory. Postural sway was assessed via displacement of the head-arm-trunk segment and tracked with a reflective marker placed on the participants’ shoulder. Sway parameters such as mean radius, sway area and range of sway excursion in the mediolateral and anteroposterior directions were calculated. Results indicated that the application of noise reduced sway in both young and elderly participants. However, results were differential in that elderly participants gained more in mediolateral motor control performance than did the young participants. This is not unexpected since younger participants may have near-optimal levels of sensory feedback compared to the elderly who often suffer lateral postural instability (Maki, Holliday et al. 1994) deficits as well as higher sensory feedback thresholds.

**Gait Stability**

Another important aspect of overall stability is stability during gait. Dynamic stability is key to safe locomotion, especially for the elderly (Lemaire, Biswas et al. 2006). Biomechanical gait and static postural stability measures are predominately based
on analysis of COP from a force platform to obtain postural sway measures such as COP velocity, range of COP excursions, sway length, sway area, oscillation frequency, etc. However, in order to better understand stability during locomotion, other variables should be assessed. There are several ways to quantify dynamic stability. A few of the measures already discussed are functional ability tests such as the Berg Balance Scale, the Star Excursion Balance Test, the alternating step test and tandem gait test. Another more detailed and quantifiable method to evaluate human locomotion performance is though thin in-shoe pressure sensors that contain an array of force sensitive cells that measure pressure distribution between two surfaces. The F-Scan system uses in-shoe pressure sensors that contain 960 load cells to detect the dynamic pressure gradient across the surface of the foot (Tekscan Inc.). Pedar-X is another similar system that measures pressure distribution with 256 load cells on each sensor. Both are wireless with built-in memory that can be downloaded to a computer at a later time.

**Plantar pressure measurement systems.** Insole systems such as the F-Scan system have been shown to be better for measuring COP trajectory during gait than measurements from a force platform (Debbi, Wolf et al. 2012). There are uniquely different COP locations between the foot and the shoe sole and between the shoe sole and the ground. Measurements using a force platform indicate the pressure between the shoe sole and the force plate, not the pressure between the shoe and the foot and therefore may not be a fully accurate representation of forces applied to the body at the foot. COP measurements recorded by a Pedar-X insole system have been shown to be different than measurements recorded from AMTI force plates (Debbi, Wolf et al. 2012). The location of COP measured by the force plate differed by an RMS error of 6.3 mm in the ML
direction and by 43.0 mm in the AP direction. This was explained by the fact that there is
greater movement in the AP direction during gait and so error in the AP direction should
accordingly be higher. Though measurement of force plate COP may not be as accurate
as the insole COP measurements, Debbi et al. (2012) asserted that it gives an approximate
location of COP and, using a specially designed algorithm, force plate measurements can
be adjusted to improve the accuracy of the COP trajectory during gait.

**F-Scan stability measures.** The F-scan system yields many different gait
parameters, including, but not limited to the following (Lemaire, Biswas et al. 2006).
First, the center of force (COF) position curves can be generated to show the trajectory of
the COF throughout the gait cycle. Also, AP stability during gait is exhibited by the COF
moving smoothly from the heel to the forefoot, so any backward shifts in COF position
are an indication of instability. Backward progressions result in a negative slope on a
displacement versus time curve and can be quantified from insole pressure data by taking
the first derivative of the COF position versus time curve. Slightly different than for AP
stability, the first derivative for ML COF position is expected to transition from positive
to negative because the COF should move slightly laterally through midstance and return
to the medial side before push-off. However, unexpected transitions between positive
and negative first derivatives are used to indicate stability during gait as well. Lateral
plantar pressure is an indication of how far the body’s COG deviates from the base of
support and extreme lateral placements of COF can cause instability and falls, so
maximum lateral COP position is an important factor in assessing overall gait stability.
Greater maximum lateral placement would logically indicate greater instability.
Cell trigger frequency is a measure of how many times a cell is turned on and off during a step. Since a smooth transition of COP from the heel to the forefoot is an indicator of stable gait, each F-Scan cells should only activate once throughout an ideal stride. Once a cell is turned on, it can be held in the on position for a number of frames, but cell re-activation again after being deactivated indicates abnormal weight shifting and therefore abnormal gait instability. The cell trigger frequency is therefore a good measure of gait stability. Lastly, stride parameters such as stride time (ST) and double support time (DST) quantify a direct correlation to stability during gait. ST is the length of time between heel strikes of one foot. DST is the length of time both feet are in contact with the ground. Unstable gait is correlated with increased ST and DST scores.

**Pressure redistribution using orthotics.** The F-Scan system has been used in many instances to evaluate changes in plantar pressure distribution with the use of different insoles (Tsung, Zhang et al. 2004; Owings, Woerner et al. 2008). Tsung et al. (2004) studied changes in pressure distribution during gait for both normal subjects and diabetes mellitus patients with sensory neuropathy but no gross foot deformities. Custom insoles are often prescribed to diabetic neuropathy patients in order to relieve high pressure at the metatarsal heads to other areas of the foot, which reduces the risk of plantar ulceration (Bus, Ulbrecht et al. 2004). Pressure distribution was measured by mean peak plantar pressure, pressure-time integral (PTI, the amount of load in a defined area of the foot multiplied by gait propulsion phase time), and mean peak contact area between the foot and support surface (Tsung, Zhang et al. 2004). Findings indicated that the use of both soft, flat prefabricated insoles and customized, contoured insoles can significantly redistribute plantar pressure in both diabetes patients and normal individuals.
by reducing local peak pressure and PTI and by maximizing contact area when compared to a shoe-only condition. However, the contoured, custom-made insoles were even more effective than the soft insoles in redistributing pressure over the whole foot. The contoured insoles exhibited a 14-20% reduction in mean peak pressure and a 20-30% increase in mean peak contact area. The larger support area generated by the contoured orthotic allowed for greater redistribution of pressure over the whole foot, particularly over the medial arch.

A similar investigation also compared reduction of in-shoe peak plantar pressures and PTI during walking with flat and custom-made insoles, quantified by in-shoe dynamic pressures measured by a Novel Pedar system (Bus, Ulbrecht et al. 2004). Results indicated that for diabetic patients, when compared to flat, over the counter insoles, custom-made insoles reduced peak pressure and PTI by 16% and 8%, respectively. However, it was also noted that the mechanical effects of the customized insoles were much larger at proximal regions of the foot that are less prone to plantar ulcerations. Custom molded insoles have also been shown to reduce peak pressure on the foot, which occurs at the metatarsal heads and heels, and to increase contact area of the foot with the ground (Kato, Takada et al. 1996). Peak pressure was significantly reduced by an average of 53.6% and contact area significantly increased by an average of 63.7%. The results of each of these three studies indicate prefabricated and custom-made orthotics are the most effective in redistributing plantar pressure during both standing and walking to prevent plantar tissues from becoming overstressed and developing foot ulcers.
Aside from prefabricated and custom-made orthotics, other types of shoe inserts have been considered for their effectiveness in redistributing plantar pressure, but may not elicit the same effectiveness and prefabricated and custom-made orthotics have elicited (Bonanno, Landorf et al. 2011). This study evaluated older individuals (65+ years) suffering heel pain, which is one of the most common musculoskeletal conditions of the foot. Peak pressure and contact area at the heel, the mid-foot, and the forefoot parameters were measured using a silicon heel cup, a soft foam heel pad, a heel lift and a prefabricated foot orthotic, then compared to a standard shoe condition. Although the heel cup and the foam pad also decreased peak pressure at the heel by 6%, the prefabricated foot orthotic did so by a much greater percentage (29%). The foot orthotic was the only device to increase the contact area at the mid-foot and forefoot, whereas the other devices each decreased contact area. By increasing contact area in these areas, the prefabricated orthotic more effectively redistributed plantar pressure from the heel to the mid-foot and forefoot. These results indicate that, although some heel inserts reduced heel plantar pressure, prefabricated foot orthotics are much more effective in redistributing pressure loads about the foot for individuals suffering heel pain.

Another study evaluated the effect of different types of custom insoles on plantar pressure redistribution in diabetic patients (Owings, Woerner et al. 2008). Since ulcerations often form at the metatarsal heads (MTHs), it is important to design custom insoles to offload high pressure from these areas. Foam impressions of each participants’ feet were sent to three different orthotic supply companies for fabrication of customized orthotics. Each company was supplied with information regarding location of prior ulcers, of pre-ulcers, foot deformities and areas of loss of sensation, but one company (Z)
was also supplied with plantar pressure data from the participants’ barefoot walking. Once the orthotics were made, subjects’ in-shoe plantar pressures were measured during gait through use of the Pedar-X system. It was shown that insoles manufactured by company Z (insoles Z) elicited greater unloading of pressure at regions of the foot withstanding greater amounts of pressure. Peak pressures for insoles Z were reduced by 21-37%, based on shoe type, when compared to insoles made by companies not provided with plantar pressure data. Additionally, insoles Z led to a significant reduction of 34-42% in the force-time integral than the other insoles. Regions of the foot with less applied plantar pressure did not undergo increases in pressure offset from other regions of the foot. The results from this study indicate that the design of orthotics should include plantar pressure data from in-shoe pressure analysis systems in order to design orthotics that most effectively offset the peak pressure at various regions of the foot that lead to diabetic ulcerations.

Conclusion

Several different types of foot orthotics have been engineered for varying purposes, and there have been a number of studies done to investigate the effectiveness of these orthotics on many different measures of balance, stability, pain, foot ailments, and gait parameters. While most of these investigations have reported positive effects of foot orthotics, some have reported no effects, but none, as is presently known, have reported negative effects.
THE EFFECT OF PREFABRICATED FOOT ORTHOTICS ON POSTURAL STABILITY IN OLDER ADULTS

Jacqueline Heath, Dr. Clark Dickin

School of Physical Education, Sport and Exercise Science

Ball State University

Muncie, IN 47306, USA

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Address Correspondence to:

Dr. Clark Dickin
Biomechanics Laboratory
Ball State University
3401 N. Tillotson Ave
Attn: Clark Dickin HP311
Muncie, IN 47306
Phone: (Int+1) (765) 285-5178
Fax: (Int+1) (765) 285-8762
Email: dcdickin@bsu.edu
Abstract

**Background.** Accidental falls comprise a serious health concern in older adults. Partially accounting for the high incidence rates is postural instability. While customized foot orthotics can improve certain measures of functional stability, the purpose of this study was to explore the degree to which prefabricated orthotics benefit this population and to expand the evidence base to postural stability as well.

**Methods.** Eighteen healthy older adults (72.7±4.8 years) were evaluated with and without foot orthotics, and again following 2-3 weeks of use. Functional stability was evaluated via the Timed-Up-and-Go test and the Fullerton Advanced Balance scale. Computerized posturography was used to assess stability in altered sensory environments (Sensory Organization Test) and to assess overall stability limits (Limits of Stability Test). A pressure analysis system assessed gait parameters and pressure distribution patterns.

**Results.** Foot orthotics improved stability on the Timed-Up-and-Go (p=0.003) and the Fullerton Advanced Balance Scale (p<0.001) and decreased fall occurrence on the Sensory Organization Test. Times based changes of postural stability occurred for medio-lateral sway velocity and area when only the vestibular system providing accurate information (condition 5) (p=0.001, 0.05, respectively), and under sensory conflict (condition 6) for sway velocity (medio-lateral and antero-posterior), sway path length and sway area (p=0.015, 0.021, 0.015, 0.015, respectively). An interaction effect was found for maximum excursion composite score (p=0.001) on the Limits of Stability test, as well as a main effect of time for directional control in the ML direction and composite score
Contact area increase in the midfoot and rearfoot and peak force decreased in the rearfoot \((p=0.024, 0.001, 0.03, 0.027\), respectively).

**Conclusions:** Results indicate that foot orthotic use can improve functional measures of stability in older adults. It is unclear whether the time-based changes in postural stability are attributable to the orthotics or are a result of learning effects. Regardless, improvements in stability with prefabricated foot orthotics may help decrease the risk of falls in this population.
Introduction

Accidental falls comprise a serious problem for older adults in the United States, where one in three adults aged 65 and older experience falls each year (O'Loughlin, Robitaille et al. 1993; Hornbrook, Stevens et al. 1994). Approximately 20-30% of these fallers suffer moderate to severe injuries such as hip fractures and head trauma (Black, Maki et al. 1993). More than 90% of hip fractures occur as a result of falls and 25% of those will die within six months of the injury (Weigelt 1997). Fall injuries are the leading cause of both nonfatal injuries and unintentional injuries that cause death in older adults, accounting for over 20,400 deaths in 2009 (Kochanek, Jiaquan et al. 2011). In 2010, 2.35 million older adults were treated in emergency departments for fall injuries and of these, more than 662,000 had to be hospitalized (CDC 2012). Falls also have severe consequences on psychological well-being and quality of life as well, where about 43% of those who experience fall injuries at home that require hospital admission are discharged to a nursing home (Alexander, Rivara et al. 1992). Further, a history of falls develops fear and anxiety for both the faller and their family that naturally leads to a self-imposed reduction in activity level, independence and often social isolation and depressive symptoms (Gregg, Pereira et al. 2000). These consequences are even more ominous when coupled with the rapidly rising rate of fall and fatal fall occurrence. From 1993 to 2003, there was a substantial increase of 55.3% in US death rates due to falls in adults aged 65 and older. As the consequences of falls are many and incidence rates are great and expected to increase, the need for further research in fall prevention is becoming much more critical.
The correlation between fall risk and poor postural stability in older adults is well documented (Overstall, Exton-Smith et al. 1977; Tinetti, Speechley et al. 1988). Individuals having suffered multiple falls perform more poorly on balance and functional tests, exhibiting 20-30% greater postural instability in comparison to non-fallers (Menz & Lord, 2001a; Melzer, Benjuya, & Kaplanski, 2004). Though not statistically significant, substantial differences in stability limits between these elderly groups are also observed in the antero-posterior and medio-lateral direction.

Balance maintenance is directly related to the visual, somatosensory, and vestibular sensory information available to the central nervous system (CNS) regarding the location of the body’s center of gravity (COG) (Nashner, 1989). Older adults suffer reduced quality and quantity of sensory information which is a major contributor to decreased postural stability. Specifically, loss of cutaneous pressure sensation is a normal result of aging and has been linked to postural instability in the elderly (Tanaka, Noriyasu, Ino, Ifukube, & Nakata, 1996). Foot orthotics are one intervention that has been shown to improve postural stability in older adults (Gross, Mercer, & Lin, 2012).

Foot orthotics optimize lower extremity function by supporting and realigning the foot into a more mechanically stable position (Wu 1990). Realigning the foot and increasing the foot-to-ground surface area contact allows for joint mechanoreceptors in the talocrural and subtalar joints to detect important sensory information and increases neurosensory stimulation at the feet, thereby enhancing the afferent somatosensory feedback to the CNS crucial for postural control (Guskiewicz and Perrin 1996). Many studies documenting improved postural stability with foot orthotics attribute the
improvements to improved quality and quantity of somatosensory information (e. g., Hamlyn, Docherty, & Klossner, 2012).

Orthotics have been shown to improve postural stability in a number of other populations suffering balance impairments as well. Individuals suffering ankle instability or sprain have poorer postural stability than healthy individuals, but custom-made orthotics have been shown to decrease their postural sway and improve functional stability (Orteza, Vogelbach et al. 1992; Guskiewicz and Perrin 1996). These improvements were attributed to increased support to and realignment of the injured subtalar and talocrural joints, allowing for proper joint mechanics and increased joint mechanoreceptor function. Improvements have also been observed with orthotics in populations with structural abnormalities resulting in decreased postural stability, such as cavus and planus feet (Hertel, Gay, & Denegar, 2002). COP velocity during single leg stance with and without visual input significantly decreased over a 6-week period for those with more than 7° forefoot varus. For individuals with rearfoot malalignment, decreased postural sway in single- and double-limbed stance was reported over a six-week period as well (Mattacola, Dwyer et al. 2007).

For the investigations considering individuals with conditions resulting in a balance deficit, it appears that orthotics can restore the decreased balance performance (Orteza, et al., 1992). For older adults, it is possible that the postural stability deficits induced by loss of somatosensory information at the foot could be restored with the application of foot orthotics. However, despite recent literature regarding the effects of foot orthotics on various populations, there has been little research investigating the role
of orthotics in the elderly. One study found improvements on balance for older adults using arch supports, as quantified by the Berg Balance Scale (BBS), the Timed-Up-and-Go and (TUG) test, observed immediately and after a six-week period of orthotic use (Mulford 2008). A different investigation examined the effect of extensively customized orthotics on static and dynamic postural stability measurements in adults at a high risk of falls. Static stability was quantified by the single-leg and tandem stance tests and dynamic stability by the tandem gait and alternating step tests. Significant improvements were observed for all tests immediately following the application of foot orthotics, but no additional improvements were found after two weeks of orthotic use. These results indicate that customized orthotics have prominent and immediate effects on both static and dynamic balance, possibly making up for the balance deficit caused by loss of plantar sensation. One possible reason for the lack of evidence for continued improvement with longer-term use is the low level of difficulty or precision in the balance tests used in previous studies. Future studies may identify more longitudinal improvements with continued orthotic use by assessing balance with higher precision during more dynamic tasks and through the manipulation of sensory information to help isolate potential elevated functioning via orthotics increasing contact area.

The majority of studies assessing balance and posture have used static or clinical assessments but have not thoroughly addressed more dynamic tasks of postural control. Dynamic stability is key to safe locomotion, especially for the elderly (Lemair, 2006). Biomechanical gait and static postural stability measures are predominately based on analysis of COP from a force platform to obtain postural sway measures, but useful
information regarding plantar pressure distribution can also be obtained via in-shoe pressure sensors. These pressure sensors assess the dynamic pressure gradient across the surface of the foot. Research has demonstrated that using both customized and prefabricated foot orthotics effectively redistribute plantar pressures by maximizing contact area, resulting in reduced local peak pressures (Tsung, Zhang, Mak, & Wong, 2004). In older adults, peak pressure at the heel is significantly reduced with orthotics by redistributing pressure to the midfoot and forefoot by increasing the contact area in these sections (Bonanno, Landorf et al. 2011).

Taken together, both prefabricated and customized foot orthotics have shown positive effects on increasing static and dynamic postural stability. However, prefabricated orthotics boast a modest price tag of $10-$90, whereas customized orthotics cost around $225-$500, warranting a comparison of the effects of the two types. Prefabricated orthotics are also much easier to obtain, posing a much more realistic method to increase stability for individuals suffering poor postural stability. In several studies investigating differences between the two, no significant differences were found (Landorf et al., 2006; Baldassin, Gomes, & Beraldo, 2009). Therefore, the use of prefabricated orthotics may be just as beneficial for the general older adult population.

**Purpose**

More research is needed to better understand the benefits of foot orthotics in the elderly. The purpose of this study was to explore the potential benefits of prefabricated foot orthotics on measures of postural sway, stability limits, dynamic functional stability and redistribution of plantar pressure. Significant improvements would contribute to the
evidence that prefabricated foot orthotics may be a economical and effective method to reduce fall risk in the elderly.

Methodology

Participants

Eighteen individuals (8 male, 10 female) over 65 years of age volunteered to participate in this study (age = 72.5 ± 4.8 years; height = 170.4 ± 8.7 cm; mass = 80.5 ± 14.5 kg). Volunteers were recruited by advertising in a local community center and fitness center for older adults. Requirements for participation were verified via a health activity questionnaire (Appendix I) and included no foot orthotics use in the past year, history of vestibular or neurologic disorders, unexplained falls or dizziness, or injury that could affect postural stability, and being in good general health. All participants demonstrated at least 20/30 vision (with usual corrective lenses) to eliminate poor vision as a covariate impairing balance (Gross, Mercer et al. 2012) and had not used any medications that affect the CNS or ability to balance (e.g. sedatives, stimulants, benzodiazepines) within 24 hours of testing. Written informed consent was provided prior to participation, in accordance with the Ball State University Institutional Review Board, Muncie, IN.

Equipment

Foot orthotics used in this study were the Powerstep® ProTech Full Length prefabricated orthotics (Remington Products, Inc., Wadsworth, Ohio), which feature a strong polypropylene shell for support, encased in a double-layer Poron®/EVA cushioning and a Poron® heel cushion for shock absorption (Appendix II). The heel
cradle is contoured for neutral fore and rear foot posts to enhance stability. Footwear used for testing was a standardized walking shoe.

Computerized posturography was assessed using a NeuroCom® SMART Balance Master (NeuroCom International, Clackamas, OR) to provide an objective assessment of dynamic postural stability. It is composed of a 45 x 45 cm dual force plate on a rotational axis with the capability to measure vertical forces exerted by a person’s feet via four transducers oriented vertically at each corner of the platform. The force platform was enclosed by a moveable visual surrounding and integrated with software to analyze kinetic balance data.

**Functional stability assessments protocol.** The Fullerton Advanced Balance (FAB) Scale (Appendix III) was used to assess the multiple dimensions of static and dynamic balance (Rose, Lucchese et al. 2006). Each of its ten tasks (e.g. a tandem walk on a straight line and standing on one foot) is scored on an ordinal scale from 0 to 4, totaling a maximum score 40 points. The Timed-Up-and-Go (TUG) test evaluates an individual’s functional mobility. It measures the time the subject takes to rise from a standard arm chair (seat height 47 cm) and walk three meters, return to the chair, and sit back down, as measured by a stopwatch to the nearest hundredth of a second. Score on this test is the time required for task completion, measured in seconds, where lower scores indicate greater functional mobility.

**Limits of Stability assessment protocol.** The Limits of Stability (LOS) test, which has been shown to be a reliable test for evaluating stability limits in eight directions around their center of support (ICCs between 0.69 and 0.91) (Clark, Rose et al. 1997). Each individual’s feet were placed according to the manufacturer’s specifications.
LOS measurements were obtained directly from the NeuroCom software and reported as a percentage of the subjects’ theoretical stability limits, as calculated by the system based on height.

**Postural stability assessment protocol.** Postural sway was assessed in altered and unaltered sensory environments via the Sensory Organization Test (SOT) in the NeuroCom system. The SOT challenges postural stability via sway referencing by altering the availability and/or accuracy of three sources of sensory information from the visual, vestibular and somatosensory systems. Sway referencing synchronizes the rotation of the support surface and/or surroundings with the person’s antero-posterior postural sway, in that as the individual sways forward, the support surface and/or surrounding room sway forward synchronously. The sway-referenced support is used to minimize or alter the accuracy of somatosensory information, whereas the sway-referenced surrounding, which extends beyond the visual periphery, is used to provide inaccurate visual sensory information. These methods reduce the quality of sensory feedback regarding postural sway, thereby challenging postural control (Nashner 1989). The six sensory conditions of the SOT assessed were (1) eyes open with fixed support (Baseline); (2) eyes closed with fixed support (EC); (3) eyes opened with sway-referenced surrounding (EOR); (4) eyes opened with sway-referenced support (EOF); (5) eyes closed with sway-referenced support (ECF); and (6) eyes open with sway-referenced support surface and surroundings (EORF). During postural assessments, the participants’ feet were positioned according the manufacturer’s specification and their arms remained at their sides while looking straight ahead into the visual surrounding room. A safety harness suspended from an overhead beam was worn to support the subject in the case of
loss of balance. Three trials for each sensory condition (i.e., conditions 1-6) were presented in a random, unannounced order, each lasting 20 seconds. The order of the SOT and LOS trials was randomized, but the same randomized order was used for each repeated SOT and LOS assessments. The subjects were not informed of the testing order.

**Gait stability assessment protocol.** The F-scan system used in-shoe pressure sensors (0.18 mm thickness) containing as many as 960 load cells to detect the dynamic pressure gradient across the surface of the foot during ambulation (Tekscan, Inc., South Boston, MA). Sensors were cut to the size and shape of each subject’s shoe and secured to the shoes’ insole or orthotic (depending on orthotic condition) with double-sided tape. Data was collected at a sampling rate of 50 Hz for 12-14 steps at a self-selected pace, preceded by walking time spent to acclimate to temperature changes in the shoe. Subjects were asked to walk with normal pattern and pace for two walking trials, for which first and last steps were omitted and dependent variables averaged in data analysis.

**Testing**

All subjects reported to the testing laboratory on two separate occasions, separated by approximately two weeks (16.9±3.4 days), in order to assess the effect of orthotic use over an acclimation period. Each stability test (the SOT, LOS, TUG, FAB and F-scan) was performed twice on both days of testing; with and without orthotics. The standardized footwear was worn for all stability testing, including the SOT and LOS test, as per Mattacola, et al (2007). For the foot orthotic condition, the shoe insoles were removed and replaced with the orthotics. To eliminate potential learning effects, a familiarization trial was provided for the SOT and LOS tests on both days. The order of
balance testing and orthotic/no orthotic condition was randomized and repeated at follow-up to eliminate effects of testing order or fatigue. Subjects maintained logs of orthotic wear and were required to wear them for a minimum of 8 hours per day until their follow up appointment.

**Measures of Interest**

Force plate data from the NeuroCom® SMART Balance Master were collected at a frequency of 100 Hz. All load cell data was exported for processing using a customized Python program (Python, Python Software Foundation), where it was filtered using a fourth order dual pass zero-phase shift Butterworth filter with a cutoff frequency of 3 Hz. To determine the effect of foot orthotics on balance measures, the filtered data from the SOT were then used to calculate variables of postural stability, including root mean squared COG sway velocity in the ML and AP directions (MLvel, APvel), sway path length (SPL), and sway area (SA). SPL is a measure of the total amount of sway and is the total distance the COG travels in space during the trial. SA is an estimate of the area over which the subject swayed during the trial, a statistically based estimate of an ellipse that encloses 95% of the data points on the COG trajectory calculated using the following equation:

\[
\text{Sway Area} = 2\pi F_{0.05(2,N-2)}\sqrt{s_{AP}^2 s_{ML}^2 - s_{APML}^2}.
\]

In this equation, \(s_{AP}^2\) and \(s_{ML}^2\) represent standard deviation of all AP and ML COG locations during the trial, \(s_{APML}^2\) represents their covariance and \(F_{0.05(2,N-2)}\) is the F statistic at a 95% confidence level with N data points (Stins, Ledebt et al. 2009). Lower values of COG velocity, sway length and sway area indicate greater postural stability.
The number of losses of balance during the SOTs was used to determine if differences in the frequency of falling existed between each of the time-orthotic conditions. A loss of balance was defined as an instance in which an individual altered the position of his/her base of support or fell into the supporting harness.

Measurements of stability limits were obtained directly from the NeuroCom Software and included Endpoint Excursion (EPE), Maximum Excursion (MXE) and Directional Control (DCL). EPE measures the distance of the initial movement toward the designated target whereas MXE is the maximum distance traveled toward the target. DCL compares the amount of movement in the intended direction to total movement. These measures were taken for the forward, backward and medio-lateral (as an average of the right and left) directions, as well as for the composite score reported by the NeuroCom software. Higher scores indicate greater stability limits.

Gait measurements obtained from the F-Scan software included stride time (ST), double leg stance time (DLS), single leg stance time (SLS), %DEV, and for the forefoot, midfoot and rearfoot: peak plantar pressure (PPP), peak force (PF) and mean contact area (MCA). ST is the average time to complete a stride cycle, DLS and SLS are the average time in a double-limbed and single-limbed stance per step, respectively, and %DEV is the percent deviation between time on the right and left limbs. PPP is the peak plantar pressure in the defined area and MCA is the averaged foot-to-ground contact area during gait.
**Statistical Design**

For all statistical testing, the two independent variables were orthotic condition (Without/With orthotics) and time (pre/post). To determine the effects of prefabricated orthotics on postural sway, a 2 (orthotic condition) x 2 (time) x 6 (sensory conditions: BASE, EC, EOR, EOF, ECF, EORF) within-subjects RM-ANOVAs was performed for each of the four dependent variables from the SOT test, including MLvel, APvel, SPL and SA. A chi-square test was used to determine significant differences between the number of total falls on the SOT during the four testing occasions. To determine the effects of orthotics on stability limits, a 2 (orthotic condition) x 2 (time) x 4 (direction: forward, backward, ML and composite) within-subjects RM-ANOVAs was performed for the dependent variables EPE, MXE and DCL. Effects on functional mobility and stability were evaluated with 2 (orthotic condition) x 2 (time) within-subjects RM-ANOVAs for scores on the TUG test and FAB scale. Three, 2 (orthotic condition) x 3 (foot section: forefoot, midfoot, rearfoot) within-subjects RM-ANOVAs were performed on PPP, PF and MCA to determine differences on dynamic gait stability on the F-Scan tests. Four one-way RM-ANOVAs were run for ST, DLS, SLS and %DEV. Follow-up pairwise and mean contrasts and Bonferroni adjustments were performed where appropriate. Additionally, effect sizes were calculated for each dependent variable using Cohen’s d calculations. All statistical analyses were conducted using SPSS statistical software (SPSS, Inc., Chicago, IL).

**Results**
All assessments were completed by each individual participating in the study. Results for balance tests before and immediately following the insertion of the orthotics into the shoes, and after 2-3 weeks of wearing the orthotics are shown in Tables 1-3 and Graphs 1-5 (Appendix III). Participants were instructed to wear the orthotics for a minimum of 8 hours per day after becoming accustomed to the orthotics, and indeed participants wore their orthotics for an average of 8.51 ± 2.98 hours per day during the 2-3 week period.

Clinical Tests of Balance: The TUG Test and FAB Scale

A significant main effect of foot orthotic condition was found for TUG scores (F(1,16)=48.88, p=0.003, d=0.82), such that subjects performed the test more quickly while wearing foot orthotics than when not, both before (8.71 s vs. 9.15 s) and after (9.05 s vs. 9.30 s) the two week acclimation period. Average scores for each condition are depicted in Figure 1.

A significant main effect of foot orthotic condition was also observed for the FAB scale, such that subjects scored higher when wearing orthotics than when not (F(1,16)=12.09, p<0.001, d=1.65), both before (33.4 vs. 35.6) and after (33.7 vs. 36.3) the two week acclimation period. Scores for the FAB scale are shown in Figure 2. No main effects for time or interaction effect were found for either the TUG test or FAB scale (p>0.05).

Postural Stability: The SOT

Frequency of falls was significantly different between the four testing occasions (χ²(3)=9.7, p<0.05), where seven of the eleven total falls occurred during the PreWithout
condition (64%), two falls occurred during the PreWith condition (18%), two falls occurred during the PostWithout condition (18%) and no falls occurred during the PostWith condition. When collapsing frequencies over time, a significant difference was also found between testing occasions with and without orthotics ($\chi^2(1)=4.5$, $p<0.05$), and between the initial and follow up testing occasions ($\chi^2(1)=4.5$, $p<0.05$). The eleven total falls were experienced by only seven of the eighteen subjects; eleven of the subjects did not experience falls. Contrasting between SOT condition, one fall occurred during condition 5 and the remaining ten falls occurred during condition 6 of the SOT.

Figures 3(a)-(d) illustrate summarized data of averaged MLvel, APvel, SPL and SA for each SOT condition. A main effect of time was found for MLvel on conditions 5 and 6 ($F_{(1,16)}=17.97$, $p=0.001$, $d=0.99$; $F_{(1,16)}=7.23$, $p=0.015$, $d=0.63$, respectively) and for the APvel and SPL on condition 6 ($F_{(1,16)}=7.27$, $p=0.021$, $d=0.60$; $F_{(1,16)}=7.26$, $p=0.015$, $d=0.63$). A significant main effect of time was found for SA on condition 3, 5 and 6 ($F_{(1,16)}=4.86$, $p=0.042$, $d=0.52$; $F_{(1,16)}=4.43$, $p=0.05$, $d=0.50$; $F_{(1,16)}=7.34$, $p=0.015$, $d=0.64$, respectively). No main effects for orthotic condition or interaction effects were found for any SOT condition.

Several SOT measures approached significance with notable effect sizes (Table 4), including a main effect of time on MLvel and SPL for condition 2 and on APvel for conditions 1 and 2 ($d=0.38$ to 0.46). Also approaching significance were main effects of orthotic condition on MLvel for conditions 3 and 4, APvel for condition 1 and on SPL for condition 2 ($d=0.35$ to 0.44).
Limits of Stability: LOS Test

There was significant interaction effect for the MXE composite score ($p=0.001$, $F_{(1,16)}=16.47$, $d=0.492$), such that scores on the first day were higher with orthotics (86.9% vs. 84%), but at follow up, scores decreased slightly with orthotic wear (85.2% vs. 84.5%) (Figure 5). There was also a significant main effect of time on DCL for the ML direction and composite score ($F_{(1,16)}=6.11$, $p=0.024$, $d=0.58$; $F_{(1,16)}=4.80$, $p=0.043$, $d=0.52$, respectively). No statistically significant differences were noted for EPE on the LOS test. However, several other main effects approached significance and had correspondingly notable effect sizes (Table 5). For the forward direction, these included a main effect of time on EPE in the forward direction and a main effect of orthotic condition on DCL in the backward direction, EPE and MXE in the forward direction, and EPE composite score ($d=0.36$ to 0.48).

Gait Stability from Plantar Pressure Measures

Figure 6 displays averages of MCA, PPP and PF with and without orthotic use for the forefoot, midfoot and rearfoot. MCA increased significantly for the midfoot and rearfoot ($p=0.001$, $F_{(1,16)}=16.95$, $d=0.97$; $p=0.03$, $F_{(1,16)}=5.44$, $d=.55$). PF significantly decreased for the rearfoot ($p=0.027$, $F_{(1,16)}=5.89$, $d=0.57$), but had a decent effect size for the midfoot as well ($p=0.08$, $F_{(1,16)}=3.37$, $d=0.43$). No significant changes were observed for any of the three foot regions for PPP or for the gait parameter measures of ST, DLS, SLS or %DEV ($p>0.05$).
Discussion

The results of this study indicate that measures of functional mobility and overall functional postural stability can be improved by wearing foot orthotics. Additionally, certain measures of postural stability pointing to specific mechanisms may be improved by wearing the orthotics daily over a time period. The four tests (the TUG test, FAB scale, SOT and LOS test) used to evaluate the effects of prefabricated foot orthotics on balance were chosen for their capability to quantify functional mobility (TUG test and FAB scale), the performance of each sensory system in maintaining postural stability (SOT), and the functional region of stability (LOS test), addressing several different aspects of balance.

Functional Mobility and Stability

Previous research has indicated that with use of custom-made orthotics or arch supports, measures of functional stability can be improved for older adults (Mulford 2008; Gross, Mercer et al. 2012). Specifically, performance on the Berg Balance Scale (similar measurements to the FAB scale) and the TUG test has been shown to improve immediately with use of arch supports and to continue to improve after a 6-week period of wear (Mulford 2008). Results from the present study on the TUG test and FAB scale also indicate that immediate improvements of functional mobility and stability can be made with the use of prefabricated foot orthotics. However, continued statistical improvement was not observed after a 2-3 week acclimation period, indicating no additional improvements in functional mobility after a short acclimation period. Improvements on the FAB scale with orthotics, when present, were typically observed on
the tandem gait test, when subjects were visibly steadier and made fewer missteps while wearing the orthotics (average score improving from 2.4 to 3.6 for the 12 subjects with an original deficit), and on the single-leg stance, when participants were able to hold the stance longer and were again visibly more stable (average score improving from 2.0 to 3.5 for the 9 participants with an original deficit). These tasks are comparable to the tests used on a different study that showed improvements in functional stability with use of customized orthotics for older adults with balance impairments, which evaluated performance on the 1-leg stance test, tandem stance test, tandem gait test and the step test (Gross, Mercer et al. 2012). Similar to the present study, there were no additional improvements at the follow up after four weeks of orthotic wear. It is possible that further improvements may occur with a longer period of acclimation. Further study could consider evaluating balance at longer intervals of multiple months, even up to one year. With both the FAB scale and TUG test shown to be a predictor of faller status in older adults (Hernandez and Rose 2008; Viccaro, Perera et al. 2011), it is apparent that the use of prefabricated orthotics improved performance on both of these assessments. Thus, it can then be presumed that the orthotics may be an effective way to help reduce the risk of falls in older adults.

Though functional performance improved immediately after the insertion of prefabricated foot orthotics, it did not improve any further after a 2-3 week period of orthotic use. Previous studies differ in regards to whether stability measures continue to improve after a period of use (Mulford 2008; Gross, Mercer et al. 2012). The present discrepancy may be due to the difference in length of time orthotics were worn before the
follow-up assessment, which was 2-3 for this study, versus six weeks in the previous (Mulford 2008). However, this seems to be unlikely since there is no indication of movement towards better scores after the acclimation period. It may be that the incongruity with this previous study is due in part to the activity level and health status of the sample populations. In the previous work, 85% of the participants rated their health from fair to good, 40% of the subjects were afraid of falling and 21% had fallen within the past six months. In the present study, subjects were recruited primarily from adult fitness groups, no one had a history of unexplained falls, and reported an average score of 1.4 ± 0.6 on a Likert scale from 1 to 7 when asked how worried they were about falling, where a score of 1 corresponds to not worried at all. The average number of days the subjects of the present study participated in regular physical exercise was 3.4 ± 1.9 days per week, and 33% of subjects rated their health as “excellent”, 55% as “very good”, and 11% as “good”. Healthier subjects having fewer balance difficulties in this study may not have had as large a deficit in postural stability on which to improve as less active subjects in previous studies.

**Postural Stability (SOT and LOS test)**

The decreased frequency in falls on the SOT with foot orthotics suggests that the participants were better able to maintain balance in altered sensory environments while wearing orthotics. This lower frequency of falls at both appointments is not likely to be attributable to a learning effect since the order of foot orthotic condition (whether tested first with or without orthotics) was randomized between subjects. These findings provide
additional evidence that foot orthotics may decrease the risk of loss of balance in older adults.

When assessing the efficacy of foot orthotics in altered sensory environments, the only significant changes were with respect to time and occurred mostly in the more challenging sensory conditions (5 and 6). It is suspected that these significant changes may be partially due to a learning effect since the improvements occurred on conditions which do not challenge somatosensory input. Since orthotics are expected to improve stability by increasing somatosensory input, improvements due to the orthotics would be expected on conditions incorporating somatosensory information, but this was not the case. However, because the SOT has been shown to be fairly reliable with a familiarization trial (Ford-Smith, Wyman et al. 1995), it may be that the foot orthotics actually did improve the function of the balance system, particularly in challenging sensory environments. These proposed improvements due to orthotics maybe attributed to increased structural support with the orthotics rather than increased tactile stimulation. On the other hand, several variables of sway velocity and SPL for conditions 1-3, which allow unaltered somatosensory input, show notable mild to moderate effect sizes (0.35<d<0.46) for the effect of foot orthotic wear, suggesting improvement for several balance measures with orthotic use. Given the general trend of improved balance performance, there is preliminary evidence that use of prefabricated foot orthotics improve overall postural control.

The interaction effect observed for composite MXE score is difficult to interpret. The improved scores with orthotics on the first day was not replicated on the second day,
when scores with and without orthotics were similar. It could be that the prolonged use of orthotics led to a more rigid base of support. Alternatively, the differing trends could be due to extraneous causes, such as different testing strategies at follow-up. It was hypothesized that the use of orthotics would improve the overall measures of volitional stability through improved performance on the LOS test. This, however, was not supported by the data in that there were no significant main effects with orthotic use on any of the LOS measures. However, there were moderate effect sizes for foot orthotic condition, such as for EPE composite score (representing all directions) and EPE and MXE in the forward direction. Because EPE is an indirect measure of confidence in the control of balance, this may indicate that older adults feel more stable when wearing the orthotics and are thereby more confident shifting their COG to their stability limits.

As suggested earlier, it is suspected that a lack of concrete significant findings on the SOT and LOS may be due to the good health, activity level, and balance status of the sample population. A healthy sample population with no history of falling was used as a conservative approach in order to apply findings to the general population that foot orthotics may be an effective measure to prevent the occurrence of falls. Previous studies have focused on populations suffering balance deficits, such as those with chronic ankle instability (Hamlyn, Docherty et al. 2012) or ankle sprain (Hertel, Denegar et al. 2001) and identify improvements with foot orthotics in measurements of postural control that are similar to those measured on the SOT. In these and other studies, improvements were seen only in the impaired groups, not in the unimpaired groups. As several SOT and LOS measures in the present study showed trends towards significant improvement with
moderate effect sizes (Table 4 and 5), future studies should assess the impact of prefabricated orthotics in a more at-risk population. It may also be beneficial to target older populations with specific foot types, such as those with malalignments (Mattacola, Dwyer et al. 2007). For such subjects, prefabricated foot orthotics designed for specific foot types may better realign the foot into a more stable position for more optimal postural control.

**Mechanism of Improvement**

Similar to previous authors (Mattacola, Dwyer et al. 2007; Sesma, Mattacola et al. 2008), we believe that two factors may have contributed to improved functional and postural stability. Orthotics increase support to the arches of the feet which increases stability of the base of support and also increase the ground-to-foot contact area. This theory is supported by the results of the plantar pressure analysis, which show increased surface area contact between the foot and the ground in the midfoot and rearfoot regions. Increasing surface area contact increases the tactile stimulation of the plantar foot surface and thus it is believed that foot orthotics improve somatosensory input to the balance system. Additionally, previous investigation has shown that an insole with a raised perimeter improves stability during gait and lowers fall frequency (Perry, Radtke et al. 2008). Similarly, the edges of the tested prefabricated orthotic and rim of the heel cup may have played a part in increasing somatosensory input. Plantar pressure analysis also indicated a redistribution of force in the midfoot and rearfoot that decreased the peak force applied to those sections of the foot. This force redistribution may contribute to improved support to the foot structure. These findings, specifically increased contact
area and a corresponding redistribution of force, are in agreement with previous research that has identified similar effects of prefabricated orthotics in older adults (Bonanno, Landorf et al. 2011). Both of these factors, namely improving base of support stability and somatosensory input, are suspected to contribute to the observed improvements in functional and postural stability.

**Conclusions**

The current study explored the effects of prefabricated foot orthotics on functional and postural stability of healthy older adults. It was found that prefabricated foot orthotics improved functional mobility and stability, as well as trends toward increases in postural stability and overall region of stability. Therefore, prefabricated foot orthotics use may be a viable and more economical approach to decrease the risk of injurious falls in older adults than customized foot orthotics investigated in previous research.

**Acknowledgements**

Special thanks to the Ball State Biomechanics Laboratory and to the ASPIRE Grant.
References


Hernandez, D., & Rose, D. J. (2008). Predicting which older adults will or will not fall using the Fullerton Advanced Balance scale. *Arch Phys Med Rehabil, 89*(12), 2309-2315.


Chapter 4: Summary and Future Recommendations

Summary

Accidental falls present a huge problem in the US, where one in three older adults aged 65 and older experience falls each year. Falls lead to a myriad of physical, emotional, social and financial consequences, so the need for ways to decrease the risk of falls in older adults becomes paramount, especially in light of the large baby-boomer population reaching retirement age. The correlation between fall risk and poor postural stability has been well documented in literature, so methods to improve older adults’ postural stability could potentially lead to a decrease in fall incidences and a higher quality of life. Foot orthoses have been a tool investigated to improve balance in populations suffering a balance deficit, such as individuals with chronic ankle instability, but additional research is necessary to better understand the efficacy of orthoses to improve balance control in older adults. The purpose of this study was to determine the
effects of prefabricated foot orthotic use on functional and postural stability measures in older adults.

A group of adults age of 65 and up completed four balance tests and plantar pressure sensor analysis while wearing prefabricated foot orthotics and while wearing just shoes, both before and following a two-week period of daily orthotic wear. Improvements with the use of orthotics were observed on two functional stability tests that evaluated mobility and stability on tasks similar to those faced in daily life. Fewer falls also occurred on the SOT while wearing foot orthotics than when not and several time-based improvements were seen on the more challenging conditions of the SOT after wearing the orthotics for a 2-3 week period. Trends towards improvements with reasonable effect sizes for sway variables in sensory conditions involving somatosensory input were also noted. Improvements in measures of LOS occurred in DCL, indicating better control over posture. Plantar pressure analysis revealed increased contact area in the midfoot and rearfoot regions with orthotic use, which supports the theory that the observed changes in balance with use of orthotics is due to increased somatosensory input to the central nervous system. Pooled together, the changes observed in the present study provide evidence that prefabricated foot orthotics can enhance balance control in the elderly.

**Future Recommendations**

The sample population of this study included healthy and active older adults and therefore the results should be generalized specifically to this population. It is suspected that more significant and pronounced effects of prefabricated foot orthotics would have
been observed had a frailer, at-risk sample of elderly participants been investigated. Expanding this research to such a population is a potential direction for future study. Additionally, the investigated prefabricated foot orthotic was chosen to represent other prefabricated orthotics. However, it may be that prefabricated orthotics with specific alterations (e.g. with posting) would be more appropriate for individuals with certain foot typing. Future studies should also consider addressing foot typing in the administration of specific variations of prefabricated foot orthotics. Additionally, for some subjects, fatigue may have played a factor in balance performance testing due to the number of tests performed at each appointment, possibly confounding the results of this study. The length of time required to complete balance assessments should be a consideration in the experimental design of future study as well.


Appendix I

Ball State University  Health/Activity Information (OA)

Biomechanics Laboratory - Physical Education, Sport & Exercise Sciences

Name  ____________________________________________

Address __________________________ City __________ State ____ Zip ________

Home Phone # ____________________ Gender: Male ___ Female ____

Age: _____ Year of birth: ________

Ethnicity _______________ Highest level of education completed ________________

Whom to contact in a case of emergency ____________________ Ph# ______________

Name of your physician ___________________ Phone # ______________

2. Have you ever been diagnosed as having any of the following conditions?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Yes (✓)</th>
<th>Year of Onset</th>
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<tbody>
<tr>
<td>Heart attack</td>
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<tr>
<td>Transient ischemic attack</td>
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<td>Angina (chest pain)</td>
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<td>High blood pressure</td>
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<td>Stroke</td>
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<td>Peripheral vascular disease</td>
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<tr>
<td>Diabetes</td>
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<td>Condition</td>
<td>Frequency</td>
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<tr>
<td>Neuropathies</td>
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<td>(problems with sensations)</td>
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<tr>
<td>Respiratory disease</td>
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<td>Parkinson’s disease</td>
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<td>Multiple sclerosis</td>
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<td>Polio/Post polio syndrome</td>
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<tr>
<td>Epilepsy/seizures</td>
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<td>Other neurological conditions</td>
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<td>Osteoporosis</td>
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<td>Rheumatoid arthritis</td>
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<td>Other arthritic conditions</td>
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<td>Visual/depth perception problems</td>
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<td>Inner ear problems</td>
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<td>Recurrent ear infections</td>
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<tr>
<td>Cerebellar problems (ataxia)</td>
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<tr>
<td>Other movement disorders</td>
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<td>Other vestibular disorders</td>
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<td>Chemical dependency</td>
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<td>(alcohol and/or drugs)</td>
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<td>Depression</td>
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<td>Cancer</td>
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<tr>
<td>Joint replacement</td>
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<tr>
<td>If YES, describe what kind</td>
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</table>

If YES, describe what kind.
If YES, which joint (e.g. knee, hip) and side (left or right) ________________________________

Cognitive condition ____________
(examples: difficulties with reasoning, memory, perception)
If YES describe condition ____________________________________________________________

Uncorrected visual problems ____________
If YES, describe type ________________________________________________________________

Any other type of health problem?
__________________________________________________________
If YES, describe condition: __________________________________________________________

3. Do you currently suffer any of the following symptoms in your legs or feet? Yes (✓)

Numbness ____________
Tingling ____________
Arthritis ____________
Swelling ____________

4. Do you currently have any medical conditions for which you see a physician regularly? YES or NO

If YES, please describe the condition(s) ________________________________________________
__________________________________________________________
__________________________________________________________

5. Do you require eyeglasses? YES or NO

6. Do you require hearing aids? YES or NO
7. Do you use an assistive device for walking? YES or NO or Sometimes

If so, what type?__________________________________________________________

8. List all medications that you currently take (including ‘over-the-counter’ medications)

<table>
<thead>
<tr>
<th>Type of medication</th>
<th>For what condition?</th>
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</table>

9. Have you required emergency medical care or hospitalization in the last three years? YES or NO

If YES, please list when this occurred and briefly explain why.

________________________________________________________________________

10. Have you suffered any injury to the head or lower extremities in the past year? YES or NO

If YES, please list when this occurred and briefly explain condition or injury.

________________________________________________________________________

10. Have you ever had any condition or suffered any injury that has affected you balance or ability to walk without assistance? YES or NO

If YES, please list when this occurred and briefly explain condition or injury.

________________________________________________________________________

11. How many times have you fallen within the past year? ______

Did you require medical treatment? YES or NO

If YES to either question, please list the approximate date of the fall, the medical treatment required and the reason you fell in each case (e.g., uneven surface, going down stairs, etc.).

________________________________________________________________________

________________________________________________________________________
12. Are you worried about falling? (Circle a number below)

1 - not  2 - a little  3 - moderately  4 - very  5 - extremely

13. Do you have any history of unexplained falls or dizziness? **YES** or **NO**
If **YES**, please explain.

14. How would you describe your health?

_____ Excellent  _____ Very good  _____ Good  _____ Fair  _____ Poor

15. In the past 4 weeks, to what extent did health problems limit your everyday physical activities (such as walking and household (indoor or outdoor chores)?

Not at all  _____ Slightly  _____ Moderately  _____ Quite a bit  _____
Extremely  _____

16. How much "bodily pain" have you generally had during the past 4 weeks? (While doing normal activities of daily living):

None  _____ Very little  _____ Moderate  _____ Quite a bit  _____
Severe  _____

17. In general, how much depression have you experienced within the past 4 weeks?

None at all  _____ Slight  _____ Moderate  _____ Quite a bit  _____
Extreme  _____

18. In general, how would you rate the quality of your life? (Circle the appropriate number)

1 - very low  2 - low  3 - moderate  4 - high  5 - very high

19. Please indicate you ability to do each of the following (**circle appropriate response**).
a. Take care of own personal needs--like dressing yourself 2 1 0

b. Bathe yourself, using tub or shower 2 1 0
c. Climb up and down a flight of stairs 2 1 0
(like to a second story in a house)
d. Walk outside one or two blocks 2 1 0
e. Do light household activities -- like cooking, cleaning the shed, washing dishes, sweeping a walkway 2 1 0
f. Do your own shopping for groceries or clothes 2 1 0
g. Walk 1/2 mile (6-7 blocks) 2 1 0
h. Walk 1 mile (12-14 blocks) 2 1 0
i. Lift and carry 10 pounds (full bag of groceries) 2 1 0
j. Lift and carry 25 pounds (medium to large suitcase) 2 1 0
k. Do most heavy household chores -- like scrubbing floors 2 1 0
vacuuming, raking leaves
l. Do strenuous activities -- like hiking, digging in garden, moving heavy objects, bicycling, aerobic dance exercises strenuous calisthenics, etc. 2 1 0

19. In general, do you currently require household or nursing assistance to carry out daily activities? YES or NO
If yes, please check the reasons(s)?

   a. Health problems ___
   b. Chronic pain ___
   c. Lack of strength or endurance ___
   d. Lack of flexibility or balance ___
   e. Other reasons: _______________________________________

20. In a typical week, how often do you leave your house? (to run errands, go to work, go to meetings, classes, church, social functions, etc.)

   _____ less than once/week   _____ 3-4 times/week
   _____ 1-2 times/week   _____ most every day
21. Do you currently participate in regular physical exercise (such as walking, sports, exercise classes, house work or yard work) that is strenuous enough to cause a noticeable increase in breathing, heart rate, or perspiration?

Yes ____  No _____  If yes, how many days per week?

One ____  Two ___ Three ___  Four ___  Five ___  Six ___  Seven ___

22. When you go for walks (if you do), which of the following best describes your walking pace:

_____ Strolling (easy pace, takes 30 min. or more to walk a mile)
_____ Average or normal (can walk a mile in 20-30 minutes)
_____ Fairly brisk (fast pace, can walk a mile in 15-20 minutes)
_____ Do not go for walks on a regular basis

23. Approximately how long has it been since your last meal?  ___________

24. If you smoke, how long has it been since your last cigarette/cigar/pipe/chewing tobacco?  ___________

25. Approximately how long has it been since you consumed any caffeine?

(e.g., cola drinks, coffee, chocolate milk or hot chocolate, energy drinks)  ___________

26. Did you require assistance in completing this form?

None (or very little) _____ Needed quite a bit of help ______

Reason: __________________________

Thank You!
Appendix II

PowerStep ProTech Full Length Orthotic used for testing
Fullerton Advanced Balance (FAB) Scale Scoring Form

Subject #: ____________________________
Date of Test: ________________________

Test Equipment: Stop watch; 36” ruler; pen or pencil; 6” bench; metronome; 2 airex pads and one or more 12 inch lengths of non-slip material.

1. Standing with Feet Together and Eyes Closed.

   Equipment: None
   Verbal Instructions: “Bring your feet together, and fold your arms across your chest. Close your eyes when you are ready and remain as steady as possible until I instruct you to open your eyes.”
   Grading: Please mark the lowest category that applies.

   (0) Unable to obtain the correct standing position independently.
   (1) Able to obtain the correct standing position independently but unable to maintain the position or keep the eyes closed for more than 10 seconds.
   (2) Able to maintain the correct standing position with eyes closed for more than 10 seconds but less than 30 seconds.
   (3) Able to maintain the correct standing position with eyes closed for 30 seconds but requires close supervision.
   (4) Able to maintain the correct standing position with eyes closed for 30 seconds safely.

   Additional Comments _____________________________________________________________

2. Reaching Forward to Retrieve an Object (pencil) Held at Shoulder Height with Outstretched Arm.

   Equipment: Pencil, 12 inch ruler
   Verbal Instructions: “Try and lean forward to take the pencil from my hand and return to your starting position without moving your feet from their present position.”
   Grading: Please mark the lowest category that applies.

   (0) Unable to reach the pencil without taking more than 2 steps.
   (1) Able to reach the pencil but needs to take 2 steps.
   (2) Able to reach the pencil but needs to take 1 step.
   (3) Can reach the pencil without moving the feet but requires supervision.
   (4) Can reach the pencil safely and independently without moving the feet.

   Additional Comments _____________________________________________________________
3. Turn 360 Degrees in a Right and Left Direction.

**Equipment:** None.

**Verbal Instructions:** “Turn around in a full circle, **pause**, then turn in a second full circle in the opposite direction.”

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

(0) Needs manual assistance while turning.
(1) Needs close supervision or verbal cueing while turning.
(2) Able to turn 360 degrees but takes more than 4 steps in both directions.
(3) Able to turn 360 degrees but unable to complete in 4 steps or less in one direction.
(4) Able to turn 360 degrees safely and takes 4 steps or less in both directions.

Additional Comments ________________________________________________________________

4. Step Up and Over a 6” Bench

**Equipment:** 6 inch high bench. (18 X 18 inch stepping surface)

**Verbal Instructions:** “Step up onto the bench with your right leg; swing your left leg directly up and over the bench and step off the other side. Repeat in the opposite direction with your left leg as the leading leg.”

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

(0) Unable to step onto the bench without loss of balance or manual assistance.
(1) Able to step up onto the bench with lead leg but trailing leg contacts bench or swings around the bench during swing-through phase in both directions.
(2) Able to step up onto the bench with lead leg but trailing leg contacts bench or swings around bench during swing-through phase in one direction.
(3) Able to correctly complete the step up and over in both directions but requires close supervision in one or both directions.
(4) Able to correctly complete the step up and over in both directions safely and independently.

Additional Comments ________________________________________________________________

5. Tandem Walk

**Equipment:** Masking tape.

**Verbal Instructions:** “Walk forward along the line, placing one foot directly in front of the other such that the heel and toe are in contact on each step forward. I will tell you when to stop”.

**Grading:** Please mark the lowest category that applies. An interruption refers to a lateral step, failure to achieve heel-toe position on certain steps, or loss of balance.
(0) Unable to complete 10 steps independently.
(1) Able to complete the 10 steps with more than 5 interruptions.
(2) Able to complete the 10 steps with 5 or less interruptions.
(3) Able to complete the 10 steps with 2 or less interruptions.
(4) Able to complete the 10 steps independently and with no interruptions.

Additional Comments

6. Standing on One Leg

Equipment: Stopwatch.
Verbal Instructions: “Fold your arms across the chest, lift your preferred leg off the floor (without touching your other leg), and stand with eyes open as long as you can.
Grading: Please mark the lowest category that applies.

(0) Unable to try or needs assistance to prevent falling.
(1) Able to lift leg independently but unable to maintain position for more than 5 seconds.
(2) Able to lift leg independently and maintain position for at least 5 but less than 12 seconds.
(3) Able to lift leg independently and maintain position for at least 12 but less than 20 seconds.
(4) Able to lift leg independently and maintain position for the full 20 seconds.

Additional Comments

7. Standing on Foam with Eyes Closed

Equipment: Stopwatch; two Airex™ pads with one length of non-slip material placed between the two pads and one additional length of non-slip material between the floor and first pad if the test is being performed on a non-carpeted surface.
Verbal Instructions: “Step up onto the foam and stand with feet shoulder width apart. Fold your arms over your chest, and close your eyes when you are ready. I will tell you when to open your eyes.”
Grading: Please mark the lowest category that applies.

(0) Unable to step onto foam and/or maintain standing position independently with eyes open.
(1) Able to step onto foam independently and maintain standing position but unable or unwilling to close eyes.
(2) Able to step onto foam independently and maintain standing position with eyes closed for 10 seconds or less.
(3) Able to step onto foam independently and maintain standing position with eyes closed for more than 10 seconds but less than 20 seconds.
(4) Able to step onto foam independently and maintain standing position with eyes closed for 20 seconds.

Additional Comments ________________________________________________

8. Two-footed Jump for Distance

**Equipment:** 36 inch ruler; piece of masking tape.
**Verbal Instructions:** “Try and jump with two feet as far but as safely as you can”.
**Grading:** Please mark the lowest category that applies.

(0) Unable to attempt or attempts to initiate two-footed jump but one or both feet do not leave the floor.
(1) Able to initiate two-footed jump but one foot either leaves the floor or lands before the other.
(2) Able to perform two-footed jump but unable to jump further than the length of their own feet.
(3) Able to perform two-footed jump and achieve a distance greater than the length of their own feet.
(4) Able to perform two-footed jump and achieve a distance greater than twice the length of their own feet.

Additional Comments ________________________________________________

9. Walk with Head Turns

**Equipment:** Metronome set at 100 beats per minute.
**Verbal Instructions:** “Walk forward while turning your head from left to right with each beat of the metronome. I will tell you when to stop.”
**Grading:** Please mark the lowest category that applies.

(0) Unable to walk 10 steps independently while maintaining 30 degree head turns at an established pace.
(1) Able to walk 10 steps independently but unable to complete required number of 30 degree head turns at an established pace.
(2) Able to walk 10 steps but veers from a straight line while performing 30 degree head turns at an established pace.
(3) Able to walk 10 steps in a straight line while performing 30 degree head turns at an established pace but head turns less than 30 degrees in one or both directions.
(4) Able to walk 10 steps in a straight line while performing required number of 30 degree head turns at established pacing.

Additional Comments ________________________________________________
10. Reactive Postural Control

Equipment: None.
Verbal Instructions: “Slowly lean back into my hand until I ask you to stop.”
Grading: Please mark the lowest category that applies.

(0) Unable to maintain upright balance, no observable attempt to step- requires manual assistance to restore balance.
(1) Unable to maintain upright balance, takes two or more 2 steps and requires manual assistance to restore balance.
(2) Unable to maintain upright balance, takes two or more 2 steps but is able to restore balance independently.
(3) Unable to maintain upright balance, takes 1-2 steps but is able to restore balance independently.
(4) Unable to maintain upright balance, but is able to restore balance independently with one step only.

TOTAL SCORE = /40
Table 1. Functional Stability Tests Results

<table>
<thead>
<tr>
<th></th>
<th>PreW/O (SD)</th>
<th>PreW/ (SD)</th>
<th>PostW/O (SD)</th>
<th>PostW/ (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timed Up and Go (sec)</td>
<td>9.15 (1.96)</td>
<td>8.71 (1.73)</td>
<td>9.30 (1.77)</td>
<td>9.05 (1.88)</td>
</tr>
<tr>
<td>Fullerton Advanced Balance Scale Score (FAB)</td>
<td>33.44 (3.01)</td>
<td>35.56 (2.72)</td>
<td>33.67 (4.00)</td>
<td>36.28 (3.14)</td>
</tr>
</tbody>
</table>

Note: Possible range for the FAB scale is 0-40, where higher scores indicate better balance.
Table 2. Limits of Stability Test Results

<table>
<thead>
<tr>
<th>LOS Measure</th>
<th>Direction</th>
<th>PreW/O (SD)</th>
<th>PreW/ (SD)</th>
<th>PostW/O (SD)</th>
<th>PostW/ (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPE (%)</td>
<td>M-L</td>
<td>79.9 (9.3)</td>
<td>82.4 (6.4)</td>
<td>81.4 (11.3)</td>
<td>83.2 (10.7)</td>
</tr>
<tr>
<td></td>
<td>Forward</td>
<td>54.7 (9.6)</td>
<td>55.7 (8.2)</td>
<td>56.9 (13.3)</td>
<td>63.0 (10.9)</td>
</tr>
<tr>
<td></td>
<td>Backward</td>
<td>49.2 (11.8)</td>
<td>52.9 (12.5)</td>
<td>53.9 (13.7)</td>
<td>50.9 (13.8)</td>
</tr>
<tr>
<td></td>
<td>Composite</td>
<td>66.1 (7.1)</td>
<td>68.5 (6.4)</td>
<td>68.5 (9.3)</td>
<td>70.2 (8.3)</td>
</tr>
<tr>
<td>MXE (%)</td>
<td>M-L</td>
<td>96.4 (8.56)</td>
<td>99.2 (7.0)</td>
<td>96.9 (8.6)</td>
<td>95.3 (9.6)</td>
</tr>
<tr>
<td></td>
<td>Forward</td>
<td>72.3 (10.5)</td>
<td>73.7 (9.6)</td>
<td>70.5 (12.7)</td>
<td>75.3 (10.7)</td>
</tr>
<tr>
<td></td>
<td>Backward</td>
<td>70.3 (15.6)</td>
<td>74.8 (13.8)</td>
<td>75.9 (12.8)</td>
<td>71.8 (16.6)</td>
</tr>
<tr>
<td></td>
<td>Composite</td>
<td>84.0 (6.8)</td>
<td>86.9 (6.0)</td>
<td>85.2 (6.4)</td>
<td>84.5 (7.1)</td>
</tr>
<tr>
<td>DCL (%)</td>
<td>M-L</td>
<td>79.4 (4.6)</td>
<td>79.4 (5.6)</td>
<td>80.4 (4.6)</td>
<td>81.5 (4.4)</td>
</tr>
<tr>
<td></td>
<td>Forward</td>
<td>81.4 (5.8)</td>
<td>78.1 (7.9)</td>
<td>80.7 (6.5)</td>
<td>81.1 (8.3)</td>
</tr>
<tr>
<td></td>
<td>Backward</td>
<td>68.6 (9.9)</td>
<td>70.4 (10.6)</td>
<td>69.3 (8.9)</td>
<td>72.9 (7.0)</td>
</tr>
<tr>
<td></td>
<td>Composite</td>
<td>77.4 (5.1)</td>
<td>77.0 (6.0)</td>
<td>77.8 (5.1)</td>
<td>79.4 (4.5)</td>
</tr>
</tbody>
</table>
Table 3. Sensory Organization Test Results

<table>
<thead>
<tr>
<th>Measure</th>
<th>Cond</th>
<th>PreW/O (SD)</th>
<th>PreW/ (SD)</th>
<th>PostW/O (SD)</th>
<th>PostW/ (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>0.219 (.086)</td>
<td>0.245 (.116)</td>
<td>0.240 (.109)</td>
<td>0.209 (.066)</td>
</tr>
<tr>
<td>MLvel (deg/s)</td>
<td>2</td>
<td>0.326 (.097)</td>
<td>0.346 (.155)</td>
<td>0.335 (.139)</td>
<td>0.288 (.100)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.272 (.085)</td>
<td>0.267 (.084)</td>
<td>0.268 (.116)</td>
<td>0.242 (.082)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.337 (.104)</td>
<td>0.316 (.106)</td>
<td>0.307 (.118)</td>
<td>0.299 (.103)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.557 (.148)</td>
<td>0.532 (.204)</td>
<td>0.496 (.143)</td>
<td>0.471 (.137)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.547 (.218)</td>
<td>0.534 (.245)</td>
<td>0.453 (.149)</td>
<td>0.458 (.134)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.634 (.193)</td>
<td>0.638 (.229)</td>
<td>0.743 (.307)</td>
<td>0.637 (.142)</td>
</tr>
<tr>
<td>APvel (deg/s)</td>
<td>2</td>
<td>1.213 (.426)</td>
<td>1.282 (.447)</td>
<td>1.427 (.558)</td>
<td>1.334 (.530)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.976 (.273)</td>
<td>0.930 (.297)</td>
<td>0.993 (.365)</td>
<td>0.941 (3.30)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.360 (.458)</td>
<td>1.295 (.523)</td>
<td>1.308 (.579)</td>
<td>1.230 (.401)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2.641 (.762)</td>
<td>2.612 (1.088)</td>
<td>2.678 (.883)</td>
<td>2.443 (.943)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2.706 (.630)</td>
<td>2.632 (.636)</td>
<td>2.421 (.691)</td>
<td>2.454 (.732)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>23.06 (6.97)</td>
<td>23.72 (9.14)</td>
<td>26.72 (10.52)</td>
<td>23.07 (5.25)</td>
</tr>
<tr>
<td>SPL (cm)</td>
<td>2</td>
<td>42.43 (13.99)</td>
<td>45.17 (16.68)</td>
<td>49.10 (18.43)</td>
<td>45.87 (17.86)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>34.34 (9.19)</td>
<td>32.88 (9.97)</td>
<td>34.87 (13.11)</td>
<td>32.93 (11.29)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>47.05 (14.18)</td>
<td>44.69 (17.17)</td>
<td>45.04 (18.82)</td>
<td>42.55 (13.36)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>90.08 (24.16)</td>
<td>89.01 (36.31)</td>
<td>90.67 (29.05)</td>
<td>82.96 (31.09)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>92.16 (22.58)</td>
<td>89.64 (22.25)</td>
<td>81.98 (23.97)</td>
<td>83.07 (24.56)</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.80 (1.43)</td>
<td>2.51 (3.56)</td>
<td>2.29 (2.51)</td>
<td>1.83 (1.42)</td>
</tr>
<tr>
<td>SA (cm²)</td>
<td>2</td>
<td>4.07 (2.69)</td>
<td>4.29 (4.72)</td>
<td>4.18 (3.11)</td>
<td>4.22 (3.62)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3.70 (1.97)</td>
<td>3.49 (3.47)</td>
<td>3.09 (2.46)</td>
<td>3.01 (2.01)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5.35 (2.99)</td>
<td>5.85 (3.79)</td>
<td>4.90 (2.65)</td>
<td>4.94 (2.74)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>14.04 (7.19)</td>
<td>14.13 (8.39)</td>
<td>11.59 (4.67)</td>
<td>11.95 (5.64)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>19.84 (14.08)</td>
<td>17.85 (8.05)</td>
<td>13.62 (5.99)</td>
<td>13.70 (6.43)</td>
</tr>
</tbody>
</table>
Table 4. P values and Cohen’s d values, pvalue(d), for main effects of time (ME time) and orthotic condition (ME FOcond) from the SOT for MLvel, APvel, SPL and SA on SOT conditions 1-6. Bolded values indicate significance or nearing significance.

<table>
<thead>
<tr>
<th>SOT</th>
<th>MLvel</th>
<th>APvel</th>
<th>SPL</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME Time</td>
<td>ME FOcond</td>
<td>ME Time</td>
<td>ME FOcond</td>
</tr>
<tr>
<td>1</td>
<td>0.545 (.146)</td>
<td>0.775 (.068)</td>
<td><strong>0.113 (.394)</strong></td>
<td><strong>0.077 (.444)</strong></td>
</tr>
<tr>
<td>2</td>
<td><strong>0.100 (.410)</strong></td>
<td>0.430 (.190)</td>
<td><strong>0.068 (.460)</strong></td>
<td><strong>0.122 (.384)</strong></td>
</tr>
<tr>
<td>3</td>
<td>0.356 (.223)</td>
<td><strong>0.130 (.375)</strong></td>
<td>0.813 (.056)</td>
<td>0.306 (.249)</td>
</tr>
<tr>
<td>4</td>
<td>0.194 (.319)</td>
<td><strong>0.155 (.351)</strong></td>
<td>0.470 (.174)</td>
<td>0.367 (.218)</td>
</tr>
<tr>
<td>5</td>
<td><strong>0.001 (.999)</strong></td>
<td>0.419 (.195)</td>
<td>0.526 (.153)</td>
<td>0.475 (.172)</td>
</tr>
<tr>
<td>6</td>
<td><strong>0.015 (.634)</strong></td>
<td>0.856 (.043)</td>
<td><strong>0.021 (.602)</strong></td>
<td>0.759 (.073)</td>
</tr>
</tbody>
</table>
Table 5. P values and Cohen’s d values, pvalue(d), for main effects of time (ME time) and orthotic condition (ME FOcond) from the LOS test for the ML, FWD and BWD directions and COMP score for EPE, MXE and DCL. Bolded values indicate significance or nearing significance.

<table>
<thead>
<tr>
<th></th>
<th>ML</th>
<th></th>
<th></th>
<th></th>
<th>FWD</th>
<th></th>
<th></th>
<th></th>
<th>BWD</th>
<th></th>
<th></th>
<th>COMP</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ME</td>
<td>FOcond</td>
<td>ME</td>
<td>FOcond</td>
<td>ME</td>
<td>FOcond</td>
<td>ME</td>
<td>FOcond</td>
<td>ME</td>
<td>FOcond</td>
<td>ME</td>
<td></td>
<td>FOcond</td>
</tr>
<tr>
<td>EPE</td>
<td>0.589</td>
<td>(.130)</td>
<td>0.264</td>
<td>(.272)</td>
<td>0.085</td>
<td>(.431)</td>
<td>0.088</td>
<td>(.426)</td>
<td>0.626</td>
<td>(.117)</td>
<td>0.837</td>
<td>(.040)</td>
<td>0.283</td>
</tr>
<tr>
<td></td>
<td>(.273)</td>
<td>(.094)</td>
<td>0.98</td>
<td>(.006)</td>
<td>0.141</td>
<td>(.364)</td>
<td>0.677</td>
<td>(.100)</td>
<td>0.936</td>
<td>(.019)</td>
<td>0.532</td>
<td>(.150)</td>
<td>0.18</td>
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<tr>
<td>MXE</td>
<td>0.264</td>
<td>(.273)</td>
<td>0.694</td>
<td>(.094)</td>
<td>0.98</td>
<td>(.006)</td>
<td>0.141</td>
<td>(.364)</td>
<td>0.677</td>
<td>(.100)</td>
<td>0.936</td>
<td>(.019)</td>
<td>0.532</td>
</tr>
<tr>
<td>DCL</td>
<td>0.024</td>
<td>(.582)</td>
<td>0.396</td>
<td>(.254)</td>
<td>0.402</td>
<td>(.203)</td>
<td>0.185</td>
<td>(.326)</td>
<td>0.297</td>
<td>(.254)</td>
<td>0.06</td>
<td>(.475)</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>(.254)</td>
<td>(.203)</td>
<td>0.402</td>
<td>(.203)</td>
<td>0.185</td>
<td>(.326)</td>
<td>0.297</td>
<td>(.254)</td>
<td>0.06</td>
<td>(.475)</td>
<td>0.043</td>
<td>(.517)</td>
<td>0.248</td>
</tr>
</tbody>
</table>
Table 6. P values and Cohen’s d values, pvalue(d) for Fscan analysis on MCA, PPP and PF for the forefoot, midfoot and rearfoot. Bolded values indicate significance or nearing significance.

<table>
<thead>
<tr>
<th></th>
<th>Forefoot</th>
<th>Midfoot</th>
<th>Rearfoot</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCA</td>
<td>0.088 (0.42)</td>
<td>0.001 (0.97)</td>
<td>0.032 (0.55)</td>
</tr>
<tr>
<td>PPP</td>
<td>0.866 (0.04)</td>
<td>0.715 (0.08)</td>
<td>0.222 (0.3)</td>
</tr>
<tr>
<td>PF</td>
<td>0.755 (0.074)</td>
<td>0.084 (0.43)</td>
<td>0.027 (0.57)</td>
</tr>
</tbody>
</table>
Figure 1. Averages values for the TUG test for each testing occasion. * TUG time was significantly lower when foot orthotics were worn.
Figure 2. Average scores on the FAB scale for each testing occasion. * FAB score was significantly greater (improved) when foot orthotics were worn.
Figure 3. SOT results, including average values and standard deviations for (a) ML velocity, (b) AP velocity, (c) Sway Path Length and (d) SA before a 2-3 week intervention period and after, both with and without foot orthotic use.

(a) * ML velocity was significantly lower at follow-up than at the initial assessment on conditions 3 and 6.
(b) * AP velocity significantly decreased at follow-up compared to the initial appointment for condition 6.
(c) * Sway Path Length significantly decreased at follow-up compared to the initial assessment for condition 6.
(d) * Sway Area was significantly decreased at follow-up compared to the initial assessment for conditions 3, 5 and 6.
Figure 4. Average scores for the LOS test, expressed as (a) Endpoint Excursion, (b) Maximum Excursion and (c) Directional Control, before a 2-3 week intervention period and after, both with and without foot orthotic use.
(b) * An interaction effect occurred for Maximum Excursion Composite score; the effect of foot orthotic condition differed based on time of assessment
(c) * Directional Control significantly improved at follow-up in the M-L direction and for composite score.
Figure 5. Interaction effect for MXE composite score of the LOS test. * The effect of foot orthotic condition on Maximum Excursion was significantly differed based on time of assessment.
Figure 6. Average values for (a) Mean Contact Area (b) Peak Plantar Pressure and (c) Peak Force from Fscan analyses with and without foot orthotics.

(a) * Mean Contact Area increased significantly in the midfoot and rearfoot when foot orthotics were worn.
(c) * Peak force decreased significantly in the rearfoot when foot orthotics were worn.