Published in final edited form as:

Conf Proc IEEE Eng Med Biol Soc. 2004 ; 7: 5107–5110.

Biomechanics of the Double Rocker Sole Shoe: Gait Kinematics and Kinetics

Jason T. Long, M.S.¹, John P. Klein, Ph.D.², Nicole M. Sirota, M.D.³, Jacqueline J. Wertsch, M.D.³, Dennis Janisse, C.Ped.⁴, and Gerald F. Harris, Ph.D.¹

¹*Orthopaedic and Rehabilitation Engineering Center (OREC) Milwaukee, WI 53226*

²*Division of Biostatistics, Health Policy Institute, Medical College of Wisconsin, Milwaukee, WI 53226*

³*Department of Physical Medicine and Rehabilitation, Medical College of Wisconsin, Milwaukee, WI 53226*

⁴*National Pedorthic Services, Inc. Milwaukee, WI 53216*

Abstract

The use of footwear with contoured soles is common in treatment and care of patients with diabetes; these rocker sole shoes are designed to alleviate loading in key areas on the plantar surface of the foot, reducing pressure in key areas and alleviating pain and potential soft tissue damage. While investigations of pressure changes have been conducted, no quantitative study to date has addressed the three-dimensional kinematic and kinetic changes that result from using these shoes. Forty (40) subjects were tested wearing both unmodified and double rocker sole shoes, and the resulting motion patterns were compared to assess change caused by the rocker sole. Overall walking speed remained unchanged throughout testing; slightly increased flexion ($<5^\circ$) was apparent at the hip, knee, and ankle during early and midstance. These results demonstrate the maintenance of gait function with minimal kinematic changes when using the rocker sole shoe. Investigations of multisegmental foot motion may reveal additional information about the contour effects; analysis of contour variations may also be warranted to investigate the possibility of controlling motion based on rocker sole parameters.

Keywords

Gait; Rocker sole shoe; Diabetes; Corrective footwear; Double rocker; Pedorthics

Introduction

Diabetes mellitus is a chronic condition described by the World Health Organization as an epidemic; worldwide it affects approximately 200 million persons, with a projected increase of 25% over the next decade (CDC, 2004). Diabetes is also a costly health care condition, with an estimated total cost of \$132 billion in 2002—direct costs of \$92 billion, and indirect costs of \$40 billion covering disability, work costs, and premature mortality.

Corresponding Author: Jason T. Long, M.S., Medical College of Wisconsin, Department of Orthopaedic Surgery, 9200 W Wisconsin Ave, Milwaukee, WI 53226, (414) 805-7456, (414) 805-7488 Fax, jlong@mcw.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Beyond the metabolic abnormalities inherent in the disease, vascular disease and neuropathy pose real threats to the patient with diabetes. Peripheral nerve injury affects 60–70% of diabetics (CDC, 2004), leading to absent or diminished sensation in the distal extremities and allowing excessive, unperceived pressures that may result in plantar ulcers (Janisse, 1993). Foot ulceration leads to deep infection, sepsis, and lower extremity amputation, with foot infection being the most common hospital admission for patients with diabetes (Pinzur, et al., 1999). Preventive pedorthic care has been shown to decrease the high plantar pressures which can lead to such conditions (Fuller, et al., 2001; Brown, et al., 2004), with rigid rocker bottom shoes among the most commonly prescribed devices. The Medicare Therapeutic Shoe Bill (PL-100-203sec4072) highlights the importance of such accommodative footwear in prevention of neuropathic ulceration, and authorizes Medicare coverage for one pair of shoes per patient per calendar year. To maximize the benefits provided by this coverage, it is important to understand the biomechanical consequences of varying prescriptions on motion and loading during gait.

The rocker sole shoe itself uses the simple concept of a contoured rigid platform which controls joint motion by rocking the foot from heel strike through toe-off. By adjusting the location and pitch of the contour, the weight of the body causes the foot to rock as it passes over the fulcrum of the shoe. The double rocker is unique in that the thinnest portion of the sole is at the midfoot, where a section of the sole has been removed (Janisse, 1993). This thin portion of the sole focuses relief of plantar pressure in a specific problem area, such as those associated with a rocker bottom foot or a Charcot foot deformity. Specific shoe design is based on pressure measurements from a floor-reaction imprint; our group has previously demonstrated the effectiveness of this design in relieving midfoot pressures without exacerbating hindfoot or forefoot pressures (Brown, et al., 2004). Other investigations of plantar pressure changes secondary to such modified footwear are widely reported in the literature (Chesnin, et al., 2000; van Schie, et al., 2000; Fuller, et al., 2001; VanZant, et al., 2001), but investigations of changes in joint motion (kinematics) and joint loading (kinetics) are less common (Peterson, et al., 1985; Schaff, et al., 1990; Mueller, et al., 1994; Mueller, et al., 1994; Mueller, et al., 1995; Dingwell, et al., 1999; Xu, et al., 1999). The studies that do exist are generally limited to observational or quantitative two-dimensional analysis.

There are a number of previously published studies that investigate the effect of rocker sole shoes on plantar pressures and temporal-spatial parameters. Schaff (Schaff, et al., 1990) found changes in forefoot peak pressures with a lateral shifting of high pressure areas. Significant changes were also seen in temporal parameters. Xu et al. (Xu, et al., 1999) examined COP changes in shoes with medial and lateral support, and found a strong relationship between COP shifting and heel design. Mueller (Mueller, et al., 1994) found an 11% reduction in step length with rocker sole use; Peterson (Peterson, et al., 1985) found minimal temporal changes in rocker shoe gait, although most differences occurred with increased walking speed. Electrogoniometric results showed significantly increased ankle plantarflexion just prior to foot contact, with decreased motion just prior to toe-off.

A limited number of these studies utilize kinematic and kinetic measures, and those that do restrict the analysis to the sagittal plane (Mueller, et al., 1994; Mueller, et al., 1995; Dingwell, et al., 1999). This lack of 3D motion analysis is a major limitation in evaluating the effect of prophylactic footwear on lower extremity biomechanics, as 2D models do not account for coronal and transverse plane motions which may be affected by the rocker contour. Our group has previously reported the biomechanical effects of the negative heel (Myers, et al., 2005) and toe-only (VanBogart, et al., 2005) rocker treatments in healthy populations.

This study was designed to quantify the changes in gait kinematics and kinetics caused by the use of bilateral double rocker sole shoes. It was hypothesized that measures of joint kinematics,

joint kinetics, and temporal-spatial parameters would be altered by the double rocker shoe compared to normal gait patterns.

Materials and Methods

Motion analysis testing was conducted using a Vicon 370 Motion Analysis System (Vicon Motion Systems; Lake Forest, CA). Video data were synchronized with analog ground reaction force data captured from two 6DOF force plates (AMTI; Newton MA). The combined video data ($f_s = 60\text{Hz}$) and analog data ($f_s = 960\text{Hz}$) were used in conjunction with a biomechanical model to calculate three-dimensional motion and loading in lower extremity joints during gait.

A. Subject Selection

Forty (40) normal adult volunteers (20 males, 20 females; age 43.4 ± 8.2 yrs; Table 1) were recruited for participation in this study. Persons with a history or physical findings of any trunk, back, or lower extremity orthopaedic abnormalities, including foot abnormalities, were excluded from this study. Following informed consent, a comprehensive physical exam was completed to confirm the absence of any neurological or musculoskeletal impairment. The ages of the subject population (30 to 60 years) reflected the patient demographic which most commonly receives prescription for rocker sole treatments. This study was approved by the Institutional Review Boards of the Medical College of Wisconsin and Froedtert Memorial Lutheran Hospital (Milwaukee, WI); all subjects provided informed consent prior to testing.

B. Testing Protocol

All testing was completed at the Motion Analysis Laboratory in the Department of Orthopaedic Surgery at the Medical College of Wisconsin. Each subject wore two pairs of shoes (P.W. Minor & Son; Batavia, NY) fitted by a certified pedorthist (Figure 1). A pair without a rocker was used as a control ("Baseline"), while the second pair ("Rocker") was modified with a double rocker contour and a rigid metal shank to maintain the integrity of the rocker contour. Each pair of Rocker shoes was individually fit by the pedorthist based on a subject-specific floor reaction imprint and standardized rocker design. The consistent design of the double rocker sole was such that the heel rocker began at a point 50% along the length of the heel and had an angle of 15° . The forefoot rocker was angled at $18\text{--}20^\circ$, and its apex fell behind the head of the fifth metatarsal. The thinnest portion of the sole was half the thickness of the unmodified sole, and was positioned under the base of the fifth metatarsal.

Each subject was instrumented with lightweight reflective markers ($d = 25\text{mm}$) placed over specific bony landmarks; marker placement followed the configuration described by Kadaba (Kadaba, et al., 1990). Relative motions were described using Euler angles as motion in the sagittal, coronal, and transverse planes, with an YXZ order of derotation. Each subject underwent six testing sessions. A testing session consisted of multiple walks on the laboratory walkway (length $\approx 6\text{m}$) while video and force plate data were collected. Walks were completed at a self-selected speed, and rest periods were provided as needed between walks. Walks continued until at least five acceptable force plate strikes were collected for each foot (i.e. the subject's entire foot struck the force plate with no contact from the contralateral foot). Each testing session resulted in data from five strides for each foot. The full testing protocol is outlined in Table 2.

Post-processing of the data required the identification of strides within each walking trial. Strides were identified within the Vicon data processing environment as two consecutive heel strikes on the same foot. Given the time points for each heel strike and the laboratory-based coordinates of the foot markers at those points, the software provided side-dependent temporal-spatial measures for each walking trial. This allowed the independent analysis and comparison

of left and right side information. Stride time also provided a means of normalizing joint kinematics and kinetics, which allowed the subsequent analysis of time-series data between subjects.

C. Statistical Methods

This study was designed as an investigation of changes in gait parameters (temporal-spatial, kinematic, and kinetic) caused by a double rocker sole treatment. Through the use of the Baseline and Rocker conditions, each participant functioned as both a test subject and his or her own matched control. Angular joint data from multiple trials within each gait session were combined and then summarized by using Fourier series (Wong, et al., 1983; Fisher, et al., 1993; Klein, 1997) to model the gait pattern in each anatomical plane. The technical details of this analysis procedure have been described previously (Myers, et al., 2005). Due to the multiple testing for the subjects, we used a 0.01 level to determine significance.

Results

Gait cycle events as defined by Perry (Perry, 1992) were adopted for descriptions used throughout the remainder of this report: initial contact (IC, 0–2%), load response (LR, 0–10%), mid-stance (MSt, 10–30%), terminal stance (TSt, 30–50%), pre-swing (PSw, 50–60%), initial swing (ISw, 60–73%), mid-swing (MSw, 73–87%), and terminal swing (TSw, 87–100%).

Temporal and Spatial Parameters

Temporal-spatial data (cadence, stride length, velocity, and stance/swing ratio) were initially compared on a per-side basis. No significant difference was found between sides for either condition, allowing left and right side information to be grouped for reporting (Table 3). No significant changes between shoe conditions were found for any of the parameters.

Joint Kinematics and Kinetics

Pelvis—Significant change from the Baseline condition was observed in sagittal plane pelvic motion across the entire stride (Figure 2). Decreased anterior pelvic tilt (relative to global laboratory coordinates) was observed at most points in the cycle, especially in Ist and ISw.

Hip—Hip kinematics for the Rocker condition demonstrated a sagittal plane flexion shift bilaterally from LR through MSt, followed by an extension shift which lasted through the remainder of the stride (Figure 2). Analysis also revealed an external rotation shift on the right side that persevered throughout the entire stride (Figure 3). Kinetically, significant change was seen primarily on the right side, where an increased extension demand moment at IC was followed by increased flexion demand moment for the remainder of stance (Figure 4). A bilateral decrease in internal rotation moment was observed at IC and again from TSt through MSw (Figure 5). Increased power absorption was observed in MSt bilaterally, and increased power generation was observed in ISw (Figure 6).

Knee—Kinematically, the knee exhibited increased flexion at IC bilaterally, and decreased flexion in ISw and MSw (Figure 2). Kinetically, the knee exhibited increased extension demand moment following LR (Figure 4). This shift toward increased extension demand/reduced flexion demand persisted through toe-off. A significant decrease in internal rotation demand moment was observed in at MSt (Figure 5). Increased power generation was observed from MSt through ISw (Figure 6).

Ankle—Kinematically, the ankle demonstrated increased dorsiflexion at IC and during MSt bilaterally, and decreased dorsiflexion in late stance and ISw (Figure 2). The foot progression angle demonstrated increased external rotation in late stance and early swing (Figure 3). Kinetic

analysis shows a prominent decrease in plantarflexion demand moment from MSt through MSw (Figure 4) and decreased internal rotation demand from MSt through ISw (Figure 5). Decreased power absorption was also observed in early MSt (Figure 6).

Discussion

A key outcome of this analysis is the maintenance of walking speed. Coupled with our previous findings that the double rocker effectively redistributes midfoot pressures without exacerbating hindfoot and forefoot pressures (Brown, et al., 2004), this means that the double rocker sole shoe successfully maintains functional level while relieving pressure. Changes observed in joint kinetics were of small magnitude. Previously reported plantar pressure changes were much larger. However, different models were used for each analysis; plantar pressure differences were measured using a seven-segment model, while kinetic differences were measured using a classic single-segment foot model. Comparison to preceding studies is limited by differences in rocker types; Peterson (Peterson, et al., 1985) found no temporal-spatial differences between normal and rocker shoes, while Mueller (Mueller, et al., 1994) reported maintenance of walking speed despite a decreased step length.

Significant changes in joint kinematics point to varying amounts of increased flexion at all joints from IC through MSt. It should be noted that the magnitude of some of these changes fell within the range of measurement error for the system (Myers, et al., 2004); however, while the magnitude of these changes is small and their physiological significance is unclear, their persistent presentation during the load-bearing portions of the gait cycle and the rigorous criteria employed in the statistical analysis suggest that their presence is not by chance. Overall, 72 of 135 compared points demonstrated statistically significant differences. For discussion purposes and based on our previous work (Myers, et al., 2005), we have ascribed physiological significance to kinematic differences of 1° or greater. Similar thresholds were set for differences in moments (0.02 Nm/kg) and powers (0.05 W).

Some elements of changes observed with the double rocker treatment are similar to those observed previously with negative heel rocker (Myers, et al., 2005) and toe-only rocker (VanBogart, et al., 2005) treatments; other elements appear to be unique to the double rocker. All three treatments provide a reduction in ankle plantarflexion demand moment and overall ankle power generation during late stance and foot off. Walking speed was also maintained with all three treatments. However, the double rocker treatment led to increased hip flexion during stance and a more oscillatory pelvis throughout the gait cycle, while the negative heel and toe-only treatments resulted in reduced hip flexion and a more neutral pelvis. Changes in knee motion observed with the double rocker treatment (increased flexion in early stance; decreased flexion in swing) were similar to changes observed with the toe-only treatment, and contrasted with the persistent increased flexion observed with the negative heel treatment. Combined with demonstrated alterations in plantar pressure, these kinematic and kinetic factors may have significant implications in shoe prescription for patients experiencing problems with stability or swing phase foot clearance.

While the absence of initial dorsiflexor demand moment at the ankle might be expected for the Rocker condition, its absence from the Baseline results is notable. In normal gait, the dorsiflexion demand moment coincides with the eccentric contraction of the tibialis anterior as the foot is lowered to the floor following initial contact. Previous investigations have reported this phenomenon at varying magnitudes and durations for barefoot walking (Scott, et al., 1991; Perry, 1992; Eng, et al., 1995). While the morphology of the Baseline curve follows that of previously reported results, a baseline shift is also apparent. Differences in walking speed between this study and previous studies may account in part for this difference; subjects in the present study did not demonstrate a difference in walking speed between shoe conditions,

but did walk approximately 25% slower than those reported in the earlier studies. It should also be noted that in the present study, extra-depth P.W. Minor shoes were used for both conditions. Most previous investigations of the effect of heel height on gait are limited to running, but there is evidence to suggest that the magnitude and timing of the dorsiflexion demand moment are affected by changes in heel height (Reinschmidt, et al., 1995). More recently, van Schie and colleagues demonstrated that increases in sole height reduce pressure loading on the metatarsal heads and toes (van Schie, et al., 2000). The intertarsal manifestations of such pressure changes would also be expected to have an effect on ankle kinetics.

The double rocker sole shoe is indicated for severely affected feet (e.g. Charcot deformity). A previous investigation has demonstrated its effectiveness at reducing hindfoot and forefoot pressures, while preventing excessive overloading at the midfoot. While the weight of the subject is transferred to the hindfoot and forefoot, there is no actual weight relief during initial contact until the forefoot makes contact with the ground. The double rocker decreases midfoot loading, while the negative heel and toe-only rocker soles increased loading in that area. The nature of these loading changes suggests that within-shoe motion of the foot may be changing between the Baseline and Rocker conditions. The model used in this protocol is not able to assess these changes in multisegmental foot motion, as the foot is represented as a single rigid segment.

Further assessment with a multisegmental foot model, in conjunction with a lower extremity biomechanical model, may be warranted for a more complete understanding of changes. This could include the nature of the measured pressure redistributions, as well as intertarsal kinetic changes and their effect on ankle kinetics. Many current multisegmental foot models are ill-suited for such an in-shoe application, as they require the application of multiple markers to the skin surface. Previous studies investigating in-shoe motion of the hindfoot have utilized windows cut in the shoes for placing markers directly on the skin (Reinschmidt, et al., 1992; Stacoff, et al., 1992; Williams, et al., 2003; Stackhouse, et al., 2004); this method may work well in the current application. Alternatively, an approach involving dynamic radiography (fluoroscopy) would provide measures of motion with no alteration to the shoe structure, and could index this motion directly to the bony segments. Such fluoroscopic methods have been validated (Anderst, et al., 2003) and are well-recognized in investigations of knee motion (Dennis, et al., 2003; Fantozzi, et al., 2003; Tashman, et al., 2004), and may hold promise for investigating the foot.

The use of normal (nonpathologic) subjects, while serving as a reliable means of comparison between shoes, also limits the study in that the response of the target population (persons with diabetes and/or peripheral neuropathy) is not being assessed.

The study is also limited by the single-visit nature of testing for the shoe; as all testing was done in one session, we cannot conduct an assessment of within- or between-day variability. It is possible that the changes observed may vary over a longer period of rocker sole shoe use. To address these limitations, further study with the patient population in question may be warranted to determine if the small magnitude of change observed in the normal subjects is a typical response, or unique to a population without foot pathology. Multi-session testing for within- and between-day variability is also warranted to investigate the possibility of transience in the changes induced by the double rocker sole shoe. Performing such testing with both normal and pathologic populations would provide an additional level of analysis missing in the current literature.

The major benefits of the double rocker modification appear to be a beneficial redistribution of plantar pressures with maintenance of walking speed. It should also be noted that the long-term effects of apparent subtleties that are statistically significant have not been defined and

may yield significant insight following further study. Further investigation is warranted to examine the changes in motion and loading in multiple segments of the foot, and their relationship to the previously measured plantar pressure changes. Additional work in the area of prophylactic footwear may include optimization of contour design, as well as investigations of postural stability and energy consumption alterations.

Acknowledgment

This research was made possible by a grant from the NIH: R01 HD31989, CFDA No. 93.929. The authors thank the following people for their support and contributions to this paper: David Brown, Robert Conley, John Humm, Kelly Myers, Tracey Ortiz, Kirsten Tulchin, Michelle Urban, Joe Van Bogart, and Correy Pletz.

References

- CDC. National diabetes fact sheet: general information and national estimates on diabetes in the United States, 2003. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention; 2004.
- Janisse, DJ. The Diabetic Foot. St. Louis, MO: Mosby; 1993. Pedorthic care of the diabetic foot.
- Pinzur MS, Shields NN, Goelitz B, Slovenkai M, Kaye R, Ross SD, Suri M. American Orthopaedic Foot and Ankle Society shoe survey of diabetic patients. *Foot & Ankle International* 1999;20:703–707. [PubMed: 10582845]
- Fuller E, Schroeder S, Edwards J. Reduction of peak pressure on the forefoot with a rigid rocker-bottom postoperative shoe. *Journal of the American Podiatric Medical Association* 2001;91:501–507. [PubMed: 11734605]
- Brown D, Wertsch JJ, Harris GF, Klein J, Janisse D. Effect of rocker soles on plantar pressures. *Archives of Physical Medicine & Rehabilitation* 2004;85:81–86. [PubMed: 14970973]
- Chesnin KJ, Selby-Silverstein L, Besser MP. Comparison of an in-shoe pressure measurement device to a force plate: concurrent validity of center of pressure measurements. *Gait & Posture* 2000;12:128–133. [PubMed: 10998609]
- van Schie C, Ulbrecht JS, Becker MB, Cavanagh PR. Design criteria for rigid rocker shoes. *Foot & Ankle International* 2000;21:833–844. [PubMed: 11128014]
- VanZant RS, McPoil TG, Cornwall MW. Symmetry of plantar pressures and vertical forces in healthy subjects during walking. *Journal of the American Podiatric Medical Association* 2001;91:337–342. [PubMed: 11466458]
- Peterson MJ, Perry J, Montgomery J. Walking patterns of healthy subjects wearing rocker shoes. *Physical Therapy* 1985;65:1483–1489. [PubMed: 4048284]
- Schaff PS, Cavanagh PR. Shoes for the insensitive foot: the effect of a "rocker bottom" shoe modification on plantar pressure distribution. *Foot & Ankle* 1990;11:129–140. [PubMed: 2074080]
- Mueller MJ, Minor SD, Sahrman SA, Schaaf JA, Strube MJ. Differences in the gait characteristics of patients with diabetes and peripheral neuropathy compared with age-matched controls. *Physical Therapy* 1994;74:299–308. [PubMed: 8140143]discussion 309-213
- Mueller MJ, Sinacore DR, Hoogstrate S, Daly L. Hip and ankle walking strategies: effect on peak plantar pressures and implications for neuropathic ulceration. *Archives of Physical Medicine & Rehabilitation* 1994;75:1196–1200. [PubMed: 7979928]
- Mueller MJ, Minor SD, Schaaf JA, Strube MJ, Sahrman SA. Relationship of plantar-flexor peak torque and dorsiflexion range of motion to kinetic variables during walking. *Physical Therapy* 1995;75:684–693. [PubMed: 7644572]
- Dingwell JB, Ulbrecht JS, Boch J, Becker MB, O'Gorman JT, Cavanagh PR. Neuropathic gait shows only trends towards increased variability of sagittal plane kinematics during treadmill locomotion. *Gait & Posture* 1999;10:21–29. [PubMed: 10469938]
- Xu H, Akai M, Kakurai S, Yokota K, Kaneko H. Effect of shoe modifications on center of pressure and in-shoe plantar pressures. *American Journal of Physical Medicine & Rehabilitation* 1999;78:516–524. [PubMed: 10574166]

- Myers KA, Long JT, Klein JP, Wertsch JJ, Janisse D, Harris GF. Biomechanical implications of the negative heel rocker sole shoe: Gait kinematics and kinetics. *Gait & Posture* 2005;24:323–330. [PubMed: 16300949]
- VanBogart JJ, Long JT, Klein J, Wertsch JJ, Janisse D, Harris GF. Effects of the toe-only rocker on gait kinematics and kinetics in able-bodied persons. *IEEE Transactions on Neural Systems & Rehabilitation Engineering* 2005;13:542–550. [PubMed: 16425836]
- Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. *Journal of Orthopaedic Research* 1990;8:383–392. [PubMed: 2324857]
- Wong MA, Simon S, Olshen RA. Statistical analysis of gait patterns of persons with cerebral palsy. *Statistics in Medicine* 1983;2:345–354. [PubMed: 6648148]
- Fisher, LD.; Van Bell, G. *Biostatistics: A methodology for the health sciences*. New York, NY: John Wiley and Sons; 1993.
- Klein, J. Statistical issues in randomized clinical trials in motion analysis. Chicago, IL: IEEE/EMBS; 1997. p. 2909-2913.
- Perry, J. *Gait analysis: Normal and pathological function*. Thorofare, NJ: SLACK, Inc.; 1992.
- Myers KA, Wang M, Marks RM, Harris GF. Validation of a multisegment foot and ankle kinematic model for pediatric gait. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on* [see also *IEEE Trans. on Rehabilitation Engineering*] 2004;12:122–130.
- Scott SH, Winter DA. Talocrural and talocalcaneal joint kinematics and kinetics during the stance phase of walking. *Journal of Biomechanics* 1991;24:743–752. [PubMed: 1918097]
- Eng JJ, Winter DA. Kinetic analysis of the lower limbs during walking: what information can be gained from a three-dimensional model? *Journal of Biomechanics* 1995;28:753–758. [PubMed: 7601875]
- Reinschmidt C, Nigg BM. Influence of heel height on ankle joint moments in running. *Medicine & Science in Sports & Exercise* 1995;27:410–416. [PubMed: 7752869]
- Reinschmidt C, Stacoff A, Stussi E. Heel movement within a court shoe. *Medicine & Science in Sports & Exercise* 1992;24:1390–1395. [PubMed: 1470023]
- Stacoff A, Reinschmidt C, Stussi E. The movement of the heel within a running shoe. *Medicine & Science in Sports & Exercise* 1992;24:695–701. [PubMed: 1602942]
- Williams DS 3rd, McClay Davis I, Baitch SP. Effect of inverted orthoses on lower-extremity mechanics in runners. *Medicine & Science in Sports & Exercise* 2003;35:2060–2068. [PubMed: 14652503]
- Stackhouse CL, Davis IM, Hamill J. Orthotic intervention in forefoot and rearfoot strike running patterns. *Clinical Biomechanics* 2004;19:64–70. [PubMed: 14659932]
- Anderst WJ, Tashman S. A method to estimate in vivo dynamic articular surface interaction. *Journal of Biomechanics* 2003;36:1291–1299. [PubMed: 12893037]
- Dennis DA, Komistek RD, Mahfouz MR, Haas BD, Stiehl JB. Multicenter determination of in vivo kinematics after total knee arthroplasty. *Clinical Orthopaedics & Related Research* 2003;37–57. [PubMed: 14646738]
- Fantozzi S, Benedetti MG, Leardini A, Banks SA, Cappello A, Assirelli D, Catani F. Fluoroscopic and gait analysis of the functional performance in stair ascent of two total knee replacement designs. *Gait & Posture* 2003;17:225–234. [PubMed: 12770636]
- Tashman S, Collon D, Anderson K, Kolowich P, Anderst W. Abnormal rotational knee motion during running after anterior cruciate ligament reconstruction. *American Journal of Sports Medicine* 2004;32:975–983. [PubMed: 15150046]

Baseline Shoe

Double Rocker Shoe

Figure 1.
Baseline (top) and Double Rocker (bottom) shoes

Figure 2.

Sagittal plane kinematics of R pelvis, hip, knee, and ankle for Baseline and Rocker shoes (mean curve with upper and lower 95% pointwise confidence bands). Positive values correspond to anterior tilt (pelvis) and joint flexion (all other joints). Points of significant difference are marked on abscissa; magnitudes of significant changes [degrees] from Baseline to Rocker are indicated.

Figure 3.

Hip rotation and foot progression angle (right-side) for Baseline and Rocker shoes (mean curve with upper and lower 95% pointwise confidence bands). Positive values correspond to internal rotation. Points of significant difference are marked on abscissa; magnitudes of significant changes [degrees] from Baseline to Rocker are indicated.

Figure 4.

Sagittal plane moments of R hip, knee, and ankle for Baseline and Rocker shoes (mean curve with upper and lower 95% pointwise confidence bands). Positive values correspond to extension demand moment (hip and knee) and plantarflexion demand moment (ankle). Points of significant difference are marked on abscissa; magnitudes of significant changes [Nm/kg] from Baseline to Rocker are indicated.

Figure 5.

Transverse plane moments of R hip, knee, and ankle for Baseline and Rocker shoes (mean curve with upper and lower 95% pointwise confidence bands). Positive values correspond to internal rotation demand moment. Points of significant difference are marked on abscissa; magnitudes of significant changes [Nm/kg] from Baseline to Rocker are indicated.

Figure 6.

Total joint power of R hip, knee, and ankle for Baseline and Rocker shoes (mean curve with upper and lower 95% pointwise confidence bands). Positive values correspond to power generation. Points of significant difference are marked on abscissa; magnitudes of significant changes [W/kg] from Baseline to Rocker are indicated.

Table 1

Subject Demographics	
Parameter	Value
n	40
Gender	20 male 20 female
Handedness	38 right-handed 2 left-handed
Age	43.4 $\pm$ 8.24 yrs
Height	67.1 $\pm$ 3.52 in.
Weight	170.7 $\pm$ 32.6 lbs.

Table 2

Summary of data collection sessions

Data Collection Session	Est. Time (min)	# Trials/Distance
Baseline Gait Analysis #1	20	3 each foot
Rocker Gait Analysis #1	20	3 each foot
Rocker Free Walk	5	~1500 m
Rocker Gait Analysis #2	20	3 each foot
Rocker Free Walk	5	~1500 m
Rocker Gait Analysis #3	20	3 each foot
Rocker Free Walk	5	~1500 m
Rocker Gait Analysis #4	20	3 each foot
Baseline Gait Analysis #2	20	3 each foot

Table 3Spatial and temporal parameters (mean $\pm$ SD).

Measure	Baseline	Rocker	
Stride Length	1.49 $\pm$ 0.14	1.48 $\pm$ 0.13	m
Cadence	108.48 $\pm$ 11.16	109.59 $\pm$ 11.20	steps/min
Velocity	1.34 $\pm$ 0.18	1.35 $\pm$ 0.19	m/s
Stance %	64.97 $\pm$ 2.27	65.00 $\pm$ 2.23	%