



Sheffield Hallam University

**Changes in gait characteristics of a normal,
healthy population due to an unstable
shoe construction.**

The Centre for Sport and Exercise Science,
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1.0 Introduction

This report was commissioned by Swiss Masai AG (Switzerland) and details research performed at and by The Centre for Sport and Exercise Science at Sheffield Hallam University. This independent research presents a scientific approach to the evaluation of gait, the results of which will inform the reader regarding the effect of MBT shoes on normal gait characteristics. The advanced biomechanics technology used will answer the following questions:

- Does wearing MBT shoes effect;
 - normal gait kinematics?
 - normal gait kinetics?

Back pain is the third most common bodily symptom after headache and tiredness with 60 -80 % of people suffering low back pain at some time in their lives. Of these, 15-30% of people have some low back pain symptoms every day and 35-40 % report low back pain lasting 24 hours or more each month (*Croft et al.*). Back pain in itself is not becoming more common , rather there is an epidemic of absenteeism due to simple back ache. In 1995-96, 117 560 500 days invalidity or sickness benefit were claimed as a result of back incapacity in the UK (Department of Social Security figures) and it is estimated that chronic back problems account for 85 % of absenteeism due to back pain (*Barton et al.* 2001).

Three systematic reviews (*Evans G , Van Tulder MW and Faas A*) have found that exercise improved pain ,disability and outcomes such as strength and flexibility.

One systematic reviews (*Bigos S*) has found that in people with acute low back pain advice to stay active speeds symptomatic recovery, reduces chronic disability and leads to less time off work compared to bed rest and traditional medical treatments such as analgesia, advice to rest and let pain be your guide to activity.

Osteoarthritis is another common cause of pain and disability in older adults (*Petersen IF , Felson DT*). Radiographic changes are seen in some joints in the

majority of people aged 60 and above. Significant clinical disease affects up to 20% of these older populations with Osteoarthritis affecting the knee being twice as prevalent as osteoarthritis of the hip in people aged over 60(Gaffney KL).

There have been three systematic reviews of the benefits of exercise and physical therapy in the management of osteoarthritis (Van Baar , Puett and La Mantia K) . All showed the positive benefits of exercise programmes from the use of strength or aerobic activities or combinations of the two. These benefits being in the form of pain reduction and improved joint function.

The average UK citizen walks in the region of 183 miles (305 Km) per year on the public highway or other unrestricted areas which are paved or tarred and over 50 yards <http://www.statistics.gov.uk/STATBASE/Expodata/Spreadsheets/D7801.xls>). This equates to a huge number of footfalls every year, each of which results in a loading effect on the joints of the lower limb and back. As such, any reduction in the cyclic loading of the structures that comprise these joints will have a significant affect on the accumulation of microdamage.

Anecdotal evidence has suggested that the frequent use of an unstable shoe construction can help in rehabilitation and even prevention of many of these complaints. The Masai Barefoot Technology (MBT) shoe (Figure 1.1) has a rounded sole in the anterior – posterior direction, by providing an uneven walking surface it challenges the muscles to maintain control over locomotion rather than relying on the stability provided by a conventional shoe.



Figure 1.1: The Masai Barefoot Technology (MBT) shoe; note the rounded sole construction in the anterior – posterior direction.

If the MBT shoe can be shown to reduce loading through the hip , knee and ankle as suggested by a preliminary study from The Human Performance Laboratory University of Calgary (*Nigg B et al.*) the potential beneficial impact the shoe could have as a tool for treating osteoarthritic hip and knee is significant.

If the MBT shoe can be demonstrated to alter loading or posture of the lumbosacral spine its application as a tool in the treatment of back pain will be significant.

2.0 Methods

Participants

Twenty-two participants (11 male, 11 female) volunteered to take part in the study; Details of the participants' age, stature and body mass are given in Table 2.1 below. All participants were physically active and free from musculoskeletal injury at the time of testing. The University's Ethics Committee approved the procedures, and written informed consent was gained from each participant before data collection. On volunteering to take part in the study, each participant was provided with a pair of Masai Barefoot Technology (MBT) shoes (Figure 1.1) which were worn during the data collection sessions in the 'MBT condition' in addition to tight fitting shorts and vests. In the 'normal condition' participants were required to wear the same tight fitting clothing and their normal exercise shoes.

	Male	Female
Age (years)	28 (4)	26 (3)
Stature (m)	175 (7)	168 (5)
Body Mass (kg)	76 (11)	68 (11)

Table 2.1: Participant details (Mean \pm SD).

Experimental set-up

All kinematic data were collected using an eight-camera digital motion capture system (Motion Analysis Corporation, Santa Rosa, CA, USA) sampling at 200 Hz. The orientation of the right handed, orthogonal global coordinate system was such that the positive x axis pointed in the direction of forward progression, the positive y axis pointed vertically upward and the positive z axis pointed to the right.

The eight cameras of the motion capture system were placed in optimal positions around a calibrated measurement volume of dimensions 5.0 × 2.0 × 3.0 m in the x, y and z directions respectively. The measurement volume was made this size to incorporate a step both before and after the stance phase on the Kistler Type 9281CA force platform (Kistler Instrumente AG Winterthur, Switzerland) which was embedded in the laboratory floor and covered with a surface common to the entire laboratory. The force platform sampled data at 1000 Hz and was time-synchronised with the motion capture system. Infra-red timing gates (Brower DETAILS) were placed 3 m apart either side of the floor-mounted force platform to monitor walking speed during the trials. A schematic representation of the experimental setup is given in figure 2.1.

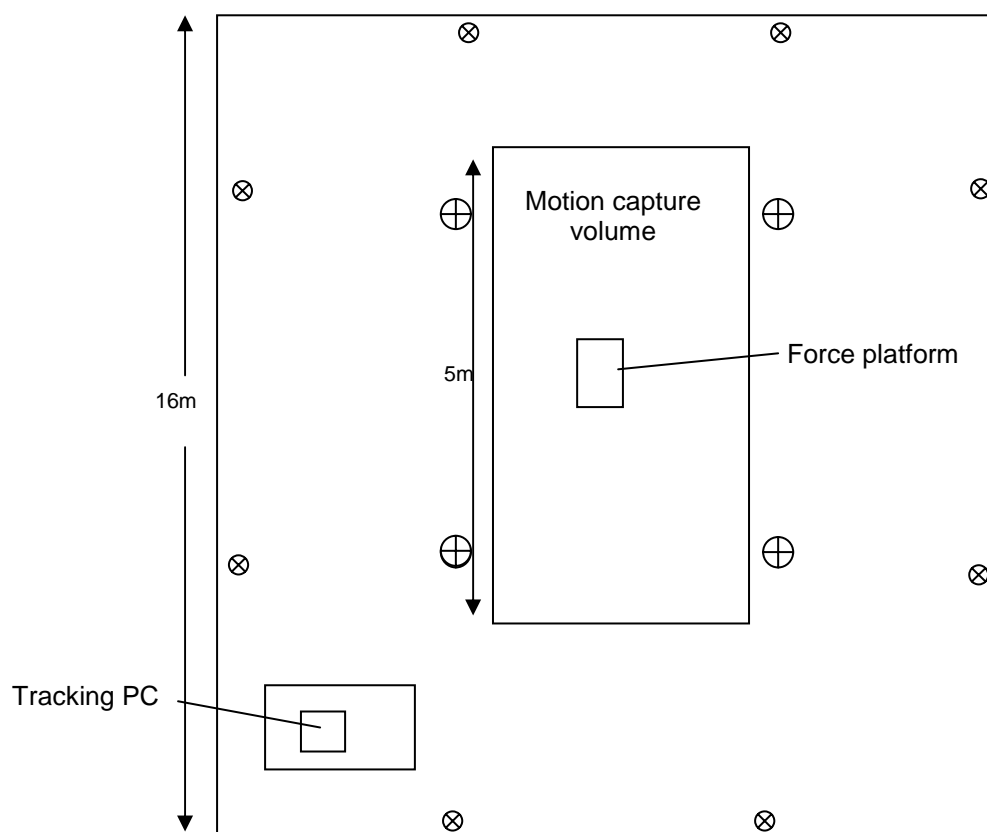


Figure 2.1: The experimental setup. ⊕ - Timing gate, ⊗ - Digital motion capture camera.

MBT gait evaluation.

Twenty two retro-reflective markers (12.5 mm diameter) were attached to each participant in locations consistent with the Helen Hayes Marker Set (Kadaba *et al.*, 1990). Markers were attached to the participants' left and right 2nd metatarsal head (closest approximation on the shoe), posterior aspect of the calcaneus (closest approximation on the shoe), lateral malleolus, lateral epicondyle, anterior superior iliac spine, acromion processe, lateral humeral epicondyle and midpoint of the radius and ulnar styloid process. Further markers were attached to the sacrum the seventh cervical vertebrae and the right scapula. In addition to these markers, four supplementary markers, mounted on 100 mm posts were attached to the lateral aspect of the participants' left and right shank and thigh (see figure 2.2).



Figure 2.2: The Helen Hayes Marker Set

Procedures

Tutorial session

Prior to testing, participants were required to attend a tutorial session in which they were provided with their MBT shoes and instruction conforming to manufacturer's specifications. Participants were then asked to endeavour to use the shoes as frequently as possible in the interval between the tutorial and data collection sessions.

Data collection session

After preparation and attachment of the Helen Hayes Marker Set, each participant was required to traverse the laboratory, approximately 16 m in length, at their preferred speed while making contact with the force platform with the appropriate foot. A right foot contact was required in the direction of the positive x axis, whereas, a left foot contact was required in the opposite direction. The participants completed five 'good' trials for each foot in both the MBT and normal shoe conditions – the order in which the participants completed the conditions was randomised. Trials were accepted when the whole of the participant's appropriate foot contacted the force platform, without any obvious alterations to their gait. Participants were permitted as many practice trials as they required to become able to consistently achieve this prior to the onset of data collection. Five seconds of kinematic data were collected using the motion capture system along with the kinetic data from the force platform. Walking speed was measured during every trial using the infrared timing gates; repeated measures t -tests were performed on these data and indicated that walking speed was consistent between conditions ($p>0.05$).

Static calibration trial

At the end of the data collection for each condition a further, static calibration trial was collected to allow for correct anatomical reference frame alignment. Additional markers were attached to the participants' left and right medial malleolus and medial femoral epicondyle. Kinematic data were collected for 5 seconds with the participant in the calibration standing position (see figure 2.2).

Data analysis

Kinematics

The three-dimensional coordinate data were filtered using a second order low-pass Butterworth filter; a cut-off frequency of 6 Hz was used and was selected through visual inspection of the fit. Hip, knee and ankle Joint Coordinate System (JCS) angles (Grood and Suntay, 1983) were then calculated using Orthotrak software (Motion Analysis Corporation, Santa Rosa, CA, USA). The three-dimensional angles of the pelvis and trunk were relative to the relative to the global coordinate system were also calculated using the orthotrak software.

The resulting angular displacement profiles were then cropped to the length of one foot contact. The vertical component of the ground reaction force was used to determine foot contact events - thresholds of 20 N and 10 N were used to determine foot-strike and toe-off respectively. Twenty-two dependent variables were taken from the kinematic data. These included the degree of angular displacement at the ankle, knee and hip joints in the sagittal plane at foot-strike and toe-off. Sagittal plane trunk and pelvis angles, relative to the global coordinate system, were also recorded at the times of these gait events. In addition to the

variables, further discrete kinematic data were recorded at the times of maximum and minimum angular displacement for each profile.

Ground reaction force

Six further dependent variables were taken from the ground reaction force data. These included; peak vertical force in the first half of stance (impact peak), peak vertical force in the second half of stance (propulsive peak), maximum propulsive force and maximum braking force.

Kinetics

The Orthotrak software was used to calculate internal resultant joint moments using an inverse dynamics technique. Dependent variables for the kinetics data included the resultant joint moment at the ankle, knee and hip joints in the sagittal plane at foot-strike and toe-off. Furthermore, maximum and minimum sagittal plane joint moments were recorded at the ankle, knee and hip joints.

Statistical analysis

Firstly, the data for each dependent variable were screened to ensure that it did not violate the assumptions of repeated measures analysis of variance (ANOVA) or *t*-test - normality, sphericity (for ANOVA only) and homogeneity of variance. A series of three-factor (condition, foot, gender) ANOVA, with repeated measures on the factors condition and foot, were performed for each dependent variable to assess differences between normal shoe and MBT walking. Ground reaction force graphs were visually inspected for the presence of a transient peak, identified by a short spike of force immediately following initial contact of the foot with the ground.

MBT gait evaluation.

A Wilcoxon matched pairs test was performed on these data to assess differences between the MBT and normal conditions. The alpha level of significance was set at 0.05 for all statistical tests.

3.0 Results and Discussion

Kinematics

Comparison of walking in normal and MBT shoes suggested that lower limb kinematics were largely unchanged (Table A1-4). Both hip, knee and pelvis kinematics were not different between the normal and MBT conditions. There were however two significant differences in kinematics; the use of MBTs elicited a significant decrease ($p < 0.05$) in the forward lean of the trunk (Figure 3.1) suggesting subjects adopted a more upright walking posture when using the MBT shoes.

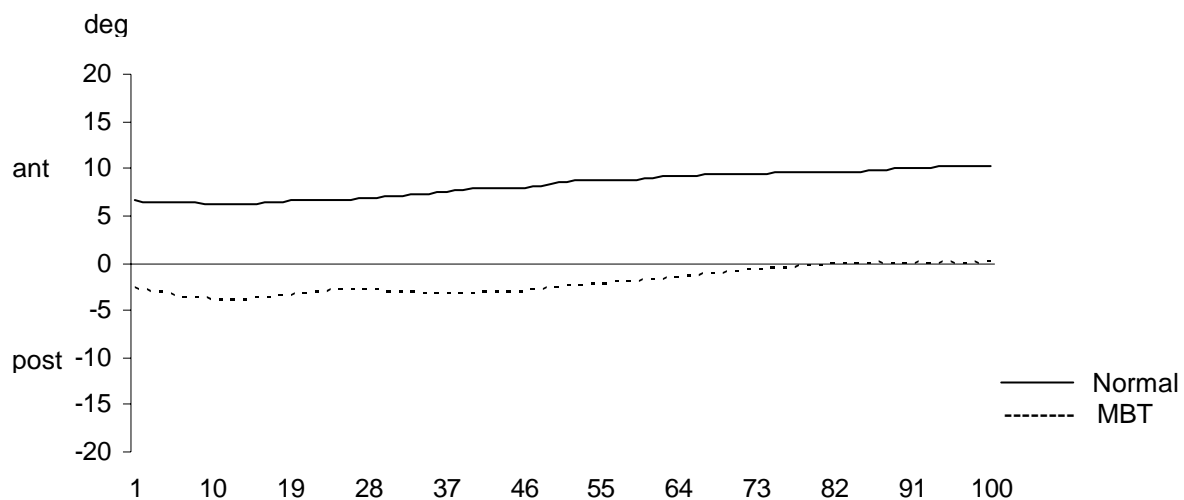


Figure 3.1: Trunk angle during the stance phase of gait for the MBT and normal condition.

At the ankle (Figure 3.2) subjects exhibited significantly higher maximum dorsiflexion angles when wearing MBT shoes ($p < 0.05$). Also evident was a significant decrease in the amount of plantar flexion following initial contact when wearing MBTs ($p < 0.05$). This is primarily due to the rolling action over the pivot point of the MBT shoe rather than the dropping of the forefoot following initial contact, as seen during normal walking.

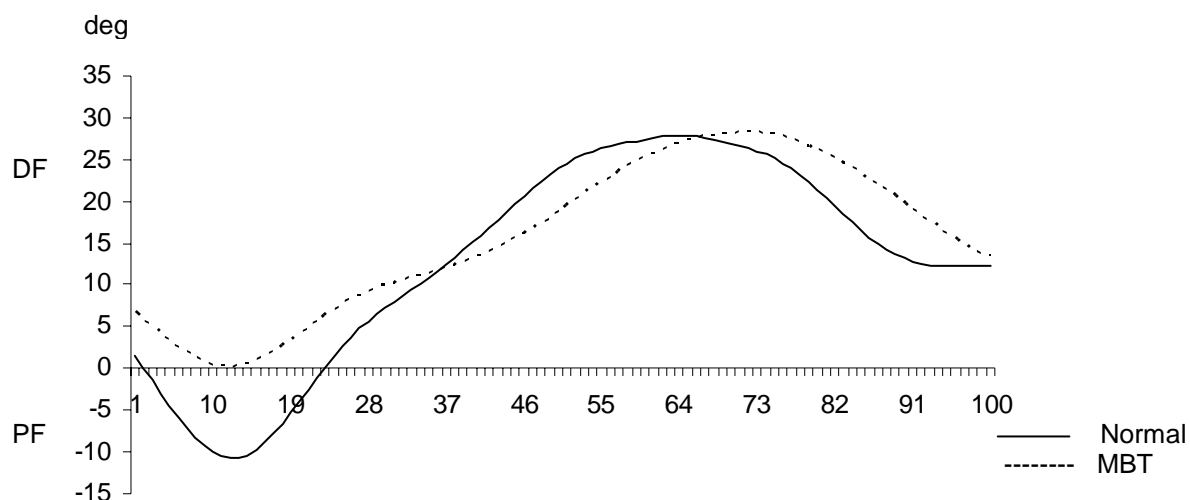


Figure 3.2: Ankle angle during the stance phase of gait for the MBT and normal condition.

Main finding: MBT shoes promote a more upright trunk posture during locomotion and a more dorsiflexed ankle position throughout stance.

Kinetics

Analysis of joint kinetics during walking showed a number of significant differences in the joint moments experienced during the MBT and normal conditions. At the hip (Figure 3.3) and ankle (Figure 3.5) there were significant reductions ($p < 0.05$) in the maximum extension and plantar flexion moments experienced during the MBT condition compared to the normal condition. Although this was not the case at the knee (Figure 3.4), there was a trend toward lower extension moments when wearing MBT shoes.

The ankle (Figure 3.5) also experienced significantly lower dorsiflexion moments during the MBT condition compared to the normal condition. This can be explained by the differences in the initial contact position during the MBT condition; the more dorsiflexed contact position and the reduced plantar flexion during the initial phase of stance. The knee (Figure 3.4) also exhibited a significantly lower flexion moment, flexion moments at the hip were found to be non-significant between conditions but showed a trend toward being lower during the MBT condition.

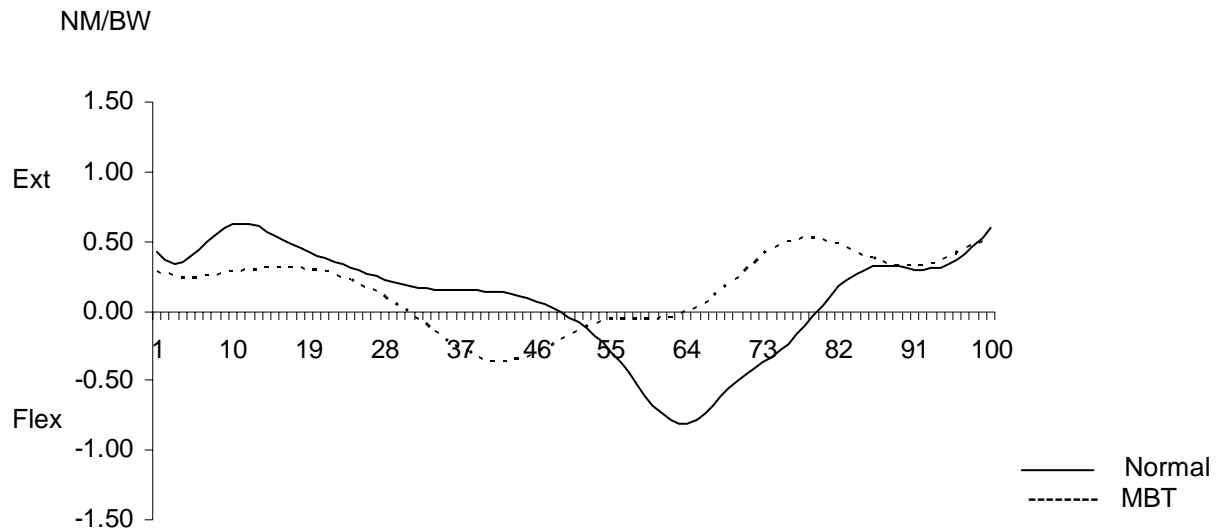


Figure 3.2: Hip flexion/extension moment during the stance phase of gait for the MBT and normal condition.

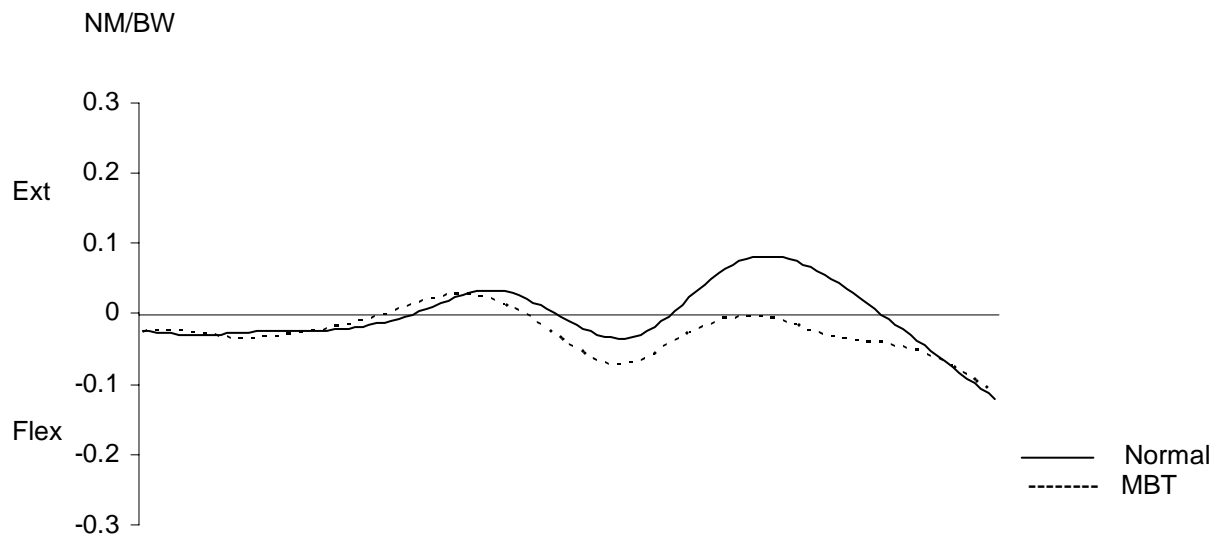


Figure 3.3: Knee flexion/extension moment during the stance phase of gait for the MBT and normal condition.

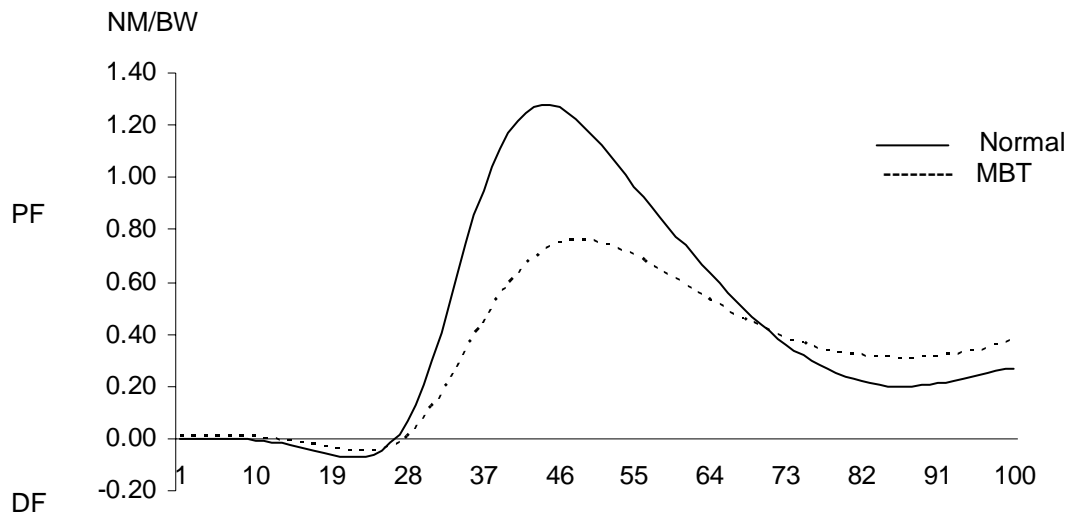


Figure 3.5: Ankle plantar flexion/dorsiflexion moment during the stance phase of gait for the MBT and normal condition.

Main finding: During the MBT shoe condition, subjects experienced reduced sagittal plane joint moments at the hip, knee and ankle.

Ground Reaction Force

Analysis of the ground reaction forces (Table A9) suggested that the MBT condition elicited a significant ($p < 0.05$) increase in the vertical impact peak. It is suggested that this is due to the increased mass of the MBT shoe when compared to the participant's normal shoes. No difference was found in the magnitude of the active peaks. Visual inspection of the vertical ground reaction force curves (Figure 3.6) suggested that the occurrence of a transient peak was more common ($p < 0.05$) in the normal condition than during the MBT condition with transient peaks occurring in 59% of the normal trials and only 27% of the MBT trials. This is probably as a direct result of the difference in foot contact with the ground when wearing MBT shoes or differences in shoe construction.

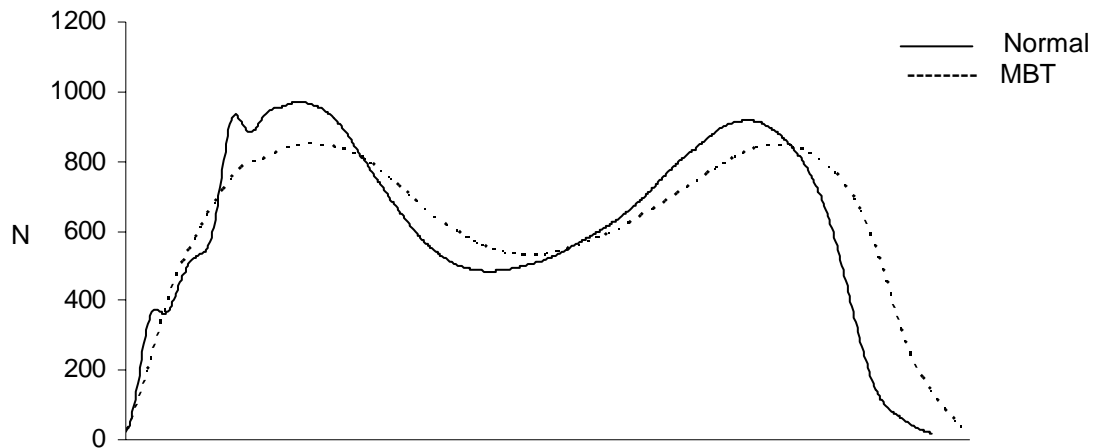


Figure 3.6: Vertical ground reaction force trace during the stance phase of gait for the MBT and normal condition.

I was also noted that where there was a transient peak present, the impact peak in the MBT condition was lower than that experienced during the normal condition. This, however, needs further investigation in order to be able to make any further assumptions.

In the anterior – posterior direction (Figure 3.7) the MBT condition showed significantly higher propulsive forces during the latter part of stance. This is probably due to the dragging motion promoted when walking in MBT shoes rather than the pushing motion used when walking in normal shoes.

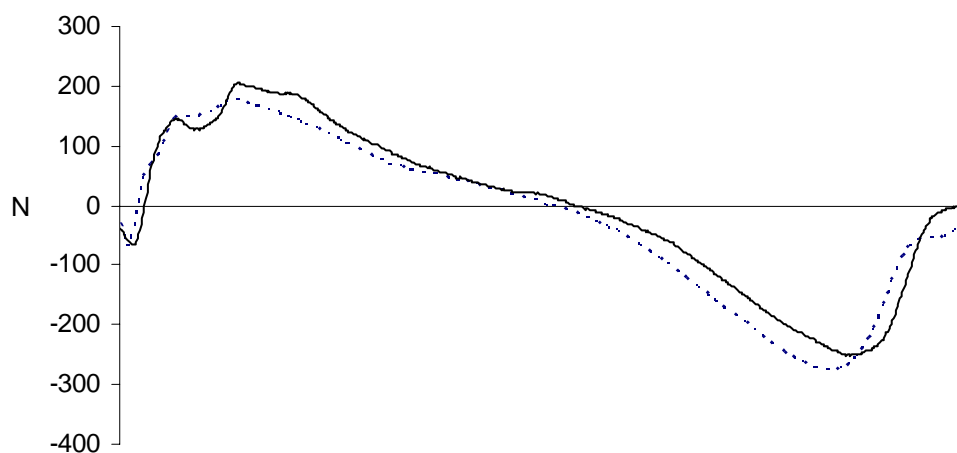


Figure 3.7: Anterior - posterior ground reaction force trace during the stance phase of gait for the MBT and normal condition.

Main finding: The incidence of transient peaks when wearing MBT shoes was lower than during the normal condition. MBT's also promote an increased propulsive (forward force).

5.0 Summary

The findings of the current study suggest that certain gait characteristics are affected during walking in a shoe of unstable construction.

Although many of the kinematic variables remained unchanged, there were significant differences in both the trunk and the ankle angles. MBT shoes promote less forward lean during locomotion suggesting a more upright posture. Although not confirmed by the present study, the probable effect is a shift in the centre of mass position closer to the centre of the base of support, possibly aligning the body more optimally for locomotion. This, in conjunction with the lower hip moments experienced in the MBT condition may suggest reduced loading of the lower back. The changes in the ankle plantar flexion / dorsiflexion angle at the ankle, was primarily due to the reduced plantar flexion following initial contact during the MBT condition when compared to the normal condition.

Kinetics at each of the joints of the lower limb were different between the MBT and normal conditions. The lower moments experienced at these joints suggests a resultant decrease in joint loading.

The major finding from analysis of the ground reaction force data is the suggestion that there is a higher incidence of transient peaks when wearing normal shoes compared to MBTs. There is some evidence suggesting that transient forces transmitted through the skeleton are the primary aetiological factor in the development of many musculoskeletal disorders. These include, osteoarthritis,

MBT gait evaluation.

stress fractures, plantar fasciitis and achilles tendonitis and low back pain (Whittle, 1999).

This initial study into the effects of an unstable shoe construction suggests that MBTs alter certain gait characteristics and that with frequent use they may reduce the incidence of some musculoskeletal problems.

References

Barton, S., Pattison, J. and Smith, R. (Eds). (2001). Clinical Evidence: Issue 6. British Medical Publishing Group, UK, London.

Grood, E.S. and Suntay, W.J. (1983) A joint coordinate system for the clinical description of three-dimensional motions: application to the knee. *Journal of Biomechanical Engineering*, **(2)**, 136-44.

Kadaba, M.P., Ramakrishnan, H.K. and Wootten, M.E. (1990) Measurement of lower extremity kinematics during level walking. *Journal of Orthopaedic Research*, **(8)**, 383-92.

National Travel Survey 2002 Provisional Results, Department for Transport. (2004) <http://www.statistics.gov.uk>.

APPENDIX A

TABLES

MBT gait evaluation.

	Hip (deg)	Knee (deg)	Ankle (deg)	Pelvis (deg)	Trunk (deg)
MBT	38.19 (8.40)	12.42 (7.71)	11.43 (4.95)	11.14 (5.96)	-3.27 * (3.79)
Normal	38.79 (8.79)	9.83 (7.70)	9.77 (5.83)	11.51 (6.42)	-1.99 * (3.94)

Table A1: sagittal joint angles (mean \pm SD) during walking for the normal and MBT conditions at foot strike (* denotes statistically significant difference between conditions).

	Hip (deg)	Knee (deg)	Ankle (deg)	Pelvis (deg)	Trunk (deg)
MBT	-0.72 (7.55)	66.08 (9.55)	10.78 (6.87)	3.01 (5.66)	0.54 * (3.86)
Normal	-0.87 (8.21)	63.50 (8.97)	10.40 (6.66)	3.46 (5.86)	1.51 * (3.81)

Table A2: sagittal joint angles (mean \pm SD) during walking for the normal and MBT conditions at toe off (* denotes statistically significant difference between conditions).

MBT gait evaluation.

	Hip (deg)	Knee (deg)	Ankle (deg)	Pelvis (deg)	Trunk (deg)
MBT	38.91 (8.55)	45.45 (9.18)	28.51 * (5.65)	12.10 (5.97)	3.37 (3.46)
Normal	39.47 (8.81)	45.11 (9.41)	26.31 * (5.99)	12.20 (6.38)	3.83 (3.46)

Table A3: Maximum sagittal joint angles (mean \pm SD) during walking for the normal and MBT conditions (* denotes statistically significant difference between conditions).

	Hip (deg)	Knee (deg)	Ankle (deg)	Pelvis (deg)	Trunk (deg)
MBT	-8.84 (7.17)	7.38 (7.36)	6.74 * (5.45)	2.19 (5.42)	-4.09 * (3.76)
Normal	-8.90 (8.07)	4.44 (8.31)	4.20 * (4.72)	2.69 (5.78)	-2.93 * (4.06)

Table A4: Minimum sagittal joint angles (mean \pm SD) during walking for the normal and MBT conditions (* denotes statistically significant difference between conditions).

MBT gait evaluation.

	Hip (Nm/bw)	Knee (Nm/bw)	Ankle (Nm/bw)
MBT	0.78 (0.59)	-0.39 (0.33)	0.04 (0.08)
Normal	0.92 (0.78)	-0.41 (0.32)	0.04 (0.08)

Table A5: sagittal joint moments (mean \pm SD) during walking for the normal and MBT conditions at foot strike (* denotes statistically significant difference between conditions).

	Hip (Nm/bw)	Knee (Nm/bw)	Ankle (Nm/bw)
MBT	0.21 (0.89)	-0.22 (0.29)	-0.01 (0.10)
Normal	0.60 (0.93)	-0.32 (0.29)	-0.03 (0.10)

Table A6: sagittal joint moments (mean \pm SD) during walking for the normal and MBT conditions at toe off (* denotes statistically significant difference between conditions).

MBT gait evaluation.

	Hip (Nm/bw)	Knee (Nm/bw)	Ankle (Nm/bw)
MBT	8.06 * (4.66)	-0.06 (0.37)	0.96 * (0.57)
Normal	12.41 * (5.68)	0.32 (1.17)	1.26 * (0.50)

Table A7: Maximum (extension / plantar flexion) sagittal joint moments (mean \pm SD) during walking for the normal and MBT conditions (* denotes statistically significant difference between conditions).

	Hip (Nm/bw)	Knee (Nm/bw)	Ankle (Nm/bw)
MBT	-0.67 (1.27)	-2.18 * (1.33)	-0.34 * (0.35)
Normal	-1.97 (4.33)	-2.99 * (1.53)	-0.73 * (0.46)

Table A8: Minimum (flexion / dorsiflexion) sagittal joint moments (mean \pm SD) during walking for the normal and MBT conditions (* denotes statistically significant difference between conditions).

MBT gait evaluation.

	fz_i (N)	fz_a (N)	fy_max (N)	fy_min (N)
MBT	840.07 * (164.54)	789.32 (110.05)	42.58 (10.37)	-45.60 * (12.04)
Normal	812.09 * (180.07)	785.59 (129.27)	41.31 (10.79)	-42.60 * (11.90)

Table A9: Ground reaction force variables (mean \pm SD) during walking for the normal and MBT conditions (* denotes statistically significant difference between conditions).