In-Shoe Pressure Distribution in MBT Shoes versus Flat-Bottomed Training Shoes: A Preliminary study

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Contents

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1.Abstract

Background: The effect shoes have on plantar pressures is of interest due to the association with foot pathology, such as ulceration and pain. Masai Barefoot Technology (MBT) shoes are a novel design with a curved sole. They have not previously been tested in this area, but their unique construction may have potential uses in pressure alleviation. The aim of this study was to assess the effect MBT shoes have on plantar pressure.

Methods: Data were collected with pressure sensing insoles, in two footwear conditions: MBT shoes and control flat-soled trainers. Mean and Peak Pressures in 4 anatomically defined areas of the foot, and Contact Area of the whole foot, were recorded in both footwear conditions.

Principal Results: Standing in the MBT shoes resulted in lower peak pressure in the midfoot (21%lower) and heel (11%) compared to in the control shoe, and much increased pressure in the toes (76%). The mean pressure was also increased in the toes and forefoot in MBT's, and decreased in the midfoot and heel. Overall, compared to the control shoe MBT's gave a pattern of pressure distribution that was shifted towards the front of the foot. However, more research is needed to assess their clinical application.

2. Introduction

Shoes receive the blame for many foot deformities and symptoms. Problems like valgus deflection develop in higher proportion in toddlers after they are introduced to shoes[14], and the higher prevalence of foot pathology in women is linked to their increased tendency to wear high heeled and ill-fitting shoes[7].

Increased plantar pressure in shoes has been linked to ulceration, stress fractures, plantar fasciitis, heel spurs and metatarslagia, among other problems [3, 15, 20, 21]. Consequently methods of lowering or redistributing plantar pressure are much sought after. Current methods use in-shoe orthotics or customised orthopaedic footwear (e.g. 'rocker bottom' shoe)[1, 15]. There is relatively little scientific evidence to support such interventions[1, 12, 28] and the benefits are assumed to come from these devices significantly altering the pattern if pressure distribution in a favourable way, for instance decreasing the pressure on the hindfoot to relieve pain in heel spurs.

Studies on plantar pressure involve either a pressure platform the subject walks over, or insole sensors that can be placed directly into the shoe. The latter type of system allows for more natural results, as the subject is less likely to adapt their walking pattern if not stepping on to a platform[19], and data can be collected continuously. The disadvantages of insole systems are that they are more susceptible to mechanical damage as they are repeatedly put in and out of shoes and their reliability after repeated or excessive loading or a hot, humid environment (e.g. in a sweaty sports shoe) is unknown[30]. However, studies examining the validity of insole measurements have found them to be reliable and useful in determining the properties of weight bearing in the foot[18, 19, 30].

Previous studies have found that shoe design can alter the plantar pressures in specific regions of the foot. Rockers soled shoes used as an intervention in diabetic feet decrease the pressure in the medial and central forefoot and toes, but increase the pressure in the rest of the foot[27, 28, 29]. High heeled shoes have often been blamed for producing foot problems by increasing the pressure in the forefoot[2, 7], yet they have also been employed as therapeutic measures when their pressure redistribution properties are beneficial, such as in plantar fasciitis, as they relieve the pressure on the aponeurosis and hindfoot. The Cochrane review[28] states that increased pressure from abnormal loading, such as from ill-fitting shoes or foot altering pathology (e.g. callouses), leads to tissue damage and ulcers.

The designers of the Masai Barefoot Technology shoe (MBT) have further developed the idea that footwear can have multiple effects on foot health and pathology. Based on observations of the Masai tribe who are not accustomed to wearing shoes, the MBT is designed to recreate natural uneven walking surfaces to reduce problems caused by today's rigid soled shoes and hard ground[31]. Amongst many other benefits[23, 31], the makers of MBTs claim that the shoe design with an unstable rounded sole (Figure 1A) distributes plantar pressure more equally and reduces the concentration of pressure on the heels.

Since the MBTs are available commercially, these effects on pressure, if beneficial could allow people to wear these shoes without consulting a specialist (e.g. orthopaedic surgeon) and could be used prior to any foot pathology to prevent it occurring. They could also be used by patients experiencing problems such as heel spurs or metatarsalgia that may be relieved by pressure redistribution[4]. The aim of this study therefore, was to systematically assess the effect of the MBT shoe on plantar pressure.

3. Methods

3.1. Subjects

Ten healthy adults, 4 male 6 female, took part in this study, sampled by convenience. All of the participants were asymptomatic and had no deformities. Shoe sizes ranged from 5 to 11 (UK), and age ranged from 21 to 39. The mean age was 24 (SD=5.46).

3.2. Materials

All the participants were fitted with MBT shoes (Fig. 1A) in the correct size. In the control condition, participants wore their own flat- bottomed sports shoe (example in Fig. 1B)

Figure.1. A) MBT shoe. Note the curved sole in anterior-posterior direction. B) Regular sports shoe used as control.

The plantar pressure measurements were made with the PEDAR-x system (Novel Electronics, Germany). The system consists of pressure sensing insoles connected to a box which attaches around the subjects waist and transmits information to the PEDAR-x software via bluetooth wireless communication. The insoles contain 99 capacitive pressure sensors which produce on the software screen a grid representing pressure distribution as the sensors are sampled at a rate of 50Hz. Each insole is 2.5mm thick and available in a range of sizes so they were fitted to each subject's shoe. Figure 2 shows the system components.

3.3. Procedure

Prior to the experiment, the participants were gathered together with an instructor from the MBT Academy* who fit each subject with the MBT shoes and led them through a short program of exercises called Dynamic Stability Training (DST), following MBT training Protocol[*, 31]. Once the participants had become acclimatised to the shoes they were taken in groups of three to the experiment area.

Each participant was tested in the experimental conditions as follows:
The correct size PEDAR insoles were fitted in to the control shoe, and the shoes tied on to the feet in the normal way. The PEDAR-x box was attached around the subject's waist and connected to the insoles (Figure 2). Before any data were collected, the insoles were calibrated, by the subject standing on one leg to unload the left then the right foot, to calculate the base line, and the subject walked up and down the room to get used to the equipment. The walkway was a level, thin carpeted space and walking

pace was whatever was comfortable for the subject to best mimic natural circumstances[11]. Data were collected as the participant walked up and down the walkway three times and then as they stood still on both feet for 30seconds. This procedure was then repeated with the MBT shoes.

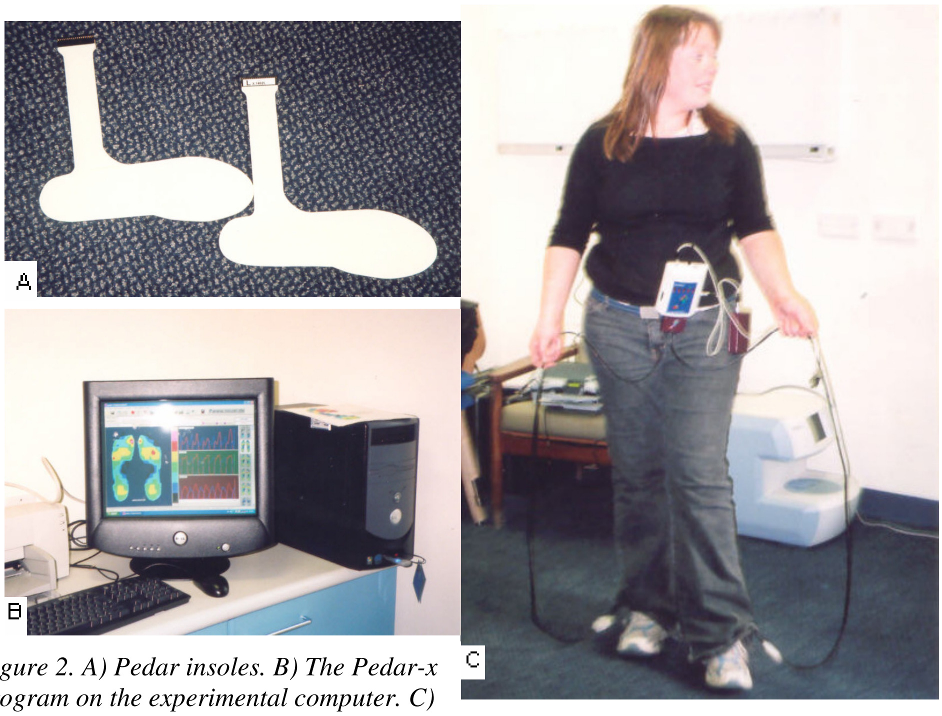


Figure 2. A) Pedar insoles. B) The Pedar-x program on the experimental computer. C) subject wearing the testing equipment.

3.4. Analysis

Data were collected and saved for each participant walking along the walkway 6 times (3 times per shoe condition) and standing (30seconds per shoe condition). For analysis the steps at the beginning and end of walking were removed from the data to discount situations were the participant would be pushing off or turning on one foot. Using the PEDAR software, the area of the insoles was divided up into 4 sections by creating a mask that groups sensors into anatomical areas. In accordance with the Footpressure Interest Group's[9] recommendations, the mask consisted of 4 areas: toes, forefoot, midfoot, heel (Figure 3).

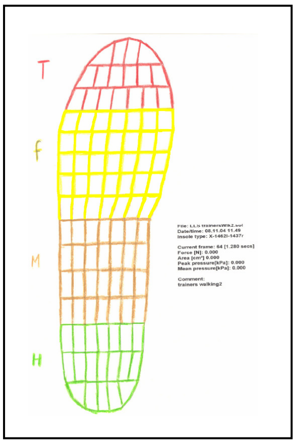


Figure 3. Representation of Mask. Red (T) = toes, Yellow (F) =forefoot, Brown (M) =midfoot, Green (H)= heel

For each section of the mask: the software calculated Mean Pressure (KPa); average pressure over all the frames, and Peak pressure (KPa); the maximum pressure that occurred in one sensor over the selected frames.

The Contact Area (cm^2), the area of all loaded sensors over the insole, was also recorded. The measurements for the left and right foot were averaged together. The resulting data were copied into SPSS (version 11.5) for statistical analysis. Average values, standard deviation and scatter-plot representation of the data were done within this program.

4. Results

MBT's decreased Peak Pressures in the forefoot and midfoot when walking, and in the midfoot and hindfoot when standing (table 1). Peak pressure was raised in the toes in MBT's in both standing and walking conditions. The most dramatic difference was during standing, where the MBT shoes increased peak pressure in the toes by 76%, and lowered peak pressure in the midfoot and heels by 21% and 11% respectively.

Table 1. a) Measured values for Peak Pressures (KPa) Walking

SHOE	MOTION		N	Minimum	Maximum	Mean	Std. Deviation
control	walking	TOES	30	182.50	587.50	307.00	104.88
		FOREFOOT	30	212.50	420.00	296.17	59.94
		MIDFOOT	30	102.50	275.00	173.25	43.85
		HINDFOOT	30	122.50	330.00	204.60	52.13
		Valid N	30				
mbt	walking	TOES	30	202.50	617.50	327.58	95.90
		FOREFOOT	30	175.00	400.00	288.08	65.85
		MIDFOOT	30	112.50	225.00	168.40	28.76
		HINDFOOT	30	130.00	307.50	208.17	44.69
		Valid N	30				

Table 1.b) Measured Values for Peak Pressures (KPa) Standing

SHOE	MOTION		N	Minimum	Maximum	Mean	Std. Deviation
control	standing	TOES	10	.00	87.50	42.25	25.04
		FOREFOOT	10	30.00	137.50	70.75	38.19
		MIDFOOT	10	50.00	135.00	86.25	29.35
		HINDFOOT	10	60.00	262.50	129.50	61.59
		Valid N	10				
mbt	standing	TOES	10	37.50	115.00	74.25	23.84
		FOREFOOT	10	45.00	155.00	88.75	31.34
		MIDFOOT	10	42.50	95.00	67.75	18.50
		HINDFOOT	10	75.00	192.50	115.50	31.79
		Valid N	10				

Table 2 shows the results for mean pressure measurements. The MBT shoe decreased the mean pressure in the midfoot and hindfoot regions in both standing and walking conditions. Again, there was a big increase in the pressure reading for the toes when the subjects were standing in the MBT's, with a mean pressure increase of 83%. The biggest decrease in pressure in MBT's was in the midfoot, with a reduction of 44% when standing and 15% when walking.

Table 2. a) Measured Values for Mean Pressure (KPa) Walking

SHOE	MOTION		N	Minimum	Maximum	Mean	Std. Deviation
control	walking	TOES	30	26.65	60.24	42.97	10.80
		FOREFOOT	30	41.37	73.24	56.92	8.96
		MIDFOOT	30	13.77	36.49	25.48	5.70
		HINDFOOT	30	44.42	102.03	71.06	14.08
		Valid N	30				
mbt	walking	TOES	30	27.57	98.30	49.93	15.05
		FOREFOOT	30	38.69	70.43	56.99	9.15
		MIDFOOT	30	11.06	32.12	21.57	5.78
		HINDFOOT	30	44.47	97.54	68.23	13.96
		Valid N	30				

Table 2.b) Measured Values for Mean Pressure (KPa) Standing

SHOE	MOTION		N	Minimum	Maximum	Mean	Std. Deviation
control	standing	TOES	10	.00	20.00	5.99	6.07
		FOREFOOT	10	2.60	30.78	17.91	10.95
		MIDFOOT	10	6.07	50.00	20.03	12.37
		HINDFOOT	10	31.58	95.90	62.92	20.18
		Valid N	10				
mbt	standing	TOES	10	6.09	28.87	11.08	6.73
		FOREFOOT	10	6.29	36.57	26.54	8.54
		MIDFOOT	10	4.96	19.14	11.31	5.63
		HINDFOOT	10	35.25	101.21	60.02	17.10
		Valid N	10				

Both the peak pressure and the mean pressure were increased in the forefoot and toes in MBT's when the subjects were standing still for 30 seconds. This may be related to the finding that compared to wearing the control shoe, MBT's increased the contact area (the number of loaded insoles) when standing so there will be more sensors giving pressure measurements in the different regions of the foot. The area bearing the weight of the person standing was increased by 11.9% (from 81.7 cm^2 to 91.4cm^2) in MBT compared to the control. There was no difference (0.02cm^2) in loaded area between the MBT and control shoe when walking.

The most consistent finding, when both standing and walking, was decreased pressures in the midfoot in MBT's.

Table 3. Contact Area (cm^2)

MOTION		N	Minimum	Maximum	Mean	Std. Deviation
standing	control shoe	20	33.77	128.95	81.68	23.87
	MBT shoe	20	70.50	114.85	91.40	13.62
	Valid N	20				
walking	control shoe	20	106.65	178.97	143.38	21.43
	MBT shoe	20	107.05	183.42	143.36	22.38
	Valid N	20				

The graphs in figures 4 and 5 demonstrate the pattern of the results. The data for standing and walking were combined in figure 5.

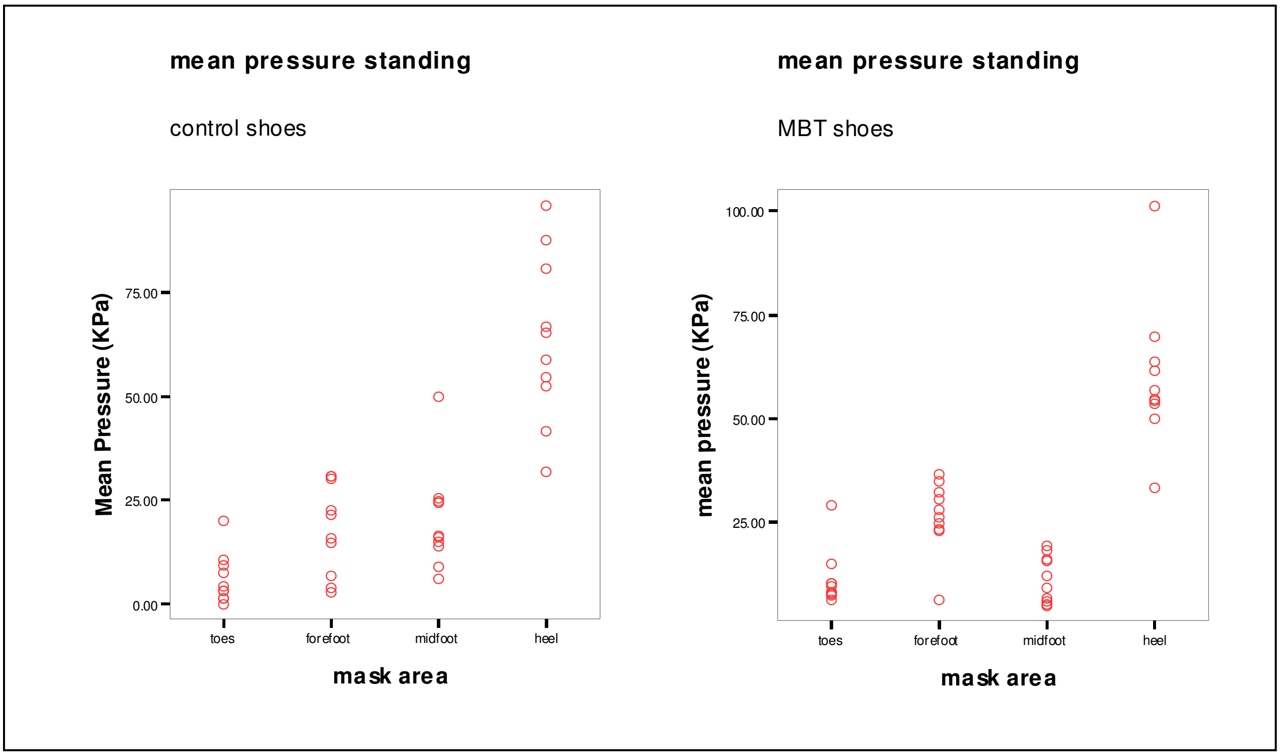


Figure 4.a) Mean Pressures when the subjects were standing.

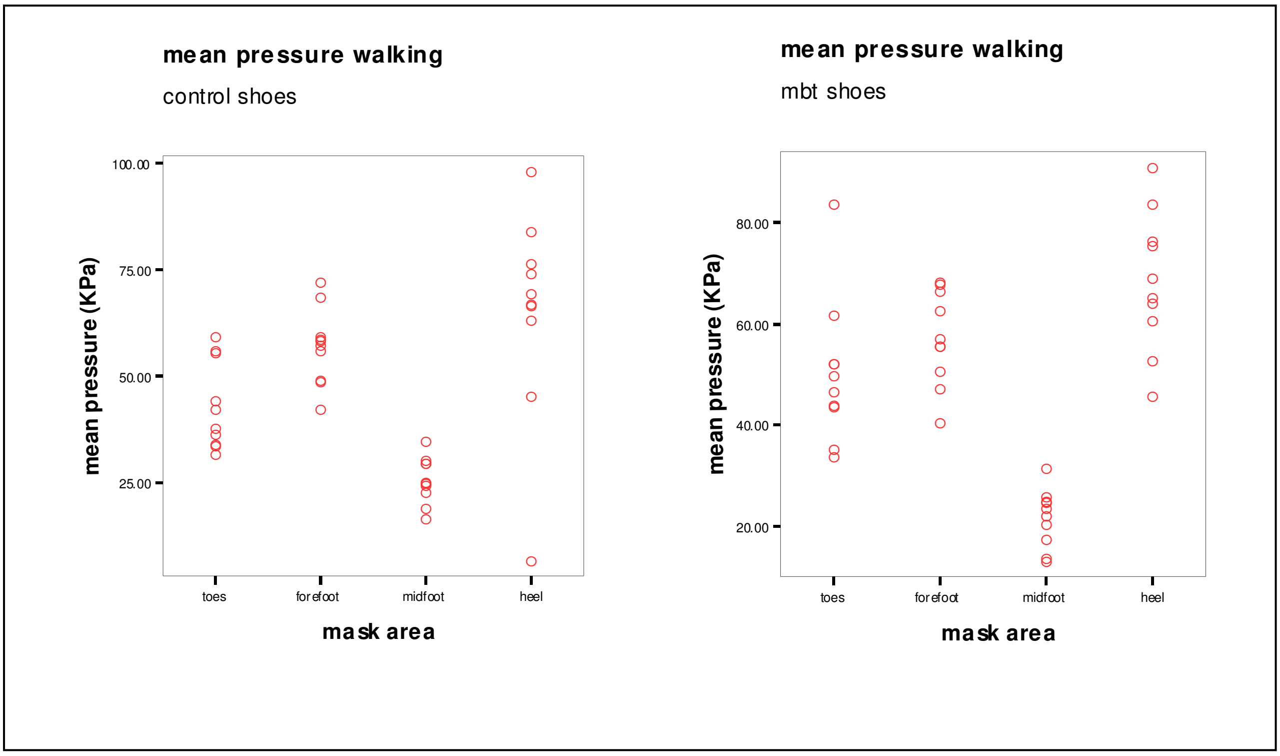


Figure 4.b) Mean Pressures when the subjects were walking.

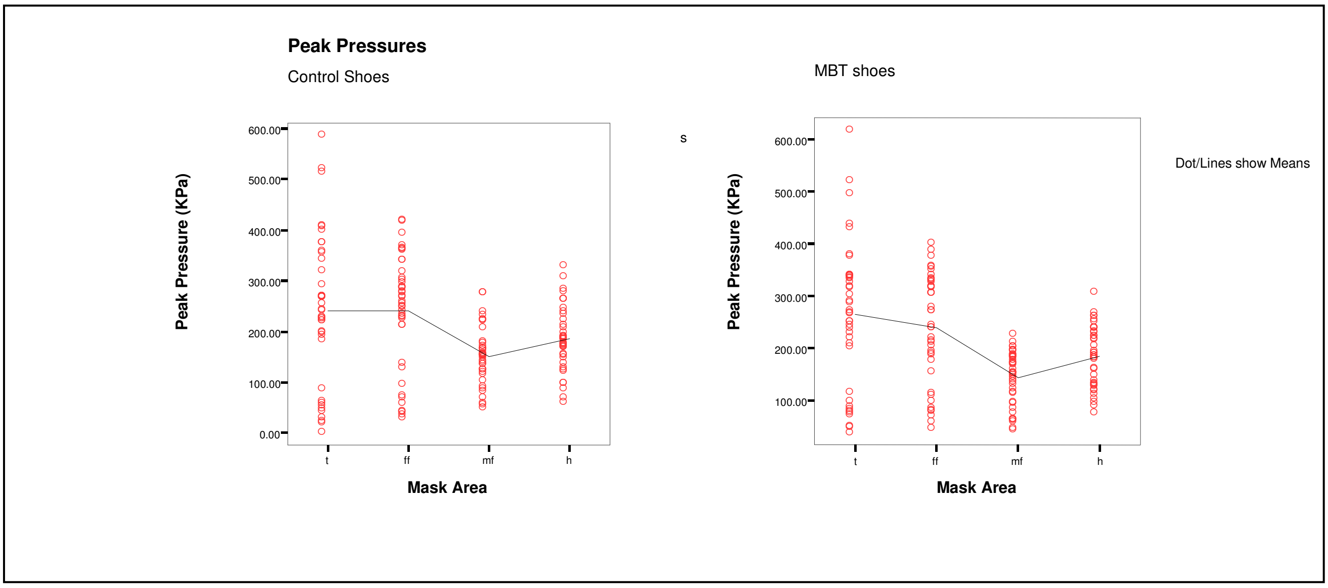


Figure 5. Scatterplots showing total Peak Pressure

5. Discussion

5.1. Findings

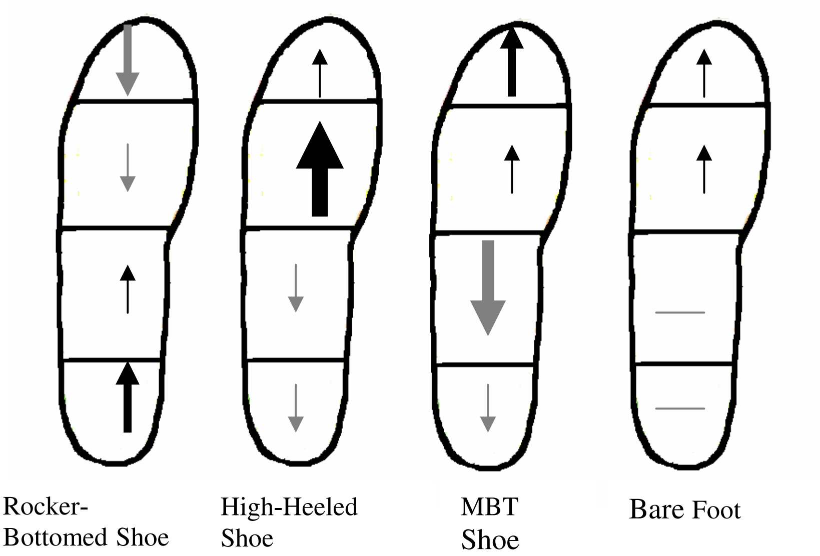
The purpose of this study was to investigate differences in plantar pressure in MBT shoes compared to normal flat training shoes.

MBT shoes altered the distribution of plantar pressure, with increases and decreases of pressure in certain regions of the foot. Overall decreases in plantar pressure were found in the posterior half of the foot, and increased pressure in the forefoot and toes. These findings are almost directly opposite to the results of studies involving rocker-bottomed shoes[26, 27, 29], where pressure is found to be decreased in the toes and forefoot and increased in the midfoot and heel.

The MBT results had more in common with those obtained by studies on high-heeled shoes [2, 8]. Nyska et al[24], and Broch et al[2], found that the pressure under the calcaneus decreases as heel height increases and there is forward shift of weight. A similar front-loading pattern is found in studies on barefoot plantar pressure[4, 8]. Differences in pressure characteristics in these conditions however are that high heels load the medial side of the foot more[24] , while bare feet distribute the pressure more evenly across the metatarsals[8]. Compared to bare feet or flat shoes, the contact area is also reduced in high-heels[8, 24]. According to Anderson et al[22], the average contact area of the foot when standing barefoot is $100cm^2$. This study found lower values than this in both types of shoes tested, but the MBT produced the largest one, closest to the barefoot value. The pattern of load bearing in MBT's therefore does appear to more closely resemble bare feet (figure 6).

The forward shift of pressure in MBT's is due to the sloping design of the shoe base displacing the weight away from the heel. Lundeen et al[17] found that pressure is decreased in the heels when walking downstairs because of the position of the foot and the fact that the heel only makes contact with the ground for a short period. In a similar way the curve away from the heel in the MBT sole means that the rear foot is only briefly in contact with the surface.

Figure 6. Schematic representation of pressure distribution characteristics in different shoe types compared to flat soled trainers. The size of the arrows represents the extent of the difference in pressure.



The anterior foot has a greater surface area than the rear and so weight redistribution onto this area may explain why the contact area is greater in MBT's. Increased area may also be due to instability. When people stand upright, their centre of gravity continually shifts around so the centre of pressure is constantly displaced[2, 21]. The rounded sole of the MBT design means that the individual is balancing and there is even greater shift of gravity[23] so more areas of the insole will be loaded over time.

5. 2. Critical analysis

The sample size of this experiment (10 participants) was too small to allow definite conclusions to be drawn and to allow further statistical analysis (such as analysis of variance). The investigation should be extended to see if the trends can be projected. Sample size was limited in this case due to the training session required prior to the experiment and the need for MBT shoes to be supplied by the manufacturer in the correct sizes.

The room in which the research was carried out was fairly narrow, so required the data to be collected while walking straight up and down. This meant there was not room for a figure of eight to be used, as is preferred by the Footpressure Interest Group protocol[9], but there was sufficient space for 16 steps which is above the minimum recommended[9]. Some papers have argued that the walkway should not be carpeted as this may affect the pressure measurements. However, in this study, the thinly carpeted room was deemed appropriate as it was level and flat and the comparison between the two shoe types in normal everyday conditions was what we were interested in. Likewise, the subjects' walking pace was not controlled, so that they could walk in a natural, comfortable way. Since walking speed can affect the pressure however[3], some studies have used methods such as metronomes to control the pace, and this area could be looked at in further investigations.

Another uncontrolled variable in this study was the control shoe. Subjects were invited to use their own flat-soled training shoe, but no other specifications were made. Consequently there were varying types of shoe; some were modern style running shoes with padding and light support features, some were plain, flat sneakers, and some were old and badly worn. According to Nyska et al[24], walking patterns may be altered and unnatural when first walking in new shoes, so using subjects own shoes and giving them training and practise time in the MBT shoes was to minimalise this. Standardising the control shoe is a common problem in plantar pressure studies as it is difficult to control all aspects of the shoe design (e.g. fastening,age) while getting them to fit the test subjects. The pressure findings should be compared to bare-foot conditions, but this is difficult to do with an insole pressure sensor.

Calibrating the PEDAR system by having the subject standing on the pressure insole may be insufficient as the insole is not loaded evenly and some sensors may thus not have been calibrated at all[25]. Also, using this method of calibration required the subject to balance on one leg, which may give an unnatural loading pattern. The PEDAR-x system can also be calibrated with an air filled bladder to uniformly load each sensor with a known pressure. This equipment was unavailable for this study but could be used in further investigations.

The pressure insoles came in a range of sizes, which were fitted to the subject's shoes, but they did not come in different widths and they may wrinkle or slip around inside the shoes. Also, the same masks were applied to all the subjects' data for analysis, but these may not have represented the same anatomical points on each individual's feet. A way to overcome this may be to use discrete pressure transducers which could be fitted to the desired points on an individual's foot. However, this would be more time consuming and would require fixation to the bottom of the foot, which may give a strange sensation to the subject and alter the way they walk[25]. The insoles used were thin and unobtrusive, and the subjects reported no change in sensation.

The mask used for data analysis (figure 3) was divided into 4 sections as it is the maximum number of regions the software would allow and the 4 regions selected are the minimum recommended by the Footpressure Interest Group[9]. Further dividing the foot area would be of interest as it could demonstrate the pressure on medial and lateral sides and allow the MBT to be more adequately compared with bare feet and high-heeled shoes, as mentioned above. The medial /lateral pressure distribution is important as pressure on the Hallux is supposedly the main contributory factor in pressure-related problems[14, 24].

5.3.Clinical relevance

High heeled shoes have been linked to many pathological processes in the feet, but have also been used therapeutically (e.g. for relief of compressive pain in the heel)[2, 14]. If MBT's have similar properties to high-heeled shoes but with pressure more evenly distributed in the forefoot and over a larger area, then they would be a better alternative. MBT's lace on to the foot so the foot is fully enclosed, so unlike most high heeled shoes, the foot can not slip forward, compressing the forefoot in the toe-box, and the gait does not have to be altered to hold the shoe on. MBT's were also reported to be extremely comfortable, so could be worn for longer periods of time. There is a correlation between pain and average pressure measurement (Hodge et al)[13], so as common sense would suggest, experimenting with different types of shoes until the most comfortable is found is likely to find the most beneficial pattern of pressure distribution.

Heel and midfoot pressure are affected by arch structure, body weight and the thickness of plantar soft tissue[20].As MBT's were found to reduce pressure in these areas, they may be useful in Pes Planus or other arch problems, obesity, and degeneration of the calcaneal fat pad with aging[3, 20]. Existing therapeutic measures for calcaneal spurs (orthotic support from heel to base of metatarsals) and plantar fasciitis, aim to relieve pressure in the midfoot and longitudinal arch[6, 10 14], so MBT's may also be of use to these patients. Rocker-soled shoes that are used to prevent ulcers or skin breakdown in neuropathic/diabetic feet[28] (distribute pressure in the opposite way to MBT's) only work if the patient is most susceptible to skin breakdown is in the usual lateral forefoot/toes area[26, 29]. If the problem is mainly in the rearfoot than MBT's may be useful.

All of the participants in this study were free of pathology and under 40; further research on patients with foot problems and in the elderly (when age-related loss of the longitudinal arch and plantar tissue may increase the need for relief of pressure in the posterior foot) would reveal more about using MBT's therapeutically.

5.4. Conclusion

MBT's produced a different profile of pressure distribution to flat-soled trainers. Further testing with more subjects and different shoe types is required but these preliminary results indicate that shoe design can have an effect on how pressure occurs through the feet and so advice about footwear could be tailored to relieve pressure in targeted areas.

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Appendix

ETHICAL ASSESSMENT FORM FOR OPTIONS STUDENTS (SSC4)

This form should be completed by both the student and supervisor. The completed form should be sent to the administrator of SSC4s at the College of Medicine Office, Teviot Place, at least 8 weeks prior to their Option projects starting. NOTE - A copy of the completed form must be kept by the student and included in the final report submitted for the examiners, and a copy must be uploaded into your portfolio.

SECTION A

1) Full Name of student Laura Louise Stewart……………………………

2) Matriculation number 0126814…………………………………………………

3) Email address of student s0126814@sms.ed.ac.uk……………………………

4) Name of supervisor Mr JNA Gibson……………………………

5) Email address of supervisor J.N.A.Gibson@ed.ac.uk……………………………………

6) Address of supervisor …………Dept of Orthopaedic Surgery (ward 209)………

…Royal Infirmary of Edinburgh…………………………

7) Title of project a) An Assessment of Weight-Bearing Characteristics in Patients Fitted with MBT (Masai Barefoot Technology) Shoes.
b) An Assessment of In-Shoe Pressure Patterns in Patients Following Mojé Ceramic Total Toe Replacement.

8) Brief outline of project Comparison of data for MBT shoes with individuals wearing normal training shoes and with patients following MTP fusion respectively.

9) Dates when the project will be performed 18 Oct 2004 – 11 Feb 2005

10) Group (A, B or C) ………A…………………………………………………

11) Where is the research going to be performed (e.g. hospital / ward, laboratory / building)

………RIE……………

SECTION B

1) Does the project involve any modification of investigation, treatment or other aspects of clinical practice?

NO

2) Does the project involve potentially physically or mentally invasive procedures on volunteers?

NO

If both answers above are NO then YOU DO NOT NEED TO FILL IN QUESTIONS 3-6, but please sign and date the form below and return it to the College Office. If you answered YES to either of the above, please complete the remainder of this form in full.