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Changes in gait and EMG when walking with the Masai Barefoot Technique

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Abstract

Background. The Masai barefoot technology® is used as a treatment option within the field of physical therapy to treat leg, back or foot problems. No information, however, is available on how Masai barefoot technology changes gait or muscle activity.

Methods. Twelve healthy subjects underwent 3D gait analysis with simultaneously collecting surface electromyography data of the leg muscles when walking with regular shoes and with Masai barefoot technology-shoes. Before data collection, subjects were trained in Masai barefoot technology. A within-subjects study-design compared walking with regular shoes and Masai barefoot technology.

Findings. With Masai barefoot technology, subjects walked slower with smaller steps. Movement pattern at the ankle showed major changes with increased dorsiflexion angle at initial contact followed by a continuous plantarflexion movement until terminal stance phase. With changed kinematics, alterations in the activity of tibialis anterior and gastrocnemius muscles could be observed. Smaller differences in movement and muscle activity were seen at knee and hip level.

Interpretation. Masai barefoot technology has never been documented in detail concerning changes in movement pattern or muscle activity. This study showed that Masai barefoot technology changes movement patterns, especially at the ankle, and increases muscle activity. It may therefore be a useful training method for strengthening the muscle groups of the lower leg. Knee flexion and electromyographic characteristics around the knee joint are slightly increased and need to be considered in patients with knee problems. Our findings provide critical detailed information on changes compared to walking in regular shoes, but the clinical relevance of those changes remains to be determined.

Keywords: Masai barefoot technique; MBT; Gait analysis; Electromyography; Physiotherapy

1. Introduction

Masai barefoot technologies® (MBT) developed a training device to strengthen the lower extremity muscles combined with the actual locomotion activity. MBT constructed a shoe with a rounded soft sole in anterior–posterior direction underneath the heel area, providing an unstable base of support with a rocker bottom. The shoes are widely used across Europe but less known around the rest of the world. The theory behind the concept is that the MBT-shoe transforms flat, hard, artificial surfaces into uneven surfaces, simulating the walking action of our barefoot ancestors, thus challenging the muscles to be more active. Within rehabilitation medicine, MBT is used by patients with a wide variety of problems. Problems related to the back (e.g. lower back pain, arthritis, neck problems, osteoporosis) are treated while it is believed that the rocker bottom of the MBT-shoe forces patients to walk more upright. Foot problems (e.g. hallux valgus, clubfoot, flatfoot, heel spur,

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Achilles tendonitis) or circulatory problems (e.g. diabetes mellitus) are treated with MBT while it is thought that MBT stimulates the intrinsic musculature of the foot and increases the blood flow. It is also suggested that MBT footwear serves as a proprioceptive tool thereby enhancing ankle stabilizing musculature. Patients are usually informed about MBT by their physiotherapist. MBT is also used by sportsmen and women while it is believed to strengthen their leg muscles by wearing the shoes during their daily activity. Obese people use MBT during walking in order to reduce body fat by enhancing energy expenditure. MBT is also used by healthy people to decrease health risks by integrating MBT in their daily living. No clinical effects of MBT, however, have been supported scientifically.

Although MBT has not been scientifically investigated, two previous studies have evaluated a similar shoe with an unstable rocking base of support. Each study investigated a different aspect. Attinger Benz et al. (1998) compared kinematic and kinetic parameters in non-symptomatic subjects walking with missing-heel shoes (an earlier model of MBT) and with a normal shoe-sole geometry. A reduced walking speed was found with the missing-heel shoes as a consequence of a shorter stride length combined with an increased cadence. The walking pattern differed drastically at the ankle joint, resulting in a sudden rocking motion at the heel followed by a significantly prolonged and augmented dorsiflexion. No differences were found at the level of the knee and hip joints. Kinetic analysis showed differences in the ground reaction force parameters until mid-stance. Attinger Benz et al. concluded that depending on the individual situation, these changes may be either (a) of considerable therapeutic value or (b) an unnecessary load for passive and/or active structures of the lower limbs and the spine.

Yamamoto et al. (2000), in contrast, examined the physiological and biochemical effects of wearing heel-less shoes over a wide range of walking speeds. It was concluded that walking exercise in heel-less shoes induced an increase of the calf blood flow at a moderate speed, and increased glycogen metabolism and noradrenaline secretion at a faster speed. The study by Yamamoto et al. did not include any electromyographic (EMG), kinetic or kinematic data but the results could indicate higher muscle activity of the calf muscles.

The purpose of the present study is to investigate how MBT changes the gait pattern and muscle activation. Surface EMG recordings of selected lower extremity muscle groups and three dimensional (3D) gait analyses were made in healthy adult subjects with regular street shoes and with MBT. Because MBT has become a product often used for therapy by physiotherapists and is sold by regular sport stores and orthopaedic shoe-makers, it is important to realize how MBT changes walking pattern and muscle activation.

2. Methods

2.1. Subjects

Twelve healthy subjects, 6 males and 6 females, volunteered to participate in this study (age: 38.6 (SD: 13.2) years, height: 173.3 (SD: 6.3) cm, weight: 77.4 (SD: 12.3) kg). Before data collection, all subjects underwent an instruction session of approximately 1 h by an official MBT-trainer and physiotherapist, followed by a training period of at least 4 weeks to ensure the appropriate MBT-technique. The subjects were asked to wear the shoes as much as possible and use them during daily living activities. All subjects were able to wear the shoes for a full day at the time of testing. On the day of data collection, the participants were screened again to assure the correct technique before data collection. Since the MBT-technique can only be employed with the specially designed sole geometry of the MBT-shoe, it was assumed that walking in regular shoes would not be affected. The subjects were asked to bring their own pair of street shoes normally worn during the day. Exclusion criteria for the shoes were: open-shoes (i.e. slippers, loafers) or high heels of more than 3 cm. A picture of the shoe used for MBT is shown in Fig. 1. The sole is constructed as a Sendersil construction from 12 layers but no tests on the sole material have been conducted for this study.

2.2. Study protocol

The study protocol consisted of 3D-gait analysis and lower extremity muscle activity measured under three conditions. The first condition was barefoot walking to get the subjects used to the testing surroundings. The second and third conditions were walking, wearing the individual regular shoes and the MBT-shoes. The sub-

Fig. 1. Shoe used in the Masai barefoot technology® (MBT).

jects walked at a self-selected speed. Testing continued until a minimum of six trials with clear data sets were collected for each testing condition. Data when walking with regular shoes were compared to data when walking with MBT.

2.3. Gait analysis

3D-gait analysis was made using a six-camera, 50 Hz movement analysis system (VICON 370, Oxford Metrics Ltd., UK). This system incorporated infra-red sensitive solid-state cameras for locating and tracking fixed reflective markers through space. The 15 markers were spheres (diameter 25 mm) covered with retro-reflective tape affixed with double-sided tape to specific landmarks bilaterally of the subject's legs according to the Helen Hayes Marker set described by Kadaba et al. (1990). This marker set included markers on the right and left anterior superior iliac spines, lateral midthigh, lateral midshank, lateral femoral epicondyle, lateral malleolus, second metatarsal head, calcaneus, and one marker on the sacrum. The heel and toe markers were placed on the shoes at the positions best projecting the anatomical landmarks. All other markers remained at the same positions throughout the testing protocol. Height, weight, leg length, widths of the ankles and knees, and tibial torsion were measured for appropriate anthropometric scaling. Joint angle data were expressed in percentage of gait cycle using the Polygon software (Oxford Metrics ltd., UK). A gait cycle starts with initial foot contact and ends with the following ipsilateral initial contact. Statistical analysis was performed to examine the significance of observed differences between peak values of variables at particular points in the gait cycle in the sagittal plane for hip, knee, and ankle joint complex. Since only little pelvic movement is expected, here the mean position over the whole gait cycle was calculated (Perry, 1992). The value for each point of interest was taken from all trials and averaged within subjects.

2.4. EMG measurements

Surface EMG was recorded simultaneously with the 3D-gait analysis. Bipolar Ag/AgCl surface electrode pairs with an electrode diameter of 10 mm and an inter-electrode spacing of 22 mm were placed on the clean shaven skin overlying the medial gastrocnemius, lateral gastrocnemius, tibialis anterior, vastus medialis, vastus lateralis, rectus femoris, and semitendinosus muscles of the subjects preferred leg when hopping. Preference was determined by asking the subject to hop on one leg for 5 m. For electrode placement, the SENIAM (Hermens et al., 1999) recommendations for surface EMG were followed. The ground electrode was placed overlying the tuberosity of the tibia. EMG signals were pre-amplified and band-pass filtered (10–700 Hz) using a Zebris system (Zebris, Tübingen, Germany; amplifiers of Biovision, Wehrheim, Germany) at a sampling rate of 2500 Hz. Initial contact and foot-off were determined using two force plates (Kistler Instrumente AG, Winterthur, Switzerland) embedded in the floor. The next ipsilateral initial contact was determined with the use of a small accelerometer (Biovision) attached to the heel. Force plate and accelerometer data were sampled at the same frequency as the EMG data.

The electromyographic signal was full wave rectified and then the data were time normalised by dividing the gait cycle into 16 equally spaced intervals ($\Delta 1$–$\Delta 16$). Root mean square values for each muscle signal were calculated for each of these time intervals. For each subject the maximum value of the EMG was calculated when walking barefoot and all other EMG data were expressed as percentage of this maximum value using the MATLAB software package (The MathWorks Inc., Natick, USA).

For all parameters, data of six trials under each condition were averaged for each subject. Paired *t*-tests were applied to EMG and kinematic data to determine changes between walking with regular shoes and with MBT. The level of significance was set at $P < 0.05$.

3. Results

3.1. Time–distance parameters

Time distance parameter results are shown in Table 1. When compared to walking in regular shoes, the cadence ($P = 0.044$), stride length ($P = 0.008$), step length ($P = 0.029$), and walking speed ($P = 0.006$) were significantly decreased during the MBT condition. Stride time ($P = 0.036$) and single support ($P < 0.001$) significantly increased during the MBT condition.

3.2. Kinematic data

No significant differences in the kinematic data from the frontal and transverse planes were found. Figs. 2 and 3 show the mean sagittal movement curves of pelvis, knee joint, hip joint and ankle-joint-complex. The results of particular kinematic data and values of the movement curves are presented in Table 2. For the sagittal plane movements, pelvic tilt did not alter when walking with MBT, but subjects had a reduced range of motion (RoM) throughout gait at the hip joint (48.2° (SD:4.2°) vs. 43.0° (SD: 6.1°)). This was due to a reduction in both peak hip flexion (42.7° (SD: 3.9°) vs. 40.0° (SD: 4.4°)) and peak hip extension (5.5° (SD: 5.2°) vs. 3.6° (SD: 6.1°)). At the knee joint level, RoM was also reduced (64.6° (SD: 4.5°) vs. 57.3° (SD: 6.6°)) with reduction in both peak knee flexion (67.4°

Table 1
Time–distance parameters

	Reg. shoes	MBT
Cadence (steps/min)	113.7 (12.0)	111.1 (10.6)[a]
Stride time (s)	1.06 (0.10)	1.09 (0.10)[a]
Stride length (m)	1.47 (0.10)	1.39 (0.13)[a]
Step length (m)	0.73 (0.05)	0.70 (0.07)[a]
Walking speed (m/s)	1.39 (0.15)	1.28 (0.12)[a]
Single support (%)	0.40 (0.03)	0.42 (0.04)[a]
Double support (%)	0.26 (0.04)	0.24 (0.03)
Foot-off (%)	61.7 (1.6)	61.1 (1.1)

Data are mean (SD) for walking with regular shoes and with the Masai barefoot technique (MBT).
[a] Statistical significant.

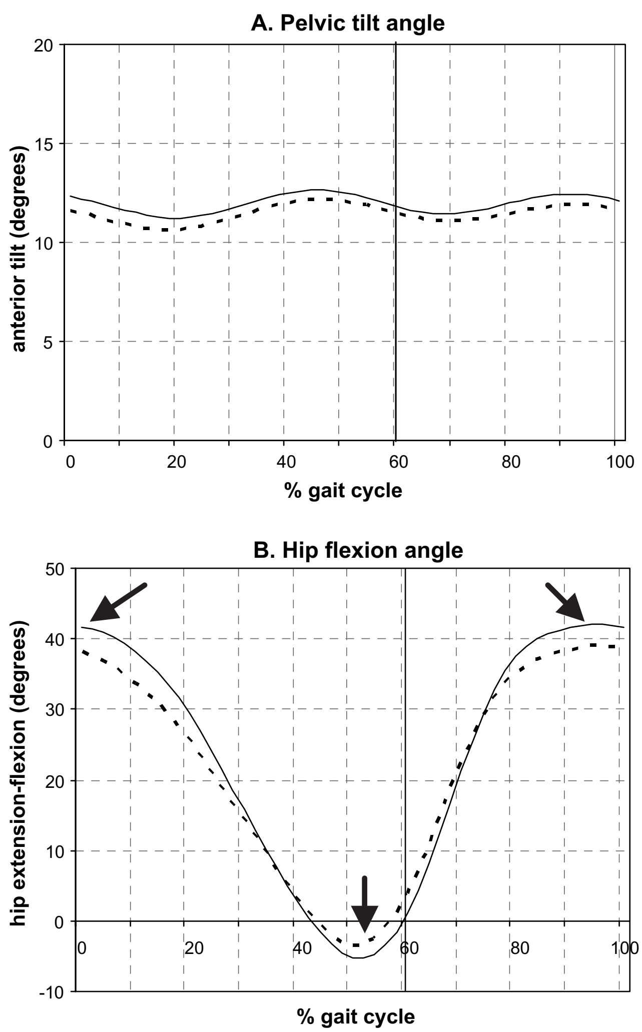

Fig. 2. Sagittal plane kinematic data of pevis and hip. Curves are mean (SD) for walking with regular shoes (—) and with the Masai barefoot technique (MBT) (- - - -); ↑ : statistical significant parameters.

(SD: 3.3°) vs. 63.6° (SD: 4.6°)) and minimal knee flexion (2.9° (SD: 3.0°) vs. 6.4° (SD: 3.9°)).

At the ankle-joint-complex, the dorsiflexion angle at initial contact increased from 2.9° (SD: 4.4°) when wear-

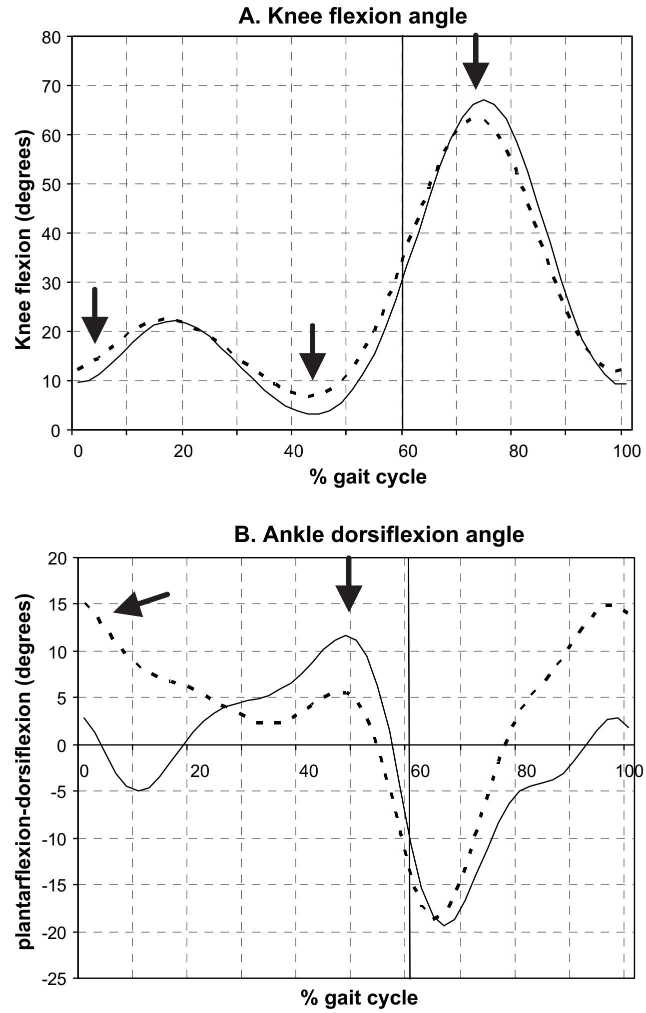

Fig. 3. Sagittal plane kinematic data of the knee and ankle joint complex. Curves are mean (SD) for walking with regular shoes (—) and with the Masai barefoot technique (MBT) (- - - -); ↑ : statistical significant parameters.

Table 2
Sagittal plane kinematic data parameters

		Reg. shoes (°)	MBT (°)
Pelvis	Mean pelvic tilt	12.0 (3.6)	11.5 (3.6)
Hip	RoM	48.2 (4.2)	43.0 (6.1)[a]
	Peak flexion	42.7 (3.9)	40.0 (4.4)[a]
	Peak extension	5.5 (5.2)	3.6 (6.1)[a]
Knee	RoM	64.6 (4.5)	57.3 (6.6)[a]
	IC flexion	9.7 (3.8)	12.2 (3.4)[a]
	Peak flexion	67.4 (3.3)	63.6 (4.6)[a]
	MS min flexion	2.9 (3.0)	6.5 (4.1)[a]
Ankle	RoM	31.5 (5.3)	34.8 (8.4)
	IC dorsiflexion	2.9 (4.4)	15.0 (4.6)[a]
	TS dorsiflexion	11.6 (4.2)	5.6 (7.2)[a]
	Peak dorsiflexion	11.8 (4.2)	15.8 (4.3)
	Peak plantarflexion	19.7 (6.0)	19.0 (6.0)

Data are mean (SD) in degrees; RoM: range of motion; IC: initial foot contact; min: minimum; TS: terminal stance; MS: mid stance.
[a] Statistical significant.

ing regular shoes to 15.0 (SD: 4.6) with MBT. With a continuous plantarflexion movement, the dorsiflexion angle decreased at terminal stance from 11.6° (SD: 4.2°) with regular shoes to 5.6° (SD: 7.2°) with MBT. RoM did not change throughout the gait cycle.

3.3. EMG

Data of the muscle activities are shown in Fig. 4. Compared to walking with regular shoes, tibialis anterior muscle activity was decreased in the first 0–12.5%

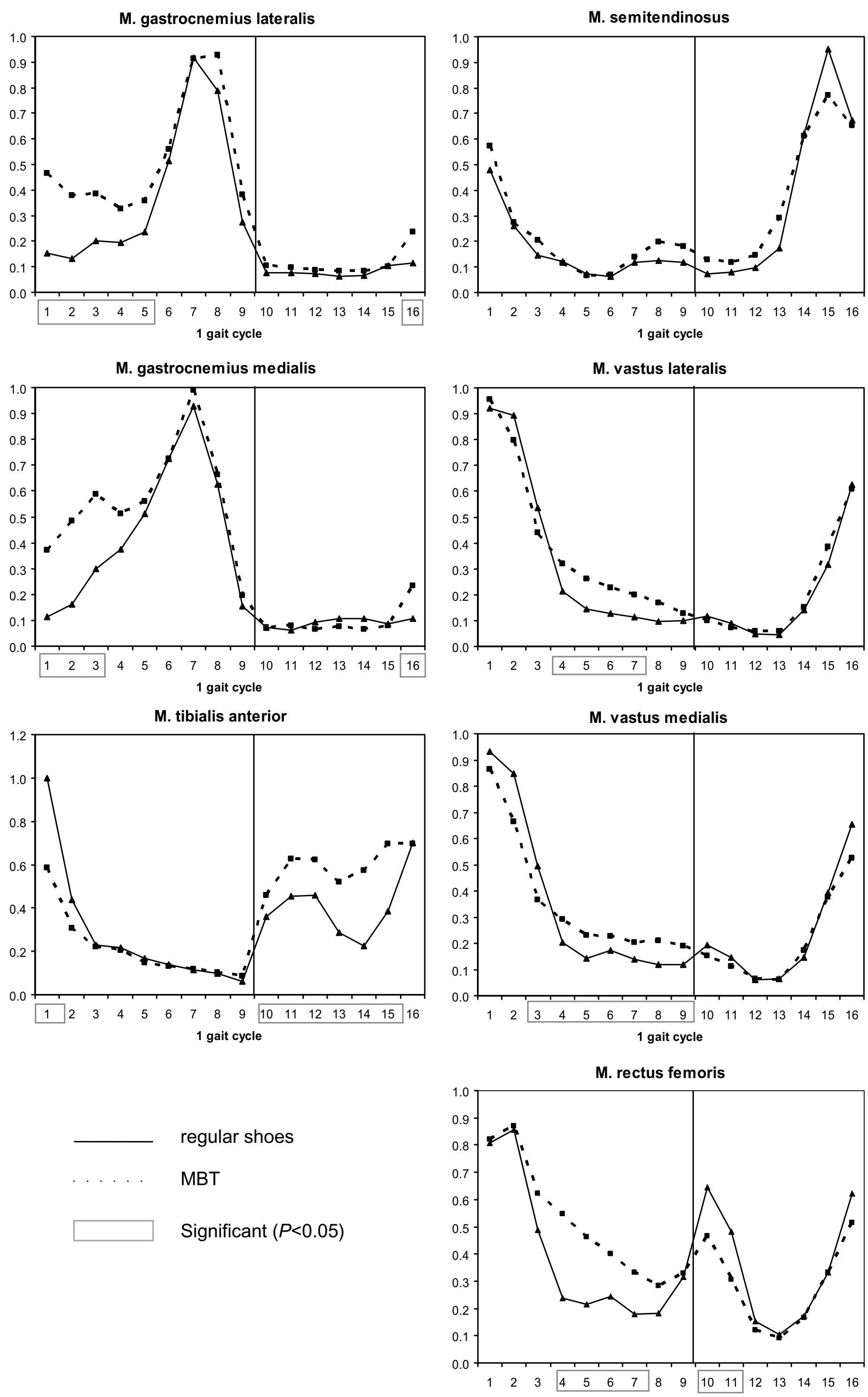

Fig. 4. Electromyographic data when walking with regular shoes and with the Masai barefoot technique (MBT). Curves are mean (SD) for walking with regular shoes (—) and with the Masai barefoot technique (MBT) (- - - -).

of the gait cycle, i.e. initial contact and loading response phase, and increased during the whole swing phase of gait with MBT. For the antagonist muscles, gastrocnemius medialis and lateralis, the level of activity was increased from terminal swing phase until midstance. The vastus medialis and lateralis muscle groups showed elevated levels of activity starting at mid-stance phase to toe-off. The rectus femoris muscle showed elevated activity in mid-stance phase and reduced activity in stance-to-swing transition period. Activity of the semitendinosus muscle did not show any alterations when walking with MBT compared to walking with regular shoes.

4. Discussion

MBT is a special walking technique with a specially designed shoe. MBT is used by a wide range of people: patients with foot, leg, or back problems, sportsmen, and healthy people. Because MBT has become a product often used for therapy by physiotherapists but is also sold by regular sport stores and orthopaedic shoe-makers, it is important to realize how MBT changes walking pattern and muscle activation. As no such information was available, this study investigated the changes in walking pattern and muscle activity when walking with MBT compared to regular shoes. With MBT, movement pattern around the ankle joint showed major changes. Dorsiflexion angle at initial contact was increased and followed by a continuous plantarflexion movement. With these changes, muscle activity of tibialis anterior and the gastrocnemius muscles altered accordingly. Smaller alterations in movement and muscle activity were seen at knee and hip level and subjects walked slower with smaller steps.

Any particular speed can be achieved by a combination of a certain step length and cadence. In this study, the subjects were free to choose their own comfortable walking speed. With MBT, subjects walked significantly slower due to a smaller stride length as well as a slight reduction in cadence. It is likely that part of the changes in the kinematic data at the hip, i.e. reduced peak hip flexion at initial stance and range of motion over the gait cycle, are due to this decrease in stride length (Messier et al., 1992; Van der Linden et al., 2002). The findings of this study agree with Attinger Benz et al. (1998) who looked at kinematic and kinetic parameters in non-symptomatic subjects walking with missing-heel shoes, i.e. a previous model of the shoe used in this study, and with a normal shoe-sole geometry. Although it is interesting that walking speed decreases with MBT, it would also be interesting to know how subjects would increase their walking speed with MBT to the speed achieved with regular shoes and if kinematic data of the hip would also increase and normalise.

When walking with MBT, both the gait pattern and muscle activity changed. Premature activation of the gastrocnemius muscles started in terminal swing phase. The activity of the gastrocnemius muscles during terminal swing up to toe-off is necessary for the continuous plantarflexion movement with MBT. The activity of the gastrocnemius muscles activation at the end of swing phase and early stance phase coincides with antagonistic activity of the tibialis anterior muscle. This co-contraction may contribute to stabilization of the ankle joint upon heel-strike and the improvement of foot stability during early stance phase. The soft heel together with the thicker shoe-sole, which results in a raised position of the ankle joint above the floor, makes the MBT-shoe less stable. The co-contraction of the gastrocnemius and tibialis anterior muscles compensate for this instability. The increased muscle activity of the tibialis anterior muscle during swing phase is necessary for the increased dorsiflexion movement compared to walking in regular shoes.

Activity of the vastus medialis and lateralis muscle groups was increased with MBT during most of the stance phase. Knee flexion in this part of the gait-cycle also increased with less extension of the knee during mid-stance phase. Walking with this slight increase of flexion at the knee joint could increase the load on this joint and therefore care must be taken in patients with knee problems when prescribing MBT. Although activity of the rectus femoris muscle was also increased during this period of the gait cycle, similar to the vasti muscles, this is actually believed to be cross-talk activity from the vasti muscles. A study by Nene et al. (2004) comparing surface and fine wire EMG of the rectus femoris muscle during gait, clearly showed that, with the fine wire method, this muscle was only active in the stance-to-swing transition period. A burst of EMG activity recorded at initial contact by the surface signal but not by the fine wire EMG, was due to cross-talk from vastus intermedius. It was concluded that rectus femoris is active only during stance-to-swing transition and the activity during swing-to-stance transition, as described in the literature, is very probably due to cross-talk.

5. Conclusion

In conclusion, this study showed a change in gait pattern when walking with MBT compared to walking with regular shoes. It has been shown that with kinematic changes at the ankle-joint-complex, muscle activity of the gastrocnemius and tibialis muscles increased and the co-contraction of these muscles could provide for stability. MBT could therefore be used as a training method to strengthen the leg muscles. MBT should be used cautiously in patients with knee problems since it was shown that subjects walked with slightly more flexion during stance phase accompanied with increased muscle activity of the vastus medialis and lateralis. Activity of the rectus femoris muscle reduced during the stance-to-swing transition period.

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