

Nigg, B., Federolf, P., von Tscharnher, V., Nigg, S. (2012). Unstable shoes: Functional concepts and scientific evidence. *Footwear Science*, 4, 73-82.

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Unstable Shoes – Functional Concepts and Scientific Evidence

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Conceptual review article for submission to Footwear Science
As part of the special issue on “Instability Thematic Issue”
September 2011

Key words: Unstable shoes, stability, muscle training, pain, injuries

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Word count abstract: 303

Word count text: 5785

Acknowledgements

The authors received funding from the da Vinci Foundation of Calgary, Canada, from the company Masai Barefoot Technology (MBT) in Switzerland and the Natural Science and Research Council of Canada (NSERC).

Abstract

The purpose of this paper is (a) to discuss the conceptual idea behind the development of unstable footwear and (b) to discuss the validity and scientific support of some selected claims made with respect to unstable shoes.

Concept:

Unstable shoes are built to provide a trainings device that uses instability as a strategy to train and strengthen muscles in the human locomotor system.

Specific Claims:

1. Ample evidence circumstantiates that unstable shoes currently on the market produce a substantial and significant increase of instability. The effects are most evident during standing but are also apparent in gait.
2. Unstable shoes induce an increase of activity in certain muscles in about 80 % of the population. The affected muscles change between different subjects. The highest relative increases were found in the small muscles crossing the ankle joint complex.
3. "Muscle toning" is, from a scientific point of view, not well defined and experimental data associating "muscle toning" with unstable shoes are not available.
4. There is evidence that unstable shoes improve the static balance performance of users whose balance skills are comparatively low. However, if the balance skills of a person are already good, then training effects through the use of unstable shoes are not detectable.
5. There is indirect evidence that unstable shoes reduce forces in the joints of the lower extremities.
6. There is conclusive evidence that unstable shoes can reduce the level of perceived pain. This has been confirmed in subjects suffering from pain in the knee joint and for subjects with low back pain.

Based on the results of this overview it seems that unstable shoes are associated with several possible benefits. It also seems that the effects are not consistent between different subjects. In our experience, positive effects can be shown for about 80 % of the test subjects.

Introduction

In the late 1990s, new walking and running shoes were brought to the market with a round and unstable shoe sole. The company that started this development was MBT (Masai Barefoot Technology out of Switzerland). These shoes were rather quickly a marketing success and currently, there are more than 25 companies that produce and sell such unstable shoes. These shoes were claimed by some of their users to produce excellent health and well-being related effects. The company MBT was also the leader in conducting research of this “unstable shoe concept” and, after some years of searching and understanding the effects of these changes to the shoe, it seems appropriate to summarize the current knowledge with respect to (a) the underlying concept and (b) specific claims that are made concerning such unstable shoes.

Whether on purpose or by coincidence, the concept used for these shoes was and is *to use instability as a training device*. Many claims were made about the effects produced by unstable shoes including that unstable shoes

- a) produce defined instabilities,
- b) increase muscle activities,
- c) improve muscle toning of the lower extremities,
- d) improve stability of the users,
- e) reduce joint loading and
- f) reduce pain.

The list of claims made could be expanded. However, the ones listed seem to include the majority of claims used in marketing statements of the major companies involved in the unstable shoe business.

The purpose of this paper is (a) to discuss the functional concept used for these unstable shoes and (b) to discuss the validity and scientific support of some selected claims made with respect to unstable shoes.

The concept

The concept of the “unstable shoes” did not always exist. The first unstable shoes were built without having a clear concept. However, over time, through co-operation between industry and academia, a concept for these unstable shoes started to develop. Currently, the concept of these unstable shoes can be summarized as follows:

Unstable shoes are built to provide a trainings device that uses instability as a mechanism to train the neuromuscular control and/or to strengthen muscles in the human locomotor system.

Coaches and athletes involved in high performance have used instability as a training strategy long before the unstable shoes were brought to the market. Top athletes used unstable situations like the wobble board to both improve their performance and reduce

their risk of injury. However, the construction of the MBT shoe was (probably) the first time that a shoe was developed where instability was used as a strategy to improve general health and/or performance aspects of average people and/or competitive athletes. It was probably also the first time that a shoe intended for casual use was specifically constructed to be a training device.

Initial publications addressed changes in kinematics and/or kinetics (Kälin et al., 2005; Boyer & Andriacchi, 2009; Buchecker et al., 2010; Nigg et al., 2010; Stöggli et al., 2010; Roberts et al., 2011). Other studies addressed the effects of unstable footwear on posture (New & Pearce, 2007). Some studies discussed the effects of unstable shoes on pressure distribution (Stewart et al., 2007; Bochdansky et al., 2008; Maetzler et al., 2008) and other studies addressed training effects with unstable shoes (Kraus et al., 2006; Korsten et al., 2008; Lohrer et al., 2008; Korsten et al., 2010; Landry et al., 2010). However, this review will concentrate on some specific claims that have been made about the effects produced by unstable shoes.

Selected Claims

(1) Unstable shoes produce defined instabilities

Static stability (standing in unstable shoes)

The effects of MBT shoes on static stability have often been investigated using center of pressure (COP) measurements. Different variables were studied, the area covered by the COP and the length of the COP excursion in a given time interval being the most frequent ones.

The results of these studies showed that COP excursions significantly increased in the two-legged stance conditions, for both the anterior-posterior and the medial-lateral direction when comparing the unstable (MBT) condition to the barefoot condition (Nigg et al., 2006; Landry et al., 2010). This result is demonstrated using illustrative data for one subject (Fig. 1). The initial “instability” results showed that the unstable shoes indeed produced a more unstable condition. Interesting in this context is that the instability occurred not only in the a-p direction, the instability for which the shoe sole was constructed, but was apparent also in the m-l direction. Compared to barefoot, the increase in the distance covered by the center of pressure was about 100 percent in the a-p direction and about 50 percent in the m-l direction. For the one-legged stance, however, no significant differences between MBT shoe and barefoot condition were found (Romkes, 2008).

Another study assessed static balance and reactive balance in children aged 10-17 with developmental disabilities. The study found that static balance was not influenced by prolonged use of MBT shoes. However, significant improvements were noted in children's reactive balance both with the shoes and barefoot (Ramstrand et al., 2008). The same group also assessed balance questions for women over the age of 50 using three standardized test conditions. They found significant improvements in several elements of their balance tests after using MBT shoes for 8 weeks (Ramstrand et al.,

2010). The differences were, however, not significant between the control and the test group.

Stability in Movements (walking/running in unstable shoes)

Stability of in movements is difficult to determine and there is still a dispute between researchers of different fields (e.g. biomechanics and motor control) about the appropriateness of definitions and interpretation paradigms. Two related but not equal definitions of the “stability” of human movement characterize a) the likelihood of falling, or b) the system’s susceptibility to perturbations. Studies relying on the second definition typically investigate features of the variability of the motion. In cyclic movements, such as walking or running, these features may be a) the variability in the amplitude of characteristic movement variables, or b) the regularity or irregularity of the variable’s trajectory over multiple stride cycles (called “complexity” in motor control research).

The impact of unstable shoes on both of these features has been investigated. Stöggl et al. (2010) found an increase in amplitude variability of 35% when wearing MBT shoes for the first time. They also found that wearing MBT shoes daily over 10 weeks reduced this variability to normal values. This suggests that MBT shoes induce perturbations (instability) into the system, but that regular use of MBT shoes leads to adaptations in the motor control system that allow to fully control the amplitude variability after 10 weeks.

Other studies (Tecante et al., 2010, Federolf et al., 2011) assessed how unstable shoes affected the regularity of movement patterns over 50 stride cycles. A particularly innovative aspect of this study was that no characteristic variable was pre-selected for the analysis. Instead, the analysis was performed on the main movement components, which were identified by performing a principal component analysis on 84 kinematic posture variables. This study showed that walking in MBT shoes led to significantly less regular walking patterns. This supports the interpretation of Stöggl and colleagues’ results that the motor control system was more affected by perturbations when walking in MBT shoes. Adaptation to frequent use of MBT shoes was not investigated in this study. Such an investigation would be particularly interesting since other research has shown that after an incidence perturbing the motor control system, e.g. a concussion, variability in motion amplitudes recover rapidly, while both, the recovery of regularity features and the actual risk of falling recover much slower (Cavanaugh et al., 2005). It seems likely that an intervention affecting the postural control system such as unstable shoes may also lead to rapid adaptations in amplitude control, while the susceptibility to perturbations remains increased for a much longer time. Such a result would demonstrate that the unstable shoes still challenge and train the postural control mechanisms long after the variability in amplitudes has returned to normal.

***In summary,
There is ample evidence that unstable shoes
currently on the market produce a substantial and***

significant increase of instability. Effects are most obvious during standing but are also apparent in gait.

(2) Unstable shoes increase muscle activity

Concept

To be able to use an unstable system as a training device one has to understand the function of the muscles for stability. When the locomotor system is in a stable static condition, the muscles of the human body show low activity levels. The locomotor system can get into a position where little muscle intervention is needed to keep the body in balance. However, when in an unstable condition (e.g. on unstable shoes), selected muscles of the human body will be activated to keep the locomotor system in balance. Thus, unstable shoes can be used to activate (= train) selected muscles of the locomotor system.

Methodological considerations (solution space)

Mathematically, the human locomotor system is an over-determined system with many combinations of muscle activities available for a given movement task. Two subjects using an unstable shoe will most likely not use the same muscle-combinations for a task as simple as walking. Consequently, the calculation of group means will often provide no significant differences since some subjects will use a specific muscle only minimally while other subjects will use the same muscle frequently. Thus, an appropriate method comparing muscle activities for different shoe conditions is a subject by subject analysis, quantifying for each subject whether or not muscle activities have been different. Such an analysis will allow quantifying the percentage of subjects where a change of shoes has produced a change in muscle activity.

There is a second issue to take into consideration when analyzing the muscle activity during movements: the main reason for activating the muscles is to facilitate the movement. When moving in less stable shoes, some additional activation will be necessary to correct deviations caused by the instability. However, such corrections may not be necessary in every step. Hence, when analyzing the EMG activity in individual steps, one would expect to find large variations, even in the results of individual subjects.

Large muscles

Assessments of the effect of unstable shoes on the activity of large muscles of the lower extremities have been discussed in many marketing statements of companies with unstable footwear. For example, initial marketing claims by Reebok mentioned a 28 % increase of muscle activity for the gluteus maximus, 11 % for the hamstrings and 11 % for the “calf muscles” when compared to a control shoe during walking (not significant).

Since this is obviously an important aspect, a summary of studies focusing on unstable footwear and their effects on the major leg muscles for the different activities follows.

Standing

For standing, two studies were found. In one study, an increase in EMG intensity was found in the tibialis anterior, gastrocnemius, vastus medialis, biceps femoris and for the gluteus medius, when compared with a stable control product (Nigg et al., 2006). However, only results for the tibialis anterior showed significant increases. The average increase in muscle activity over all five muscles was 39% (not significant).

A second study (unpublished industry report) compared an MBT prototype, a standard MBT shoe which was on the market and a control product. Results showed for the two unstable products a significant increase in EMG intensity in the rectus femoris muscle, a substantial increase in the vastus lateralis, and similar intensities in the biceps femoris (Fig 2). Based on these two results, it can be speculated that in general unstable footwear appears to increase muscle activity while standing. However, as mentioned before, the use of different muscles are not consistent across subjects.

Walking

Studies analyzing activity of large lower extremity muscles while walking in unstable shoes show generally a (not significant) trend towards increased muscle activity for selected muscles when compared to stable control footwear. Significant increases in muscle activity were seen, for instance, in the biceps femoris' total EMG intensity in a "RunTone" shoe when compared to two traditional running shoes (unpublished data from an Industry Report, 2010). In this comparison, the "RunTone" showed for all muscles the highest or second highest muscle activity.

A second study found no significant differences in EMG activities between a stable control and an MBT shoe. However, the unstable MBT shoe showed (when compared to the stable control shoe) increases in muscle activity of 26 % (SD = 24 %) for the tibialis anterior, 55 % (SD = 60 %) for the biceps femoris, 52 % (SD = 82 %) for the gastrocnemius, 4 % (SD = 13 %) for the vastus medialis and 16 % (SD = 25 %) for the gluteus medius (Nigg et al., 2006).

Another study showed a decrease in the tibialis anterior muscle activity in the first 12.5% of the gait cycle (Romkes et al., 2006). However, the same study showed elevated levels of muscle activity for the gastrocnemius medialis and lateralis, rectus femoris, as well as the vastus medialis and lateralis muscle groups during specific periods of the stance phase.

Running

Limited research has been conducted on the biomechanical effects of unstable shoes while running, as a lot of the unstable products are designed for walking. In one unpublished industry report for MBT an unstable shoe was compared to traditional

running shoes. No differences were found in muscle activity during the stance phase of the gait cycle. This could partially be explained in the solution space section of this document.

Small muscles

Many (often rather small) muscles cross the ankle joint complex. When moving around barefoot (in a-p and in m-l direction) most of these muscles are used. However, when moving in shoes some of these muscles may be only little or not at all activated since the shoe takes over some of their functions. Muscles that are not used deteriorate. It has been suggested that one specific function of unstable shoes is to activate these small muscles crossing the ankle joint (Nigg, 2010).

To quantify this muscle training effect an EMG array has been developed (Coza et al., 2010). The sensor consisted of 15 bipolar EMG electrodes, which were mounted slightly above the ankle joint (Fig 3).

The tests were performed while standing quietly for 30 seconds, comparing the EMG activity of an unstable (MBT) and a relatively stable control shoe condition. The experimental results for 12 subjects showed substantial average differences. The muscle activities in the unstable shoe were about 50 to 150 % higher than for the control shoe for the flexor digitorum longus, the soleus and the peroneus longus muscles. The differences were about 500 to 800 % higher than for the control shoe for the peroneus brevis, the extensor digitorum longus and the tibialis anterior muscles (Fig. 4). The high percentage differences (up to 800 %) are partly due to the relatively small values that are being compared. The EMG activities of the peroneus brevis and longus, extensor digitorum longus and tibialis anterior are quite small in a stable shoe in the bipedal stance.

The fact that only a few results are significant indicates (as mentioned before) that the individual muscle strategies for balancing are quite different and that the different subjects used different muscles for their individual balancing task. An individual analysis showed that 10 of the 12 subjects used significantly more activity in the unstable shoe condition for at least one or more muscles. The muscles that showed most often a significant increase in activity (a training effect) were peroneus longus and brevis (9/12), extensor digitorum longus (8/12) and tibialis anterior (7/12). Similar results were found in other studies. Thus, an unstable shoe increases muscle activity for some small muscles crossing the ankle joint complex for about 80 percent of the population.

In summary:

Unstable shoes induce an increase of selected muscle activities in about 80 % of the population. The affected muscles change between different subjects. The highest increases were found in the small muscles crossing the ankle joint complex.

3 Unstable shoes produce “muscle toning” of the lower extremities,

In advertising, one of the most often claimed effects of unstable shoes is that unstable shoes “tone muscles”. Specifically, it was claimed that unstable shoes train the muscles of the lower extremities (and especially the glutei) in such a way that they appear more “defined”.

The problem with this claim is that, from a scientific point of view, “toning” is not well defined and methods to assess “toning” are currently not available. A new possibility to quantify “muscle toning” is presented in this edition of the journal (Maurer et al., 2012). However, assessments of “toning effects” of unstable shoes have not been published yet and conclusions about the effects of unstable shoes with respect to “toning” are, consequently, not available.

The possibility of “muscle toning” has been associated with an increase in muscle activity. Based on the fact that the musculo-skeletal system is over-determined and allows many different muscle solutions for the same movement the results for any study analyzing the effects of unstable shoes on “muscles toning” and consequently muscle activity will most likely show no significant differences in the mean muscle activities between unstable and stable shoes. However, this does not answer the question of whether or not unstable shoes do “tone” muscles. Again, to study this question, the analysis must be subject-specific.

The American Council of Exercise (ACE) commissioned a study addressing the question of “muscle toning” by assessing the effect of unstable shoes on muscle activity. There is no official scientific publication regarding this study. However, results can be found (and were published in the general media) in a master’s thesis (Tepper, 2010) and a report from the Departments of Physical Therapy and Exercise and Sport Science of the University of Wisconsin-La-Crosse (Porcari et al., 2010). The study compared selected muscle activities between the shoes “Easy Tone”, “Sketchers”, “MBT” and “New Balance” (no specifics about the shoe models were given). The results of the study showed no significant differences between the unstable shoes and the control shoe (New Balance). The comparisons were done for the mean EMG values and no subject specific comparisons were made.

In summary:

“Muscle toning” is, from a scientific point of view, not well defined and experimental data associating “muscle toning” with unstable shoes are not available.

To correctly evaluate toning, it first needs to be defined and quantified, as well as looked at from a subject specific point of view. Until this is done, it is impossible to prove or disprove such claims.

4 Unstable shoes improve individual stability

The concept of this claim is that unstable shoes train the small muscles crossing the ankle joint. By training these muscles one assumes that the stability of subjects is increased. Stability has been measured using different methodological approaches, and the results of these studies are addressed below.

Balance and stability related characteristics were studied with the help of sensory organizational tests, reactive balance tests and limits of stability tests (Ramstrand et al., 2010). The study tested 20 healthy women above 50 years of age using a test and a control group. The test group used an MBT shoe for the training component (4 hours per day). The results of this study showed for the test group significant improvements of the mean performance. The study had the interesting result that the performance variables were higher for the control group than for the test group. The results showed that for most variables for which the test group (MBT group) improved their balance they only improved it to the level that the control subjects already had. A possible conclusion of this study could be that unstable shoes may improve balance performance if the subjects are at the lower end of the balance performance scale.

Another study analyzed the sway path in anterior-posterior and medial-lateral direction in a group of subjects, using an unstable MBT shoe for four hours daily. They found a reduction in the sway path after 8 weeks for the MBT group (Korsten et al., 2008). The difference was not significant after 4 weeks. A similar study with similar results was published recently (Landry et al., 2010).

Another study assessed the effect of unstable shoes on balance by quantifying the time in a static and a dynamic test at zero and 12 weeks for a group of 123 patients with knee osteoarthritis (Nigg et al., 2006). The subjects were randomly assigned to a test (training with unstable shoes) or a control group. Time of balance was measured in a static test consisting in standing on one leg on a firm surface and a dynamic test consisting of the identical procedure while standing on a soft surface. The results showed that there was a significant increase (about 100 %) in the static balance test time between baseline and 12-weeks in the unstable shoe group while there was no change in balance performance for the control group. The results were interpreted by the authors as follows: The unstable MBT shoe trained the subject's proprioceptive system and the small muscles crossing the ankle joint (21). It was assumed that the balance ability of the test subjects (subjects with osteoarthritis) was rather weak at the start and that the training of the small muscles was the reason for the improved balance.

Besides the published effects of unstable shoes on balance performance, we have many quantifications of this effect in our unpublished data (e.g. industry reports). The general result of these measurements was that significant changes were found when the balance ability of the test subjects was low. Now significant changes were found when the balance performance of the test subjects was already good.

In walking improvements in the control of movement variability (Stöggl et al 2010) have already been discussed. However, these improvements have only been observed when

wearing the unstable shoes. It remains unclear if there is a transfer effect that might improve the motor control in other situations.

Thus, in summary:

There is evidence that unstable shoes improve the balance performance of users if this balance performance is rather low. However, changes in balance performance are smaller and more difficult to quantify if the balance ability is already good.

5 Unstable shoes reduce joint loading

The claim has been made that locomotion or standing in unstable shoes reduces the joint loading in the joints of the lower extremities. A reduction of external plantar and dorsiflexion moments in the ankle joint were reported recently (Boyer et al., 2009). The actual (internal) joint loading, however, can't be measured directly. Consequently, only indirect evidence can be given for this claim. The line of thinking addresses two aspects, (a) the fast changing demand on muscles in unstable shoes and (b) the change from slow reacting large muscles to fast reacting small muscles crossing the ankle joint.

Fast changing demand on muscles in unstable shoes

Forces in joints are the result of two functions, the forces as a result of the actual movement (and change of movement) and the forces due to co-contraction of muscles crossing a joint. Muscle co-contraction can, for instance, occur when standing in an uncomfortable position for a longer time period.

It is suggested that these co-contractions are reduced when standing in an unstable shoe. The instability demands from the muscles fast changing adjustments of muscle forces. Consequently, the muscles can't remain co-contracted and high joint forces due to co-contraction are avoided when using an unstable base (shoe).

The use of small muscles crossing the ankle joint

Muscle-tendon units have not only the function of producing a force, they also serve as sensors for changes in the joint angles. This function is important for postural control. Each muscle is best suited to sense changes in the direction of this muscle's line of action. The two large muscle groups acting on the ankle joint, the triceps surae and the tibialis anterior, are ideal for sensing changes in movement for flexion-extension but not well suited for sensing changes for foot ab-adduction and foot in-eversion. The triceps surae, for instance, would sense changes in in-eversion late and would have to apply extensive forces to readjust the ankle joint position because the movement would have already made progress. For many changes in position, there are small muscles that can

provide joint stability quickly and with little force, and although one does not voluntarily select specific muscles to stabilize a joint, it is the training of these smaller and “quicker” muscles that can increase the general stability of a joint. The effect of strong small muscles has been simulated with a mechanical model using small and large springs (Nigg, 2005). The model calculations assumed four strong long springs with large levers with a defined reaction time T_1 (Fig. 5 left). For the situation representing strong small muscles, the model calculations assumed again four strong long springs with large levers with the same reaction time, T_1 , and additionally four smaller springs with a smaller lever and with a reaction time T_2 (Fig.5, right) with $T_2 = \frac{1}{2} T_1$. This assumption was made because, as mentioned, some small muscles crossing the ankle joint react faster to changes in joint position. The model calculations showed that the forces in the joint and the insertions were substantially lower for the condition with the strong small springs (Fig. 5).

The results of these model calculations support the idea that strong small muscles may be an advantage for performance and protection. Consequently, if wearing MBT shoes in fact train specifically the small muscles crossing the ankle joint complex, as suggested by EMG results (section 2), then one would also expect a reduction of the actual forces in the ankle joint.

In summary:

There is indirect evidence that unstable shoes reduce the internal forces in the joints of the lower extremities.

6 Unstable shoes reduce pain in joints.

The concept of this claim is based on many anecdotal statements of users of such shoes. They often claim that after using these shoes for a certain time, pain in joints (especially knee and low back) are reduced and tasks that became cumbersome could be done easier. There are two prospective studies addressing this question both using a progressive approach.

The first study assessed the effectiveness of an unstable shoe (MBT) in reducing knee pain in persons with knee osteoarthritis (OA) compared to a high end walking shoe over 12 weeks (Nigg et al., 2006). A total of 123 subjects with moderate knee osteoarthritis were randomized to a MBT (n=57) or a Control shoe (n=66). This study found a significant reduction of pain over the 12 week period for both shoe conditions. The results suggest that special shoe interventions can reduce pain in subjects with moderate knee osteoarthritis and that unstable shoes are one such effective strategy.

The second study assessed the effect of unstable sandals on low back pain in golfers with undiagnosed low back pain (Nigg et al., 2009). Forty male golfers (handicap ≤ 15) were randomized to a control group and an intervention group. The intervention group wore unstable shoes for six weeks and the control group wore their regular shoes for

the duration of the study. Low back pain was assessed at baseline and at six weeks using visual analog scales. There was a significant and substantial (44%) reduction of subjective pain for the unstable shoe group, but no significant difference in the control group. The results indicate that unstable shoes can be used to reduce moderate lower back pain in this population of golfers without negatively affecting performance.

In summary:

There is conclusive evidence that unstable shoes can reduce the level of perceived pain. This has been confirmed in subjects suffering from pain in the knee joint and for subjects with low back pain.

The mechanism responsible for this quantified pain reduction is not well understood. It could be that the reduction of joint forces or the fast changing muscle activity (and the related reduction of co-contraction) could be a reason for this effect.

Open Research Questions

Based on the results of this overview it seems that unstable shoes are associated with several possible benefits. It also seems that the effects are not consistent between different subjects and – based on many internal results in our group – it seems that the positive effects are present for about 80 % of the population.

Future research related to unstable shoes should address the following questions:

- 1) Are there physiological or biomechanical ***mechanisms causing the observed reduction of pain?***
Studies providing evidence for pain reduction were so far only epidemiological. Possible physiological and/or biomechanical mechanisms that may cause a reduction of pain have been discussed. However, no evidence for a clear mechanism is available.
- 2) Is there a measurable effect on the ***balance skills*** when ***healthy subjects*** wear unstable shoes?
Previous studies have provided evidence that unstable shoes can be used as a tool to train balance, particularly in populations that have balance deficits. However, the balance related effect of unstable shoes is not well understood.
- 3) Is there a ***beneficial effect of walking in unstable*** shoes for healthy subjects?
It has been shown that unstable shoes change the walking kinematics and they seem to reduce joint pain in OA patients. However, it remains unclear if healthy subjects would benefit from walking in unstable shoes. Since healthy subjects do not suffer from pain, the most likely beneficial effect of MBT shoes would be a training of the motor control system. Such a training has been shown when

walking in unstable shoes (Stöggl et al 2010), but it remains unclear if this motor training also improves the control of other movements.

- 4) Are there **indirect effects** of improved balance or motor control that can be achieved by wearing MBT shoes?
For example, improved dual tasking skills, improved quality of life, or a reduced risk of suffering falls and injuries.

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Fig 1

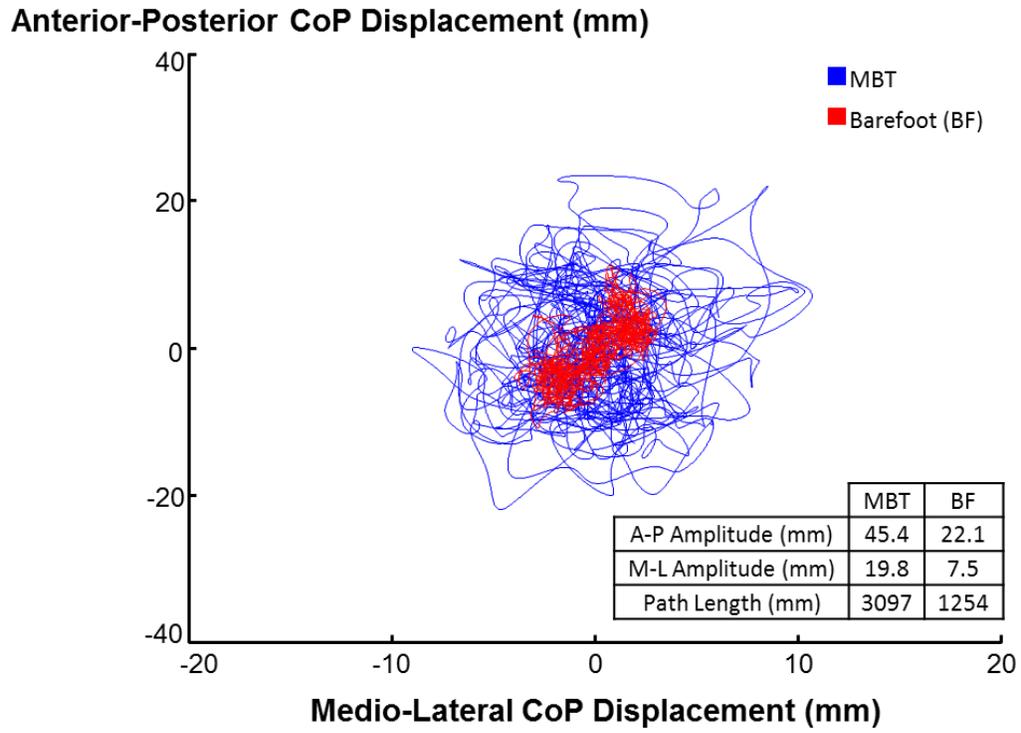


Fig. 2

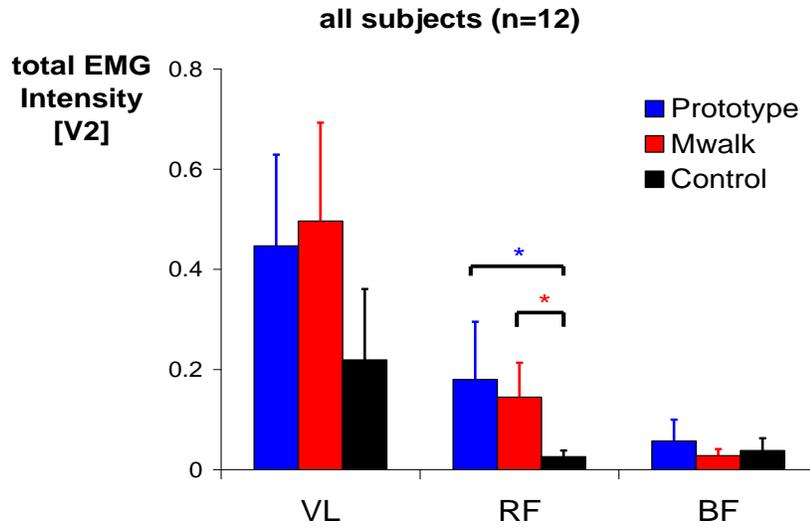


Fig. 3



Fig. 4

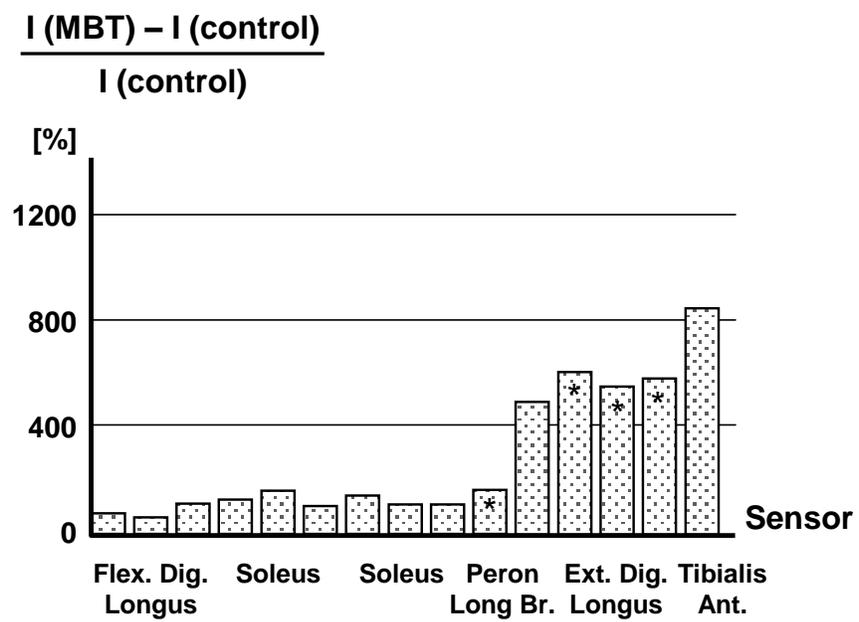
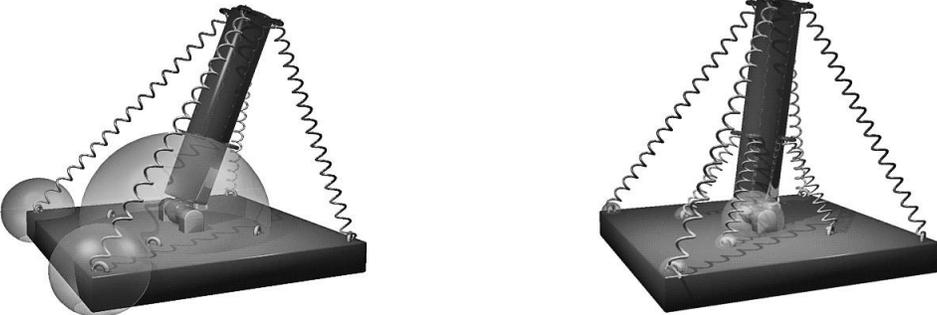


Fig. 5



- Fig. 1 Illustration of changed stability (changes in the COP excursions) for one subject standing on two legs for 30 seconds in unstable MBT shoes (blue line) and a more stable barefoot condition (red line). The inserted table shows for this trial an increase in the a-p amplitude for the unstable MBT shoe of 105 %, an increase on the m-l amplitude of 154 % and an increase in the total COP path length of 147 %.
- Fig. 2 Total EMG intensity (mean and SE) of the muscles vastus lateralis (VL), rectus femoris (RF) and biceps femoris (BF) in three test shoes for 12 subjects during quiet standing for 20 seconds. (Results from an unpublished industry report for MBT, with permission).
- Fig. 3 EMG array used for assessing the effect of unstable shoes on muscle activity of selected muscles crossing the ankle joint complex during bipedal standing (from Coza et al., 2009, with permission).
- Fig. 4 Relative average increase of the intensity (I) of the muscle activity during bipedal standing from 12 subjects (6 males and 6 females). The EMG was quantified for 30 seconds and the middle 20 seconds were used for analysis. The unstable shoe was an MBT shoe, the control shoe was a Decathlon Kalenji shoe. (from Nigg, 2010).
- Fig. 5 Effect of strong and weak small springs (muscles) on forces in the joint and in the attachment locations of the springs (insertion forces). The simulations were made assuming that the small springs react faster than the large springs. (From Nigg, 2005, with permission).