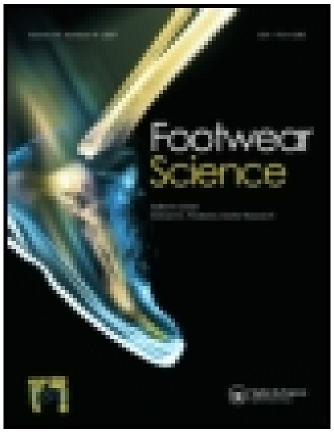


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# Influence of three different unstable shoe constructions on EMG-activity during treadmill walking - a cross-sectional study with respect to sensorimotor activation

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# Influence of three different unstable shoe constructions on EMG-activity during treadmill walking – a cross-sectional study with respect to sensorimotor activation

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**Background:** Manufacturers have introduced specific shoes featuring unstable sole constructions to induce neuromuscular training stimuli. Previous experiments focused primarily on analysing effects of unstable shoe constructions in comparison to 'regular' shoes or to barefoot walking. The aim of this study was to compare muscle activity during walking when using three different unstable shoe constructions.
**Methods:** Twelve healthy male subjects participated in this study. Muscle activities of the lower leg were analysed during treadmill walking by surface electromyography (EMG). First, each subject performed an unshod trial (BF = barefoot – control condition). Then, MBT® shoe (MBT), Finnamic-Schuh® (FIN), and Reflex Control® shoe (RC) were randomly applied and tested. EMG-activities of m. tibialis anterior, m. gastrocnemius lateralis, and m. peroneus longus were recorded. In all muscles we calculated integrated EMG (iEMG) for each ground contact phase.
**Results:** When wearing RC the muscle activity of the m. gastrocnemius lateralis and the summarised muscle activity of the lower leg increased significantly when compared to FIN and BF ($p = 0.001$ to $0.013$). There were no significant differences between RC and MBT ($p = 0.207$ to $0.212$). Concerning iEMG of m. peroneus longus and m. tibialis anterior there were no statistically relevant differences detected between testing situations ($p = 0.205$ to $1.000$).
**Conclusion:** The results of the present study indicate that different unstable shoe constructions induce varying demands to the neuromuscular system while walking on a treadmill. We expect the demands of unstable shoe constructions (MBT and especially RC) to be beneficial as sensorimotor training stimuli during walking.

**Keywords:** sensorimotor training (SMT); unstable shoe constructions; EMG-activity; treadmill walking; gait analysis



## Introduction

Balance exercises are often utilised to reduce the risk of falling and to improve neuromuscular control in dynamic situations. These sensorimotor training (SMT) regimes are commonly performed on balance boards, soft mats and unstable surfaces. Numerous studies have shown that SMT leads to improved neuromuscular control (Heitkamp *et al*. 2001, Granacher *et al*. 2006, Yaggie and Campbell 2006, Taube *et al*. 2008) and increased knee joint stiffness (Gruber and Gollhofer 2004, Gruber *et al*. 2006).

Manufacturers have introduced shoes featuring unstable sole constructions to induce neuromuscular training stimuli. Masai barefoot technologies® (MBT; Romanshorn, Switzerland) developed a shoe with a soft sole rounded in anterior-posterior direction which is widely used by patients suffering from foot and back problems. It was suggested that MBT serves as a 'proprioceptive tool thereby enhancing ankle stabilizing musculature' (Romkes *et al*. 2006, p. 76) and increases the activity of smaller extrinsic foot muscles (Landry *et al*. 2010, Sousa *et al*. 2012). Comprehensive experiments have evaluated the effects of MBTs on changes in gait characteristics, posturography and electromyography (EMG)-activity of several lower extremity muscles in healthy subjects (Romkes *et al*. 2006, Nigg *et al*. 2006a, Stewart *et al*. 2007, Stöggl *et al*. 2010, Taniguchi *et al*. 2012), in children with developmental disabilities (Ramstrand *et al*. 2008), in women aged over 55 years (Ramstrand *et al*. 2010), in women with risk factors for developing venous insufficiency (Sousa *et al*. 2012) and in patients suffering from osteoarthritis (Nigg *et al*. 2006b). These studies focused primarily on analysing effects of wearing MBT compared to 'regular' shoes or to barefoot walking. Collectively, the main results were higher EMG activities, significant changes in several kinematic parameters, increased postural sway and decreased stability during the contact phase in gait when wearing an unstable shoe construction.

Apart from the MBTs there are only a few unstable sole constructions available, e.g. the Reflex Control Schuh® (RC; Orthotech GmbH, Gauting, Germany) and the Finnamic-Schuh® (FIN; Waldi Schuhfabrik GmbH, Hassfurt, Germany) (see Figure 1). The RC is also promoted as a sensorimotor training device (Lohrer *et al*. 2008,

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Figure 1. Three shoes featuring unstable sole constructions. From left to right: Masai barefoot technologies® shoe (MBT), Finnamic-Schuh® (FIN), both characterised with a convex sole in anterior-posterior direction; Reflex Control® Schuh (RC) designed with a central sole bar to induce instability with respect to the longitudinal axis of the foot.

Turbanski *et al*. 2011). But in contrast to MBTs its central sole bar induces instability with respect to the longitudinal axis of the foot. Due to its 'convex sole design' that is similar to MBT, the FIN is advertised to increase 'endurance and strength' (http://www.finncomfort.de). But both unstable shoe constructions, the RC as well as the FIN, haven't been evaluated in a similar amount of studies as the MBT.

One previous biomechanical study analysed unstable shoe constructions (MBT, FIN, RC) during postural control in one-leg standing. That study showed that RC led to increased EMG-activity and higher postural sway in posturography measurements compared to MBT, FIN and barefoot control condition. There were no significant differences found between MBT, FIN and control condition, either in EMG-activity or in postural sway (Lohrer *et al*. 2008). Therefore, it was shown in a relatively static testing condition that different shoes with unstable sole constructions could lead to different degrees of mechanical perturbations. A biomechanical comparison of different unstable shoe constructions during walking, in a dynamic testing condition that represents daily life activities, is not yet documented. Therefore, the purpose of this study was to compare muscle activities during treadmill walking using three different shoes (MBT, FIN and RC) in a cross-section design.

Based on previous findings (Lohrer *et al*. 2008) we hypothesised that wearing these shoes while walking would lead to increased EMG-activity in lower leg muscles to compensate for the instability induced by this footwear. Secondly, we hypothesised that wearing different unstable shoe constructions while walking induces varying EMG-activities, representing shoe-specific sensorimotor stimuli, with highest EMG activity when wearing RC (Lohrer *et al*. 2008).

## Materials and methods

The testing procedure was based on biomechanical analyses using a cross-sectional study design. The investigation was in agreement with the principles outlined in the Declaration of Helsinki developed by the World Medical Association (see www.wma.net). All subjects were informed about the experimental procedures, the design of the study, as well as the possible risks and benefits of the study. They gave their informed and written consent to take part in the experiment.

### *Subjects*

Twelve healthy males volunteered to participate in the present study [age: 25.3 ± 1.4 years; height: 180.9 ± 5.5 cm; weight: 78.6 ± 8.3 kg]. Subjects were deemed ineligible if they had any limitations that could affect their walking performance on a treadmill whether it be orthopaedic, neurological or some other clinical impairment. Moreover, subjects could not have any previous experience walking with unstable shoe construction.

### *Setting*

First, subjects were adapted to unstable shoe constructions and familiarised with the testing procedure. We implemented two separate habituation sessions before the first measurement to minimise learning effects of the testing situations. In both sessions subjects were asked to walk in each of the unstable shoe constructions for 15 minutes on a treadmill at their preferred gait velocity.

One week later, definitive recordings were taken in four conditions: First, each person performed one unshod trial (control condition – barefoot = BF). Then, MBT, FIN and RC[1] were applied and tested in a block randomised order. In every testing condition subjects walked on the treadmill for at least four minutes at a standardised velocity of 1.25 m/s (4.5 km/h) representing the mean velocity of the subjects at the two habituation sessions. The step length was not standardised, as the subjects should walk in an individually comfortable gait[2]. The last 30 seconds of each trial were recorded. To avoid voluntary and involuntary changes in gait the subjects were not informed about the recording time. The treadmill was equipped with two force plates (Mechatronic, Hamm, Germany) to detect ground reaction forces on both sides (left and right leg). This enabled us to detect ground contacts and swing phases exactly. Muscle activities of the lower leg were analysed using bipolar surface electrodes (Ambu, Bad Nauheim, Germany). The EMG electrodes were applied according to recommendations of the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles) to fulfil a high standard of measurement quality (Hermens *et al*. 2000). After preparation of the skin including shaving, light abrasion, and disinfection the electrodes were placed in a centre to centre distance of 25 mm. The longitudinal axes built between the centres of the electrodes were in line with the presumed direction of the underlying muscle. EMG-activity was recorded from the enveloping muscles of the right ankle: m. tibialis anterior, m. gastrocnemius lateralis, and m. peroneus longus. All EMG-signals were filtered [cut-off frequency, 25 Hz (low) and 1500 Hz (high)] and amplified x 2500. The common mode rejection ratio was stated with 110 dB (Biovision, Wehrheim, Germany). All kinematic data measured by the force plates and all EMG-signals were synchronised and sampled with a 1000 Hz analogue-to-digital conversion rate (DAQ700, National Instruments, Austin, TX, USA) and stored on a personal computer. For each muscle we calculated the rectified and integrated EMG (iEMG).

The ground contact phases were determined by the intervals between the hit of the heel on the ground and the take-off of the forefoot. These points could easily be detected in the graphs of the ground reaction forces. For each muscle the mean values of 40 steps of iEMG per ground contact were defined as dependent variables and used for statistical analyses representing EMG-activity during stance phases.

### *Statistical analyses*

Standard statistical methods were used to calculate means, standard deviations and percentage values for dependent variables. After assuring that all data were normally distributed using Kolmogorov–Smirnov testing, a one-way analysis of variance (ANOVA) with repeated measures was used for each muscle to identify differences in iEMG per ground contact between the four testing conditions (barefoot and three unstable shoe constructions). Subsequent Scheffé post hoc tests were carried out to determine pairwise differences when significant F ratios were obtained. The $p \leq 0.05$ criterion was chosen for establishing the level of significance. For statistical analysis we used the software SPSS (Version 19.0).

## Results

When compared to the control condition (BF) we found a tendency for increased EMG-activity when subjects wore MBT and RC and a tendency for decreased muscle activities when wearing FIN. Statistically significant differences between RC and BF as well as between RC and FIN were observed in m. gastrocnemius lateralis and in summarised muscle activity of the lower leg.

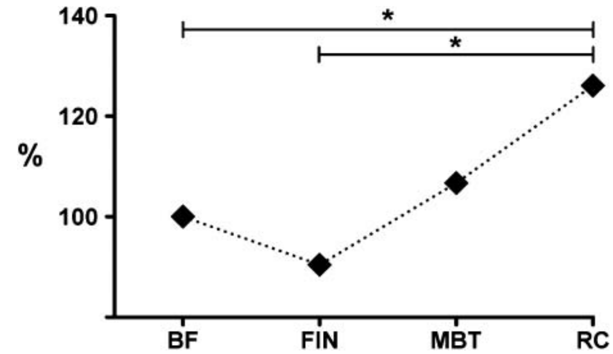


Figure 2. Comparison of EMG-activities of m. gastrocnemius lateralis during walking: The figure shows integrated EMG per ground contact phase in percentages (BF represents 100%). For each testing condition the means of 20 steps were calculated. [Testing conditions: control condition/barefoot (BF), Finnamic-Schuh® (FIN), MBT® shoe (MBT), Reflex Control Schuh® (RC)]

### *Muscle activity in m. gastrocnemius lateralis*

In m. gastrocnemius lateralis we found an increase in average iEMG activity per ground contact phase when subjects wore RC (+26.1%) and MBT (+6.7%). When wearing FIN the EMG activity was reduced by 9.6% (Figure 2 and Table 1). Statistical analyses could not detect significant differences between BF, MBT and FIN. RC led to significantly increased EMG activity when compared to BF and FIN. But there was no statistically significant difference detected between MBT and RC (Table 2).

### *Muscle activity in m. tibialis anterior*

EMG activity of m. tibialis anterior was decreased when subjects wore FIN (−8.4%). There were no differences in EMG activity between RC, MBT and BF. Furthermore, no statistically significant differences could be detected between the four testing conditions (see Table 2 and Figure 3).

Table 1. Integrated EMG-activities per ground contact phase in absolute values [mV*s]. For each testing condition the mean values of 20 steps of iEMG per ground contact were calculated. The table represents means ± standard deviations. [Testing conditions: control condition−barefoot (BF), Finnamic-Schuh® (FIN), MBT® shoe (MBT), Reflex Control Schuh® (RC)].

| | BF | FIN | MBT | RC |
|---|---|---|---|---|
| **M. gastrocnemius lateralis** | 0.095 ±0.051 | 0.086 ±0.041 | 0.102 ±0.050 | 0.120 ±0.061 |
| **M. tibialis anterior** | 0.047 ±0.018 | 0.043 ±0.018 | 0.047 ±0.025 | 0.047 ±0.020 |
| **M. peroneus longus** | 0.021 ±0.010 | 0.020 ±0.008 | 0.025 ±0.016 | 0.026 ±0.013 |
| **Summarised muscle activity** | 0.163 ±0.075 | 0.149 ±0.064 | 0.174 ±0.082 | 0.193 ±0.082 |

Table 2. Statistical p-values resulting from comparisons of testing conditions [Control condition−barefoot (BF), Finnamic-Schuh® (FIN), MBT® shoe (MBT), Reflex Control Schuh® (RC); Statistical analysis: One-way ANOVA with repeated measures and subsequent Scheffé post hoc tests].

| | | FIN | MBT | RC |
|---|---|---|---|---|
| | **BF** | 0.964 | 0.779 | **0.013*** |
| **M. gastrocnemius lateralis** | **FIN** | | 0.373 | **0.002*** |
| | **MBT** | | | 0.212 |
| | **BF** | 0.481 | 1.000 | 1.000 |
| **M. tibialis anterior** | **FIN** | | 0.501 | 0.455 |
| | **MBT** | | | 1.000 |
| | **BF** | 0.999 | 0.540 | 0.205 |
| **M. peroneus longus** | **FIN** | | 0.694 | 0.316 |
| | **MBT** | | | 0.972 |
| | **BF** | 0.856 | 0.816 | **0.015*** |
| **Summarised muscle activity** | **FIN** | | 0.238 | **0.001*** |
| | **MBT** | | | 0.207 |

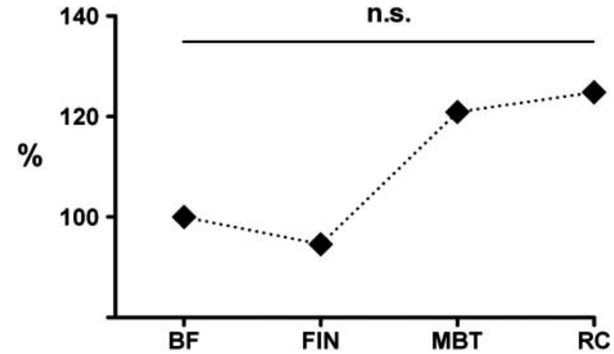


Figure 4. Comparison of EMG-activities of m. peroneus longus during walking: The figure shows integrated EMG per ground contact phase in percentages (BF represents 100%). For each testing condition the means of 20 steps were calculated. [Testing conditions: control condition/barefoot (BF), Finnamic-Schuh® (FIN), MBT® shoe (MBT), Reflex Control Schuh® (RC)]

### *Muscle activity in m. peroneus longus*

Wearing FIN again reduced EMG activity in m. peroneus longus (−5.4%) while MBT (+20.9%) and RC (+24.8%) increased the muscular activity (Figure 4 and Table 1). Despite these increases of EMG activities when using MBT and RC shoes, statistical analyses could not detect significant differences between the four testing conditions regarding m. peroneus longus (Table 2).

### *Summarised muscle activity*

The term summarised muscle activity represents the summation of the individual EMG activities of the recorded muscles (TIB+GAS+PER) representing overall neuromuscular activity of the lower leg. This parameter revealed an increase of EMG activity when subjects wore RC (+18.7%) and MBT (+7.0%) and a decrease by 8.7% in iEMG per ground contact when they wore FIN (Figure 5 and Table 1). Statistical analyses revealed significant differences when RC was compared with BF and FIN. But the difference between RC and MBT was not statistically significant (Table 2).

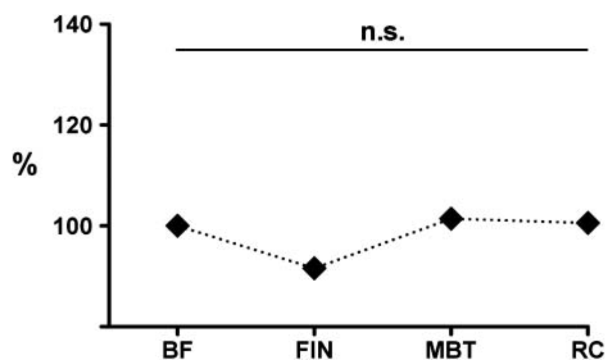


Figure 3. Comparison of EMG-activities of m. tibialis anterior during walking: The figure shows integrated EMG per ground contact phase in percentages (BF represents 100%). For each testing condition the means of 20 steps were calculated. [Testing conditions: control condition/barefoot (BF), Finnamic-Schuh® (FIN), MBT® shoe (MBT), Reflex Control Schuh® (RC)]

## Discussion

The results of the present study indicate that different unstable shoe constructions induce varying demands to the neuromuscular system during walking on a treadmill. Compared with barefoot walking, the RC and MBT had higher EMG activity in the muscles enveloping the ankle. Wearing FIN showed a trend towards less EMG activity.

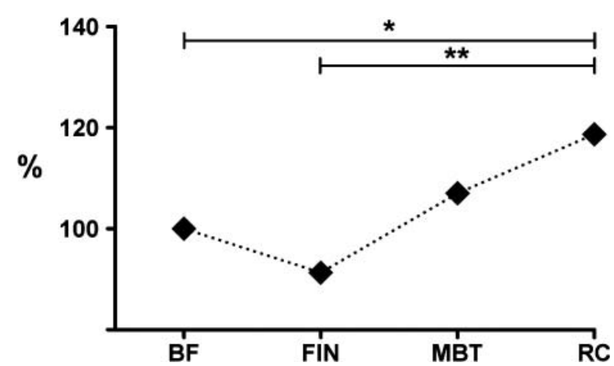


Figure 5. Comparison of summarised muscle activity of the shank during walking: The figure shows integrated EMG per ground contact phase in percentages (BF represents 100%). For each testing condition the means of 20 steps were calculated. [Testing conditions: control condition/barefoot (BF), Finnamic-Schuh® (FIN), MBT® shoe (MBT), Reflex Control Schuh® (RC)]

Therefore, we postulate that RC and MBT lead to neuromuscular stimuli eventually resulting in effects comparable to traditional SMT.

It is difficult to compare the results of the present study with further data from the literature, as we are unaware of any other reports evaluating different unstable shoe constructions. To date most studies have evaluated the effects of the MBTs in comparison to conventional shoes. Greater excursions of the centre of pressure (COP) were observed during unexcited stance when wearing MBT compared to control shoes (Nigg *et al*. 2006a). Furthermore, statistically significant differences were found in several kinematic parameters (decrease in cadence, stride length, step length, and walking speed and increase in stride time and single support) and EMG activity of several muscles when comparing MBT with barefoot walking and wearing the individuals' regular shoes (Romkes *et al*. 2006, Landry *et al*. 2010, Sousa *et al*. 2012, Taniguchi *et al*. 2012). A decrease of stability during the contact phase in gait has been shown when wearing MBT (Nigg *et al*. 2006b). These previous published data are supported by the findings of the present study. In different muscles of the lower leg we demonstrated an increase in EMG-activity during walking when wearing MBT and especially when using RC. It is hypothesised in the literature that the increase in EMG-activity could be explained by shifts in plantar pressure towards the front of the foot in MBT (Stewart *et al*. 2007). The presented effects of the RC on muscle activity that, are different to MBT and FIN, may be induced by its medial-lateral excursions during treadmill walking.

We postulate that the increases in muscular activities during walking are based primarily on reflex patterns that compensate for the destabilisation of the ankle and the subtalar joint due to the unstable sole constructions. It is well established that spinal reflexes play an important role during compensatory reactions following postural disturbances (Dietz *et al*. 1988). In general, reflex modulations occur following short- and long-term balance training on unstable surfaces (Taube *et al*. 2008) especially in the early phase of force development (Gruber *et al*. 2006). We expect these neuromuscular demands to be beneficial, acting as SMT stimuli.

It was already suggested in one longitudinal study that a six-week training programme implementing specific sensorimotor exercises performed in unstable shoe constructions (RC and MBT) improved postural control in a dynamic testing situation. The training was performed twice per week for approximately 30 minutes in each session. Compared with control subjects the RC induced a statistically significant improvement following the training period. Regarding pre-post changes, the MBT group showed improvements in dynamic balance control as well. But when compared with control subjects the results were not significantly different (Turbanski *et al*. 2011). Another experiment assessed the effectiveness of the MBT shoe in a 12-week training programme in patients with knee osteoarthritis. That study showed no statistically significant differences between the MBT shoe and control shoes concerning effects on pain reduction, posturography, flexibility, or strength (Nigg *et al*. 2006b). A recent study investigated the effects of using an unstable shoe construction (MBT) on specific balance tests in women aged over 50 years. These authors observed significant improvements in several balance tests. But results of the intervention group were again not significantly different from the control group (Ramstrand *et al*. 2010). In one long-term study effects of 'traditional' sensorimotor training were compared to wearing MBT shoes. Subjects in the MBT group were not directed to specific exercises but wore these shoes in daily life activities for at least four hours per day. The MBT group improved postural control in a dynamic testing situation. But sensorimotor training on unstable surfaces and balance boards led to considerable larger improvements in postural control when compared to the MBT group (Korsten *et al*. 2008).

Summarising these studies (Nigg *et al*. 2006b, Korsten *et al*. 2008, Ramstrand *et al*. 2010, Turbanski *et al*. 2011), wearing MBT seems to be less effective when compared to traditional SMT in terms of improving sensorimotor control. This aspect is underlined by the results of the present study revealing non-significant differences in EMG-activity during gait for MBT when compared with a control condition (barefoot walking).

As subjects who trained with RC achieved greater improvements in postural control we hypothesised that the longitudinally orientated central sole bar of the RC induces greater sensorimotor activation than the transversally rounded MBT (Turbanski *et al*. 2011). Greater instability and higher EMG-activation in single-leg standing were demonstrated for the RC when compared to MBT (Lohrer *et al*. 2008). In principle, it seems reasonable that a higher EMG activity indicates more mechanical output. Consequently, we could suggest that the observed acute changes in muscle activation could be translated into long-term SMT effects (Turbanski *et al*. 2011).

Several sensorimotor training interventions could be effective in reducing the risk of falling (Tinetti *et al*. 2003). Furthermore, it was shown in elderly people that balance training resulted in optimised reflex activity to compensate for standardised gait perturbations. The authors concluded that these training adaptations could reduce the risk of falling (Granacher *et al*. 2006). Therefore, shoes with unstable sole constructions may complement balance-training regimes, like standing or one-leg standing on unstable surfaces. In comparison to 'traditional' balance training the main advantage of unstable shoe constructions may be to combine locomotion and training stimuli in activities of daily life. Advantages would be on the one hand regularly increased sensorimotor activities that may lead to improved motor control and on the other hand that subjects are independent of training devices and therapists or other experts supervising balance training sessions.

In this study we focused on EMG activity of lower leg muscles enveloping the ankle. Therefore, we cannot comment on effects of different unstable shoe constructions on muscle activity of the thigh, hip, and spine. But these muscles also play an important role for postural control and dynamic stabilisation of the leg during gait. Moreover, there is still scientific discussion regarding whether treadmill walking sufficiently replicates the overground environment in ordinary walking (Riley *et al*. 2007, Alton *et al*. 1998). Nevertheless, we chose treadmill walking due to standardisation of the testing conditions. Implementing barefoot as the control condition may potentially bias our results. It is more demanding in regards of dynamic stabilisation of the ankle and the subtalar joint when unshod trials are compared to conventional shoes. Therefore, individual regular shoes were used as the control condition in most previous experiments.

Future studies should address effects of unstable shoe constructions on postural control and gait characteristics in elderly people. Moreover, further research should evaluate, in several subject groups, how long these shoes should be used per workout. Additionally, the question of whether these shoes could possibly induce injuries due to their unstable sole design should be addressed in further research.

## Conclusion

In conclusion, our data suggest that unstable shoe constructions (MBT and RC) could provide several neuromuscular stimuli during walking. We recommend unstable shoe constructions as one part of multifactorial SMT programmes that include exercises on unstable surfaces, balance boards, and plyometrics.

## Conflict of interests

No financial benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

## Funding

No funds were received in support of this study.

## Notes

1. Minimal mass for EU size 38: MBT −484 g; RC −426 g; FIN −393 g.
2. The subjects performed on average 55 steps during recording time. In no subject did the number of steps change between the four testing situations and all subjects could stay at the centre of the treadmill during the recording time. Therefore, we noted no significant differences in cadence or step length.

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