

A comparison of oxygen consumption, RPE and lower limb EMG activity
in toning versus running shoes on uphill, level and downhill walking

By

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BPT, Kurukshetra University, India, 2010

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

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Abstract**Supervisory Committee**

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Departmental Member**Abstract**

OBJECTIVES: Comparing electromyography and physiological measures while walking on various inclines in unstable and stable shoes.

METHODS: Eleven healthy females walked on treadmill at +10%, 0% and -10% grade for five minutes each, at self-selected pace, in stable and unstable shoes. The two sessions were done 3 weeks apart during which the subjects used unstable shoes for regular activities.

Electromyography of lower limb muscles, absolute and relative oxygen consumption, perceived exertion rating and heart rate was calculated.

RESULTS: Tibialis anterior activation varied significantly with shoe type, irrespective of grade. Soleus, vastus medialis, and biceps femoris showed activation differences in specific gait phases. There was a main effect for absolute and relative oxygen consumption, RPE and HR only with grade. Shoe type showed no effect.

CONCLUSION: Though there is no difference in overall physiological variables, but changes in electromyography in specific phases highlight possible muscle toning benefits of unstable shoes.

Key words: Unstable shoes, neuromuscular strategy, walking grades, toning, locomotion

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Abbreviations

ACSM: American College of Sports Medicine

BF: Biceps femoris

COP: Center of Pressure

EMG: Electromyography

GM: Gluteus medius

GT: Medial gastrocnemius

HR: Heart rate

MBT: Masai Barefoot Technology

OA: Osteoarthritis

RPE: Rating of Perceived Exertion

SOL: Soleus

TA: Tibialis anterior

VL: Vastus lateralis

VM: Vastus medialis

VO₂: Oxygen consumption

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“The only way to predict the future is to have the power to shape the future”

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Chapter 1

1. Introduction

A great deal of research has focused on the effects of footwear style on physical parameters of locomotion (Masood, 2011; Nigg, Hintzen, & Ferber, 2006). While the purpose of footwear has traditionally been to provide stability and comfort to the user, the unstable form of shoes have a goal to provide greater physical activity demands during walking (Masood, 2011). Moreover, unstable soles aim to replicate a soft, natural, sand-like walking surface (Romkes, Rudmann and Brunner et al., 2006) with the purpose to stimulate muscles close to the movement axis (figure 1) and thereby reduce resultant joint loading (Nigg et al., 2006). Unstable shoes are designed to modify and enhance lower limb muscle activation along with increases in other physiological variables like oxygen consumption, heart rate and rate of perceived exertion (Nigg et al., 2006; Koyama, Naito, Ozaki, & Yanagiya, 2012; Romkes et al., 2006).

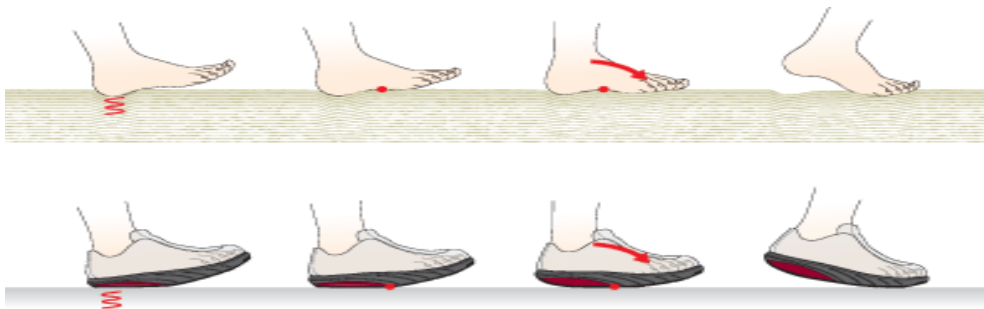


Figure 1. Barefoot walking compared to walking in unstable shoes

There have been various studies which analysed muscle activity in lower limb (Nigg et al., 2006; Romkes et al., 2006; Porcari et al., 2011) as well as other physiological responses when wearing unstable shoes (Koyama et al., 2012; Gjovaag, Dahlen, Sandvik, & Mirtaheri, 2011). Further, there have been studies which have emphasized the functional and health benefits (Yamamoto, Ohkuwa, Itoh, Yamazaki, & Sato, 2000) of unstable shoes, in terms of plantar

pressure redistribution (Stewart et al., 2007), improved balance (Ramstrand, Thuesen, Nielsen & Rusaw, 2010) and decreased joint loading (Nigg et al., 2006). While the use of unstable shoes provides possible health benefits and has received much research attention, the results of studies examining energy cost, muscle activity, functional, therapeutic and health benefits have been variable and a common consensus cannot be reached on many of these issues. Further, studies examining unstable shoes have varying methodological approaches which limit a viable comparison of findings.

The health benefits of a fitness intervention can be described in many ways. As such, health may be quantitatively expressed in terms of physiological measures, biochemical markers, and neuromuscular changes. Therefore, with respect to the use of unstable shoes, it is important to consider a vast array of possible measures to realize a health benefit. Effect of unstable shoes on general body fitness may be gauged in many ways like toning musculature or burning calories, fat loss, or reducing pain. The following subheadings are presented to facilitate discussion of the possible researched benefits of wearing unstable shoes from general health benefits to more specific musculoskeletal effects.

1.1 Energy Cost

An important proposed consequence of unstable shoe use is increased energy cost which may affect fuel metabolism relating to fat loss and lean muscle increase as well as cardiovascular benefits (Porcari et al., 2011). Energy expenditure can be measured by various means including direct measurement of oxygen consumption, biochemistry and heart rate during activity as well as monitoring indirect physiological variables including rate of perceived exertion (RPE). Additionally, ACSM has provided metabolic formulas which are useful for health and fitness

practitioners in estimating energy expenditure (Swain, 2000). Given the inconclusive results for the effect of unstable shoes on these variables it is important to continue to evaluate the impact of unstable shoe use on measures of energy cost in controlled conditions.

To exemplify, Yamamoto et al., (2000) examined the physiological and biochemical effects of wearing heel-less (unstable) shoes. Six male subjects were made to walk on a treadmill, at 0% grade and various constant speed levels, wearing regular (stable) and heel-less (unstable) shoes alternately. The induced changes included an increased blood supply to the calf muscles, concentration of lactate, glycogen metabolism, and a higher nor-adrenalin secretion. The authors suggested that heel-less shoes may increase the energy expenditure of walking and also influence muscle activation which can prove to be a health benefit. However, the authors did not deduce this statement by direct measurements and further research was required to quantify muscle work and energy cost of walking in unstable shoes. In a study undertaken by Porcari et al., (2011) the physiological and subjective comparison of unstable shoes with flat soled shoes for level or graded treadmill walking at 3 or 3.5mph speed in various combinations, revealed no significant difference in rate of perceived exertion (RPE), oxygen consumption (VO_2), heart rate (HR), or caloric expenditure. The argument that unstable shoes result in a greater weight loss or muscle strengthening/toning benefits was refuted by the authors. However, Koyama et al., (2012) found that HR and VO_2 were significantly higher while walking in unstable shoes. The energy cost was also reported to be increased by 4% but without any significant changes in RPE. In the same study an additional finding was that unstable shoes significantly increased step length but lowered step cadence. This is contrary to the findings by Romkes et al., (2006) who found subjects took smaller steps while walking in unstable shoes. Oxygen uptake and energy consumption while wearing unstable shoes and conventional jogging shoes was also compared by

Gjovaag et al., (2011). The test protocol involved ten subjects to walk on a treadmill, with inclination as 0% or 10% and walking speed as self-selected or fast. Oxygen uptake, HR, lung ventilation, RPE and energy expenditure was measured during all the given conditions. Both the types of shoes reported similar physiological responses as the subjects walked on a flat treadmill at self-selected or fast walking speed, however, the oxygen uptake, energy expenditure and HR was found to be 5%, 6% and 6.6% higher respectively, while walking fast on an uphill inclined treadmill with unstable shoes as compared with regular shoes. The minimal increment observed was attributed to the shoe type as well as treadmill inclination. The authors also reported the unstable shoes to be 432gms heavier than the control shoes, which could have caused the increased oxygen cost.

Study	Grade	Speed	Finding
Porcari et al., (2011)	0 or 5%	3 or 3.5mph	No significant difference RPE, VO ₂ , HR, Caloric expenditure
Koyama et al., (2012)	0%	3-7 kmph	Energy cost: 4% higher HR and VO ₂ significantly higher
			No significant changes in RPE
Gjovaag et al., (2011)	0 or 10%	Self-selected or fast	0% incline; both speeds Similar physiological response
			10% incline; fast speed VO ₂ : 5% higher Energy expenditure : 6% higher

Table 1. Summary of studies discussing energy cost

The summary of all the studies discussing energy cost has been tabulated in Table 1 and it reveals that overall, with respect to energy expenditure, the aforementioned multifarious findings fail to give a concrete statement. Koyama et al., (2012) found HR, VO₂ and energy cost to be

higher but not RPE. A similar physiological response was also observed by Gjovaag et al., (2011) on fast walking at uphill inclined treadmill. Porcari et al., (2011) on the contrary, documented no extra energy expenditure with unstable shoes. Thus a common consensus cannot be reached whether unstable shoes impose increased oxygen consumption over that of regular runners. Though the effect of unstable shoes on energy cost is inconclusive, this does not imply its futility. The changes brought about by unstable soles may be measured at a muscular level yet not as a physiological outcome. Proponents of generic unstable shoes claim that the wearer derives health benefits like toning of leg muscles and joint pain reduction on wearing such shoes. Studies have focussed on diverse aspects related to musculature like muscle activation and recruitment, muscle strengthening, effect on pain levels and overall impact on quality of life.

1.2 Muscle Activation and recruitment

Unstable sole is conceptualised to change the interface between the ground and the feet. This implies that there may be a probable alteration in muscle work. Therefore the specific effects of unstable shoes on lower limb muscle activity, initiation and contraction timing while walking need to be studied in detail to establish a conclusive statement. A multitude of studies have been done to analyse the muscle activation and recruitment using unstable shoes on variable terrains and speed. The following paragraphs present a few significant findings.

i. Unstable versus stable shoes

A study by Porcari et al., (2011) aimed to analyse electromyographic responses of rectus abdominus, erector spinae, gluteus maximus, rectus femoris, biceps femoris, and gastrocnemius, while walking on a treadmill at 0 and 5% grade and 3 and 3.5mph speed in various combinations,

using unstable shoes or regular athletic training shoes. The results showed that the muscle activity was similar between the two shoe conditions for all the muscles tested, yet higher with increased inclination. On the other hand, Romkes et al., (2006) performed a 3-D gait analysis with simultaneous surface EMG and showed significantly higher activation of tibialis anterior throughout the swing phase in unstable shoes. However, there were no significant differences for other muscle during the entire gait cycle but significant differences were seen during certain phases of gait cycle. The kinematic analysis revealed that, with unstable shoes, the ankle showed increased dorsiflexion angle at initial contact followed by a continuous plantarflexion movement until terminal stance phase. A similar study done by Koyama et al., (2012) reported integrated EMG of rectus femoris, vastus lateralis, biceps femoris, tibialis anterior, soleus, and medial gastrocnemius muscles. The walking protocol involved performing level treadmill walk for 3 minutes each at speeds of 3, 4, 5, 6, and 7 km/h. The results showed higher integrated EMG for medial gastrocnemius and soleus muscles with unstable shoes. Nigg et al., (2006) studied EMG activity of tibialis anterior, medial gastrocnemius, biceps femoris, vastus medialis, and gluteus medius muscles on both standing and walking in unstable shoes. During walking, EMG recordings showed an increase (non significant) in the gastrocnemius activity but a decrease (non significant) for all other muscles. However, during standing, EMG results revealed only a significant increase for the tibialis anterior muscle. Further, Landry, Nigg, & Tecante, (2010) specifically studied EMG of selected extrinsic foot muscles on standing using unstable shoes and found out that there was increased activity of the flexor digitorum longus, peroneal and anterior compartment muscles of the lower leg but not the soleus. However it must be noted that all the studies mentioned (summarised in table 2) were performed on a level surface and terrain modifications were not tested.

MUSCLE	STUDY	FINDING
Tibialis Anterior	Nigg et al., (2006)	On standing: Increased activity
		On walking: Decreased activity (non significant)
	Romkes et al., (2006)	Decreased during initial contact and loading response; Higher activation throughout swing phase
	Koyama et al., (2012)	Not significant but Tendency to be higher
Medial Gastrocnemius	Nigg et al., (2006)	On standing: Increased activity (non significant)
		On walking: Increased activity (non significant)
	Koyama et al., (2012)	Increased integrated EMG
Gastrocnemius	Romkes et al., (2006)	Increased from terminal swing phase until midstance.
	Porcari et al., (2011)	No significant difference
Soleus	Koyama et al., (2012)	Increased integrated EMG
	Landry et al., (2010)	No difference
Vastus medialis	Nigg et al., (2006)	On standing: Increased activity (non significant)
		On walking: Decreased activity (non significant)
	Romkes et al., (2006)	Increased from mid-stance to toe-off.
Vastus lateralis	Romkes et al., (2006)	Increased from mid-stance phase to toe-off.
	Koyama et al., (2012)	Not significant but Tendency to be higher
Semitendinosus	Romkes et al., (2006)	No difference
Gluteus medius	Nigg et al., (2006)	On standing: Increased activity (non significant)
		On walking: Decreased activity (non significant)
Gluteus maximus	Porcari et al., (2011)	No significant difference
Biceps femoris	Nigg et al., (2006)	On standing: Increased activity
		On walking: Decreased activity (non significant)
	Porcari et al., (2011)	No significant difference
	Koyama et al., (2012)	Not significant but tendency to be higher
Rectus femoris	Porcari et al., (2011)	No significant difference
	Koyama et al., (2012)	Not significant but tendency to be higher
	Romkes et al., (2006)	Increased at mid-stance phase; Reduced in stance-to-swing transition

Rectus abdominus	Porcari et al., (2011)	No significant difference
Erector spinae	Porcari et al., (2011)	No significant difference
Flexor digitorum longus	Landry et al., (2010)	Increased activity
Peroneus group	Landry et al., (2010)	Increased activity
Anterior compartment group	Landry, et al., (2010)	Increased activity

Table 2. Summary of electromyographic findings of various studies

ii. Differences in Muscle activation on variable inclines in stable shoes

Humans have the ability of locomotion but environment offers myriad inclines and each of them involves different muscle recruitment and biomechanics. Electromyography provides an insight about the muscle recruitment strategies and neuromuscular adjustments entailed. Franz & Kram, (2012) studied the effect of grade and speed on leg muscle activation during stance phase while walking and found out that the hip, knee and ankle extensor muscle activities increased while walking uphill (9°), but only knee extensor muscle activities increased while walking downhill (9°). Further, it was noted that leg muscle activations were higher at higher walking speed. Patla, (1986) also analysed the effect of walking on various inclines on the EMG patterns of selected lower limb muscles. The analysis revealed proximal muscles show greater increase in muscle activation than the distal muscles to meet the demands imposed by the various inclines. Yokozawa, Fujii & Ae, (2007) studied lower limb muscle activity by making the subjects run at different speeds on a level runway and a slope of 9.1% grade. The results evidenced that the activation and muscle torque of the hip extensors and flexors was augmented during uphill running at the high speed.

The findings dictate uniformly that muscle activation required for graded walking is different than level walking and additional activation is required. Franz & Kram, (2012), Patla, (1986), Yokozawa et al., (2007) clearly documented that with modulations in incline, increased muscle activation can be observed. However a detailed investigation of the effect of incline on muscle activation while wearing unstable shoes has not been performed. The only comparison between shoe types on different inclines was Porcari et al., (2011) who found no difference in muscle activity between level and 5% grade. A clearer picture of EMG comparison between shoe types (unstable versus stable) during level or incline locomotion is still required.

1.3 Functional benefits

Anecdotal evidences show that unstable shoes have also been used for a lot of therapeutic purposes and a few studies have also studied variables like foot pressure distribution, proprioception and balance which may lead to remedial and functional benefits. Therefore it is important to consider the functional benefits of unstable shoe use.

Improved proprioception and balance (decreased postural sway) can prove to be a major functional benefit from any modality and studies have confirmed the effectiveness of unstable shoes in doing so (Ramstrand, 2010; Landry, 2010; Nigg, 2006). A study by Ramstrand et al., (2010) evidenced that the usage of unstable footwear for 8 weeks can improve balance and proprioception. Another study involving unstable shoes found out that prolonged usage (6 weeks) of unstable shoes decreased the postural sway in the subjects during standing (Landry et al., 2010). This may even be advantageous in terms of improving muscle coordination especially of ankle musculature. Still, it cannot be generalised that reduction in postural sway is primarily due to continuous unstable shoe usage as in this particular study, there was an absence of a

control group using stable shoes. Nigg et al., (2006) also compared the center of pressure (COP) excursion with unstable and stable shoes. The findings illustrated that during still standing, the COP excursion was significantly greater in the unstable shoe as compared to the control shoe. The authors suggested that the subjects utilize higher level of both ankle and hip strategy to maintain a stance while standing in unstable shoes which can have functional benefits of improved balance and proprioception.

The unstable shoes, due to their unique sole shape are expected to influence the shoe pressure distribution which would be different than stable shoes (Stewart et al., 2007). Studies have been done to understand the effect of the unstable shoes on plantar pressure. In a study by Maetzler et al., (2008) the benefits of unstable shoes for diabetics were examined. The plantar pressure redistributing capacity of the unstable shoes was investigated and it was found that 6-week training with these shoes resulted in reduction of fore-foot plantar pressure which can be helpful for diabetic population as the decreased fore-foot pressure can help in reducing the incidence of ulcers diabetic foot. This is contradictory to the study done by Stewart et al., (2007) which showed opposite results with 76% increase in forefoot pressure while standing in unstable shoes. In that study, the comfort of footwear was discussed in terms of the ability of the 'shoe' to redistribute plantar pressure (Stewart et al., 2007). Mean and peak pressures in four distinct areas of the foot, and the total area of sole contact were measured by an electronic in-shoe system. Standing in the unstable shoes resulted in a 21% lesser peak pressure under the midfoot and 11% lesser peak pressure under the heel as compared to the training shoes. A 76% compensatory increase in pressure was also noted under the toes. The authors stated that although the shift in the pressure to forefoot was similar to wearing high heeled shoes but the distribution was more uniform. The authors further said that the shoes can be used to decrease the pressure from the

rear foot in some condition such as plantar fasciitis. Overall, it can be seen that there is a contradiction of having increased (Stewart et al., 2007) or decreased (Maetzler et al., 2008) fore-foot plantar pressure. As evident from above examples, unstable shoes can be used as a modality which can help in improved function and recovery from conditions like plantar fasciitis, diabetic foot ulcer etc but the results can be varied. The studies fail to reach a common consensus on the plantar pressure re-distribution effect of the unstable shoes and hence their effectiveness cannot be established. Further studies are required to understand additional therapeutic benefits of unstable shoes.

The above studies provide evidence that unstable shoes may play an imperative role in training stability and balance and can prove significant in improving function especially in older populations. Thus, it may be indicated for postural retraining or regaining balance during post-injury rehabilitative phases.

2. Summary of the Literature and need for current study

Despite the potential physical differences between traditional and unstable shoes, the muscle activity, mechanics and economy have shown to be similar with different styles of footwear. Physiological responses have been analysed in various studies but mixed results have been seen. While physiological results have been controversial, a similar trend has been observed when comparing biomechanical factors related to shoe type. It may be demonstrated that footwear choice may not have a substantial impact on the physical parameters of locomotion related to level of activity, injury and disease prevention and rehabilitation. However, it is important to consider how the dynamic constraints of locomotion may affect a comparison of shoe design on the physiology and biomechanics of walking. For example, shoe weight and

terrain have shown to greatly modify the economy of walking gait. Oxygen consumption and energy expenditure have been reported to be significantly influenced by shoe mass during locomotion (Jones, Toner, Daniels, & Knapnik, 1984; Miller & Stamford, 1987). Unstable shoes are heavier in weight than regular shoes (Koyama et al., 2012) but almost all the published studies have not considered weight equalization. Further, level walking is not the same as graded walking in terms of biomechanics (Franz & Kram, 2012), muscle activity pattern (Romkes et al., 2006) and energy cost when comparing different terrain in conventional shoes. While there seems to be a differential impact of shoe design and terrain on the biomechanics and physiology of walking, there is yet to be a quantified comparison of unstable to traditional shoes across different terrains at equivalent shoe weights. Additionally, comparing shoe styles across different terrains may indeed highlight subtle yet important differences of shoe design on walking gait. No research to date has compared stable and unstable shoes while walking downhill. Therefore, the main purpose of this study was to evaluate how unstable and stable shoes compare across measures of muscle activity, energy cost and rate of perceived exertion, over three locomotion grades (level, uphill incline and downhill incline) with normalized shoe weight.

Chapter 2

1. Introduction

A great deal of research has focused on the effects of footwear style on physical parameters of locomotion (Masood, 2011; Nigg et al., 2006). Though the purpose of footwear has traditionally been to provide stability and comfort to the user, still unstable form of shoes (like the Swiss Masai or Masai Barefoot Technology, Skechers Shape-ups etc) have been introduced with a goal to provide greater physical activity demands during walking (Masood, 2011). The basic premise behind “unstable” design has been to allow variable movement at the foot sole-ground interface resulting in joint stabilization through muscular contraction resulting in greater overall muscle activation and energy expenditure than traditional “stable” shoes. Further, specific footwear designs were postulated to counteract muscle atrophy and decrease prevalence of low back dysfunction (Masood, 2011). Unstable shoes have been purported to help by strengthening the lower leg musculature, thereby improving balance (Ramstrand et al., 2010) and facilitating blood flow in calf muscles (Yamamoto et al., 2007). Therefore, numerous scientific studies support the usage of unstable shoes in the prevention and correction of many foot problems and an important role in the rehabilitation of many gait-related problems (Romkes et al., 2006; Masood, 2011; Stewart et al., 2007). Despite the potential postulated physical differences between traditional and unstable shoes, the muscle activity, mechanics and economy have shown to be similar with different styles of footwear. Physiological responses have been analysed in various studies but mixed results have been seen. In a study by Porcari et al., (2011) the physiologic and electromyographic (EMG) responses to walking were compared in regular athletic shoes versus toning (unstable) shoes. No significant differences were reported in heart rate, oxygen consumption, muscle activity and caloric expenditure while walking in these two

diverse kinds of shoes. However, Koyama et al., (2012) found significantly higher heart rate, oxygen consumption, caloric expenditure and EMG activity while walking in unstable shoes as compared to stable shoes. While physiological results have been controversial, a similar trend has been observed when comparing biomechanical factors related to shoe type. Few studies have examined changes in muscle activity and kinematics related to walking in stable and unstable shoes and found variable results. Nigg et al., (2006) reported that tibialis muscle activity was significantly increased with the use of unstable shoes while standing, though no difference was found in other lower limb muscles. The authors did not find any significant difference in muscle activation, with different shoe types, while walking. On the contrary, Romkes et al., (2006) found significantly higher EMG in the tibialis anterior muscle while walking in unstable shoes. In terms of locomotory kinematics, unstable shoe resulted in significantly more dorsiflexed ankle position during the first half of stance (Nigg et al., 2006) but a decreased peak moment on ankle dorsiflexion and plantarflexion was evidenced in a study by Fukuchi et al., (2013). These findings indicate that unstable shoes do elicit variable effects during walking, but sufficient information is lacking to derive coherent functional conclusions.

It may be demonstrated that footwear choice may not have a substantial impact on the physical parameters of locomotion related to level of activity, injury and disease prevention and rehabilitation. However, it is important to consider how the dynamic constraints of locomotion may affect a comparison of shoe design on the physiology and biomechanics of walking. For example, shoe weight and terrain have shown to greatly modify the economy of walking gait. Oxygen consumption and energy expenditure have been reported to be significantly influenced by shoe mass during locomotion (Jones, Toner, Daniels, & Knapnik, 1984; Miller & Stamford, 1987).

Unstable shoes are heavier in weight than regular shoes (Koyama et al., 2012) but almost all the published studies have not considered weight equalization.

Further, level walking is not the same as graded walking in terms of biomechanics (Franz & Kram, 2012), muscle activity pattern (Patla, 1986) and energy cost (Gjovaag et al., 2011) when comparing different terrain in conventional shoes. Studies have reported lower oxygen consumption and energy expenditure with treadmill walking on level-ground when compared to uphill and downhill grades at similar speed (Pearce et al., 1983; Wyndham, Van der Walt, Van Rensburg, Rogers, & Strydom, 1971). Similar studies investigating modified shoe design across different terrain have resulted in differential physiological responses (Gjovaag et al., 2011; Porcari et al., 2011). Koyama et al., (2012) found significantly higher oxygen consumption with unstable shoes as compare to stable shoes while walking.

While there seems to be a differential impact of shoe design and terrain on the biomechanics and physiology of walking, there is yet to be a quantified comparison of unstable to traditional shoes across different terrains at equivalent shoe weights. Additionally, comparing shoe styles across different terrains may indeed highlight subtle yet important differences of shoe design on walking gait. A few studies (Nigg et al., 2006; Romkes et al., 2006; Porcari et al., 2011) have analysed muscle activity during walking in regular athletic shoes and unstable shoes but only during level or uphill walking. No research to date has compared stable and unstable shoes while walking downhill. Therefore, the main purpose of this study was to evaluate how unstable and stable shoes compare across measures of muscle activity, energy cost and rate of perceived exertion, over three locomotion grades (level, uphill incline and downhill incline) with normalized shoe weight. The authors hypothesized that the physiological responses such as oxygen consumption, heart rate and rate of perceived exertion along with EMG in lower limb

muscles will be higher while walking in unstable shoes as compared to stable shoes on all three grades. The authors further hypothesized that shoe type will modify the neuromuscular strategies across different walking grades.

1.1 Purpose of the study

The purpose of this study was to compare EMG activity of specific lower limb muscles, oxygen consumption, heart rate and RPE while walking on +10%, 0% and -10 % incline grade in two different types of shoes (Unstable shoes and weight equalized stable shoes).

1.2 Research Question

Is there a difference in EMG activity, oxygen consumption, heart rate and RPE on walking at +10 % grade, 0% grade and -10% grade when comparing unstable shoes with weight equalized stable shoes?

1.3 Hypothesis

1. Physiological responses like oxygen consumption, heart rate and rate of perceived exertion along with EMG in lower limb muscles will be higher while walking in unstable shoes as compared to stable shoes on all three grades.
2. Shoe type will modify the neuromuscular strategies across different walking grades.

1.4 Delimitations

1. Healthy females aged 18-40 years.
2. Participants had no lower limb orthopaedic injury or impaired walking ability.

3. Participants were free from any neurological or cardiac conditions

1.5 Limitations

1. The study was done at a set speed on all three surfaces which is not usual in everyday walking. Effects of modulation of speed were not considered.
2. The grades included were limited and consistent which is also not very probable in everyday walking.
3. No kinematic or kinetic variables were studied.

2. Methods

Data was collected over 3 weeks in University of Victoria, British Columbia. The University of Victoria Human Ethics Research Committee provided approval for this study to be conducted (see Appendix 1).

2.1 Experimental Design

The study was a random cross over design in which the participants served as self-controls. The grade and the shoe type were randomly selected and each participant went through all the combinations of grades and shoes for walking.

2.2 Participants

Eleven healthy untrained females (mean age: 25.6 years; mean height: 164.27 cm; mean weight: 62.91 kg) were recruited to participate in the study (see appendix II). None of the participants had any experience with unstable shoes before the start of the study, but were familiar with treadmill locomotion using regular running shoes.

2.2.1 Inclusion Criteria

1. Healthy females aged 18-40 years
2. Free of any lower-extremity pain or injury for a minimum period of 6 months prior to testing.
3. Not enrolled in any kind of fitness programs at time of testing
4. Not an active participant in any kind of elite sports.

2.3 Data Collection

On the day of data collection, participants were supplied with printed copies of the consent form. An explanation and familiarization of the study was provided, and any questions or concerns were addressed fully. This was followed by the participant's signature, indicating informed consent (see appendix III). All the participants were fully acquainted with the nature of the study before beginning the testing session.

2.3.1 Standardization of footwear weight

The participants were asked to bring their regular stable shoes to serve as control footwear and were provided with suitable sized unstable shoes (fig 2) on the day of testing. The shoes were weighed and weight was added (average: 182.9 g) to the stable shoes until the weight of both types of shoes was equal (see appendix IV). This was done by taping lead shots in bags just above the shoe lace.

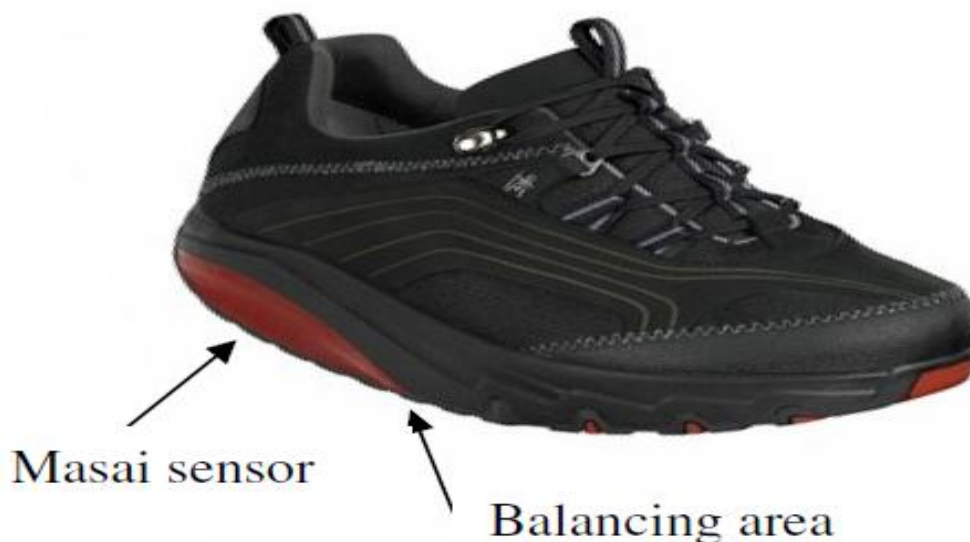


Figure 2. MBT shoe model- Chapa Black

2.4 Instrumentation

2.4.1 Electromyography (EMG)

EMG was used to measure the activity of seven muscles; medial gastrocnemius (GT), soleus (SOL), tibialis anterior (TA), vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF) and gluteus medius (GM). The participants were requested to remove hair on their legs prior to testing and the skin over the test muscles was cleaned using alcohol-dipped swabs, in order to reduce electrode impedance. After skin preparation, Delsys trigno wireless EMG surface electrodes were placed on the skin surface over muscles and secured with bandages. The electrode placement for muscles outlined above was done in accordance to the SENIAM guidelines for surface electrode placement (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The electrode placement and signal quality was verified by visually inspecting the EMG signal while the participants contracted each muscle being tested. For data analysis, custom script written LabView software was used. The data was bandpass filtered (10-500 Hz) by the Delsys hardware. The EMG data was full wave rectified by LabView script.

During testing, EMG amplitude for all muscles was collected from beginning of 2nd minute to the end of 3rd minute of each walking trial. A 30 second window with most uniform data was selected. The EMG data was cut off for each gait cycle starting and ending at the heel strike determined by the peak signal from the inbuilt accelerometers in the surface electrodes. The data was then time normalized and averaged followed by magnitude normalization with dynamic peak. Each gait cycle was then divided into 16 equidistant phases (Table 3) and mean normalized EMG activity was computed for each subject in each of 16 phases.

Phases	Stage of gait cycle
1 & 2	Heel strike to load acceptance
3 & 4	Load acceptance to mid stance
5 & 6	Midstance
7 & 8	Midstance to heel off
9 & 10	Heel off to toe off
11 & 12	Pre-swing
13 & 14	Midswing
15 & 16	Terminal swing

Table 3. Division of gait cycle into 16 sub-phases

2.4.2 Oxygen consumption

Absolute oxygen consumption was measured and relative oxygen consumption was calculated during the 5 minute walk using a Metabolic Measurement System (Parvo Medics True One 2400) and 30 second averages were reported. Crouter et al., (2006) proved the accuracy and reliability of this system. The metabolic cart was calibrated before each test trial. The subject breathed through a Hans Rudolph one-way valve and expired-air composition was analyzed. Computational software was provided with the system which calculated the 30 second average oxygen consumption in each 5 minute walk. The recordings, starting at end of 2nd min and thereafter, every 30 second till end of 4th minute were included and the average value was taken.

2.4.3 Rating of Perceived Exertion (RPE)

The participants rated their perceived exertion at end of each walking period. RPE was assessed during the final 10 seconds of each 5-minute walk using standard 6-20 Borg Scale. Stamford, (1976) proved this scale to be a sensitive and reliable measure for subjective ratings of perceived exertion during work.

Additionally, a 30 second average of heart rate (HR) was also recorded with a Polar (wear link) heart rate monitor. The readings were taken for the similar time frame as that of oxygen readings.

2.5 Testing protocol

The subjects came to the laboratory, for testing, on two separate occasions. The first test session was done when the subjects were unfamiliar with the unstable shoes. The order of the testing between the shoe types and grade was randomly assigned to the participants. Subjects were given the unstable shoes 5 minutes prior to testing and were allowed to walk in them to make them comfortable before beginning the testing session. The subjects took the unstable shoes home after the first test session and were asked to wear them as much as possible until the next test session. Three weeks were provided to the participants to adapt themselves with the shoes as Nigg et al., (2006) documented that a minimum period of two weeks is enough for such acclimatization. Each subject on an average wore the unstable shoes for 2 hours per day (0-8 hours/day; see Appendix V) for 3 weeks while walking or other activities involving standing or slow walking (see Appendix VI). The second testing was done 3 weeks after the initial testing.

In both testing sessions, the test protocol required the subjects to walk on a treadmill (Woodway) at +10%, 0% and -10% grade for five minutes each, at a self-selected pace (2.3-3.5mph; %HR_{max}: 41- 60) in each type of shoe. The pace was self selected by the participant (see Appendix VII) as per comfort and was maintained throughout the six trials at each test session. The pace was selected before the testing session was started. The participants walked in unstable shoes for about 30 seconds and determined the comfortable pace at which they could walk

through all the inclines. A five minutes rest was given after each walking trial of 5 minutes to avoid fatigue.

3. Statistics

A 2 (shoe type) by 3 (walking grade) by 2 (testing time) by 16 (walking phase) repeated measures ANOVA was performed for each muscle (Statistica 10TM). If significant main effects or interactions were found ($P < 0.05$), a Tukey post hoc analysis was done to determine specific differences. For oxygen consumption, HR and RPE, a 2 (shoe type) by 3 (walking grade) by 2 (testing time) repeated measures ANOVA was performed. The significant main effects or interactions were further analysed by Tukey post hoc analysis.

4. RESULTS

4.1 Electromyography Results

Eleven subjects completed the experimental protocol and detailed results are given below. Overall, there were no differences between pre (unaccustomed) and post (accustomed) testing yet there were significant differences for gait cycle phases for all the muscles tested. The analysis showed interactions between shoe type and gait phases as well as walking grade and gait phases in all muscles. Further, there were significant interactions between shoe type, walking grade and gait phases for all muscles except Tibialis Anterior and Gluteus Medius. Specific details of the results for each muscle are outlined below with post hoc findings. All results are discussed in relation to gait cycle being studied in 16 phases starting from ipsilateral heel strike (phase 1) to just prior to following heel strike (phase 16).

(i) Tibialis anterior

There was a main effect ($p < .000$ and $f = 22.98$) for shoe type only evident in tibialis anterior where the mean EMG amplitude for the entire gait cycle was higher in unstable shoes (Mean: 38.6 and SE .880 of max TA EMG) when compared to stable shoes (Mean 33.2 and SE .703 of max TA EMG). Tukey post hoc analysis for the interaction between shoe type and phases showed that unstable shoes were significantly lower than stable shoes at Phase 1 and unstable shoes were significantly higher than stable shoes in phases 9, 10, 12, 13, 14 and 15 (Fig 3).

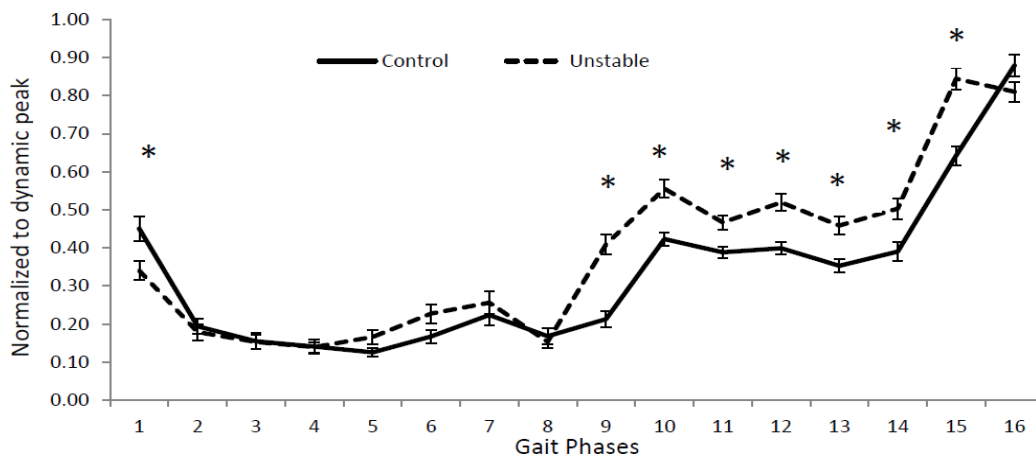


Figure 3. EMG activity in tibialis anterior while walking in stable versus unstable shoes

(ii) Soleus

While there was no main effect for shoe type for soleus, there was an interaction between shoe type and gait phases ($p=0.000$, $f=7.12$) as well as shoe type, gait phases and walking grade ($p=0.000$, $f=3.29$). Tukey post hoc analysis for the interaction of shoe type with gait phases showed that unstable shoes were significantly higher than stable shoes for phases 2 and 6 whereas unstable shoes were significantly lower than stable shoes for phase 8. Upon further analysis of the interaction between shoe type, walking grade and gait phase, tukey post hoc revealed that differences at phases 6 and 8 were only significant for level walking grade and phase 2 was only significant for uphill walking grade while no differences were noted in downhill walking (Fig. 4).

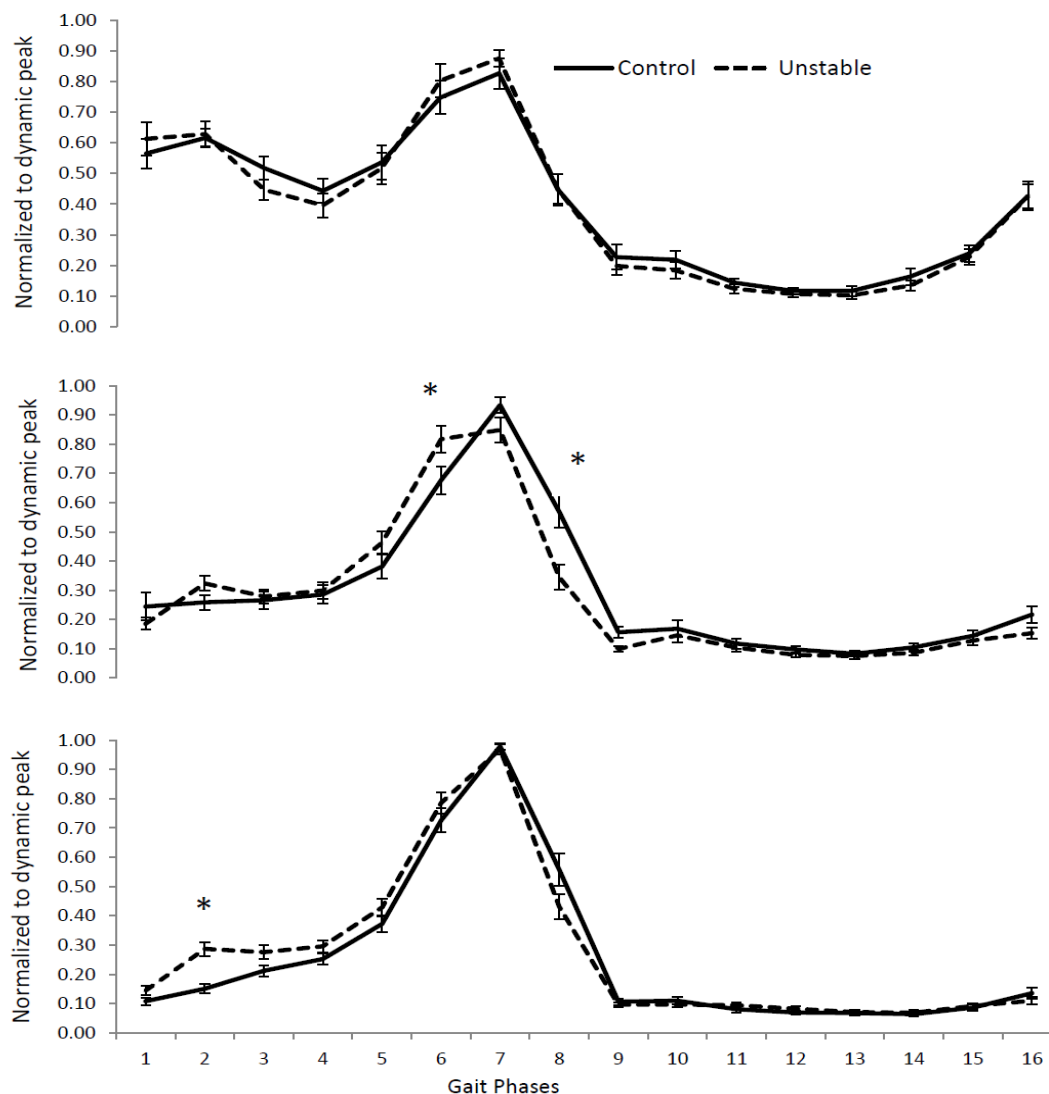


Figure 4. EMG activity in soleus while (a) Downhill, (b) Level and (c) Uphill walking

(iii) Gastrocnemius medialis

There was no main effect for shoe type but an interaction for shoe type and gait phases ($p < .000$, $f = 4.08$) and an interaction of shoe type with walking grade and gait phases ($p < .000$, $f = 3.99$). Tukey post hoc analysis for the interaction of shoe type and gait phases showed significant differences between phases 7 and 8 where unstable shoes had significantly lower values than stable shoes. Further, tukey post hoc analysis for the interaction of shoe type with walking grade

and gait phases revealed that significant differences at phase 7 and 8 were only evident during level walking (fig 5).

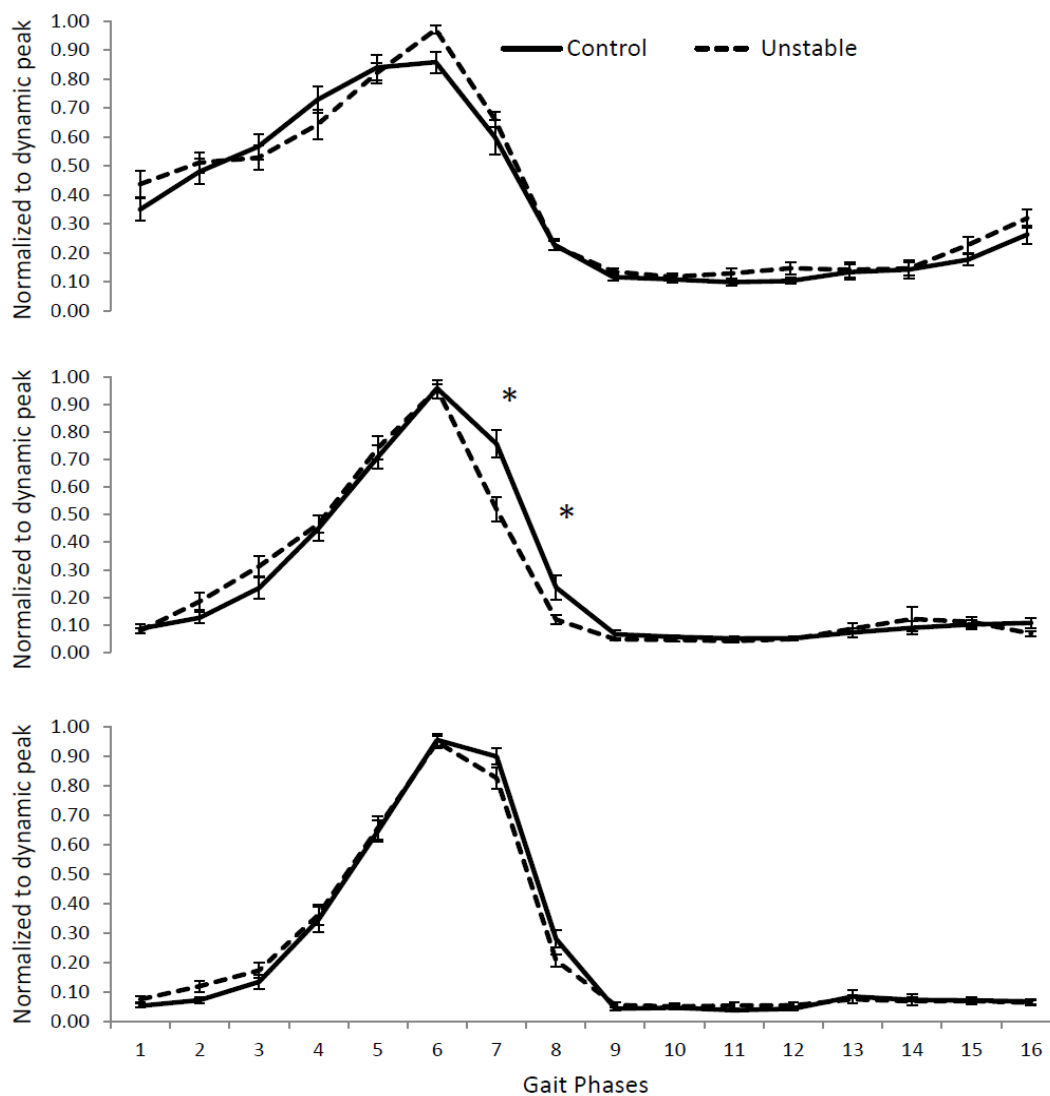


Figure 5. Gastrocnemius medialis EMG during (a) Downhill (b) Level (c) Uphill walking

(iv) Vastus lateralis

There was no main effect for shoe type but an interaction for shoe type and gait phases ($p=0.043$, $f=3.69$) and an interaction of shoe type with walking grade and gait phases ($p<.000$, $f=2.19$). Tukey post hoc analysis for shoe type with grade and gait cycle phases showed no

significant difference in shoe type while walking downhill and uphill but significant differences in phases 2 and 16 for level walking (Fig 6). The EMG activity in phase 2 was lower in unstable shoes while higher in phase 16 when compared to stable shoes.

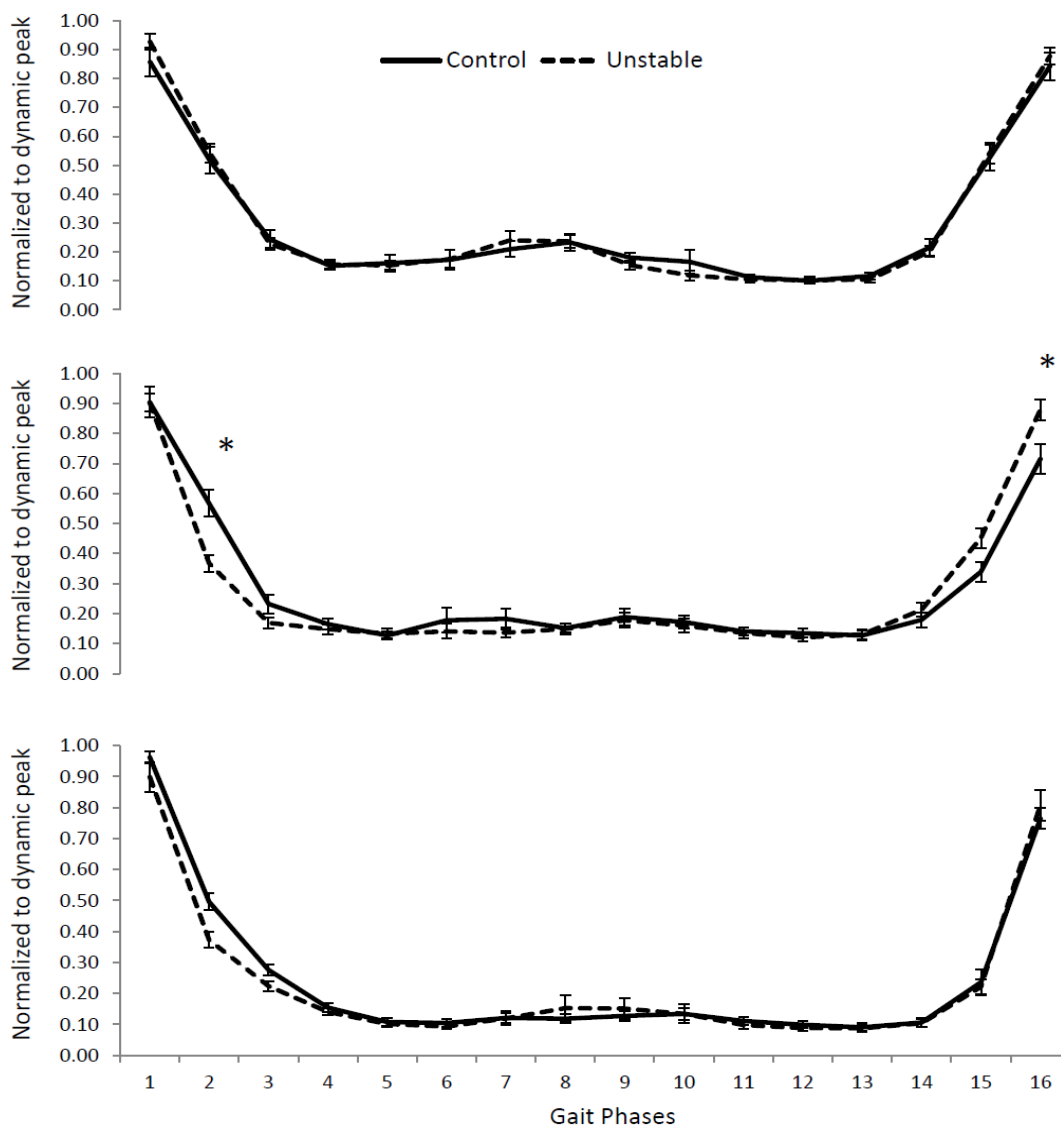


Figure 6. Vastus lateralis EMG during (a) Downhill (b) Level (c) Uphill walking

(v) Vastus medialis

The analysis showed no main effect for shoe type for vastus medialis but showed significant interaction between shoe type, grade and gait cycle phases ($p < .000$, $f = 2.45$). Tukey

post hoc analysis revealed significant difference for uphill and level walking in phase 2 and phase 16 for the interaction of shoe type, grade and phases of gait cycle (Fig. 7). The EMG amplitude during phase 2 was lower while walking in unstable shoes but higher in phase 16 when compared with stable shoes. This finding was similar for both uphill as well as level walking. There were no differences between shoe types while walking downhill.

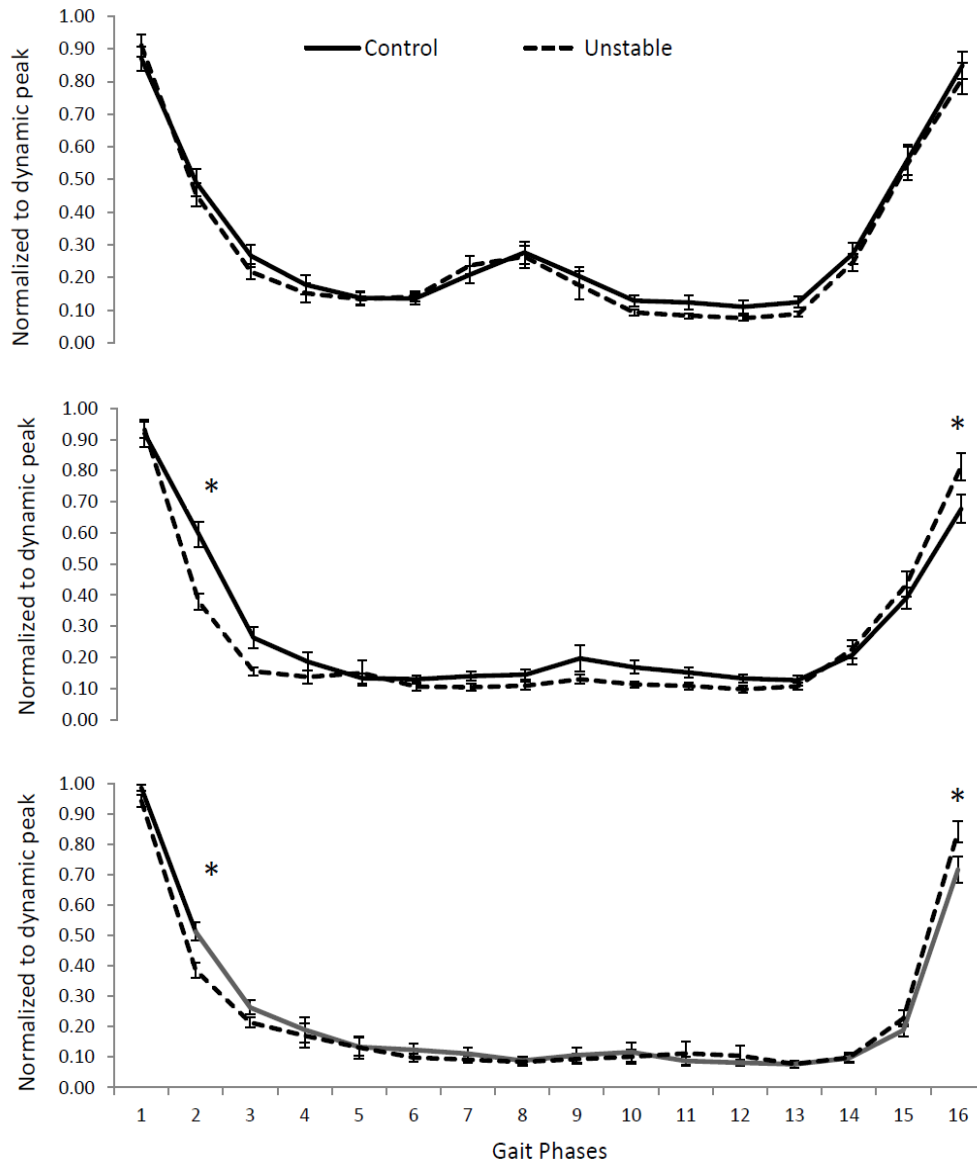


Figure 7. Vastus medialis EMG during (a) Downhill (b) Level (c) Uphill walking

(vi) Biceps femoris

The analysis showed significant interaction between shoe type, grade and gait cycle phases (p.002, f- 2.03). Tukey post hoc analysis showed significant differences between shoe types while walking downhill in phase 13, walking at level in phases 13, 15 and 16 but no significant difference while walking uphill (fig 8). The EMG amplitude in phase 13 was higher for both downhill and level walking in unstable shoes but was lower for phase 15 and 16 while walking on level surface.

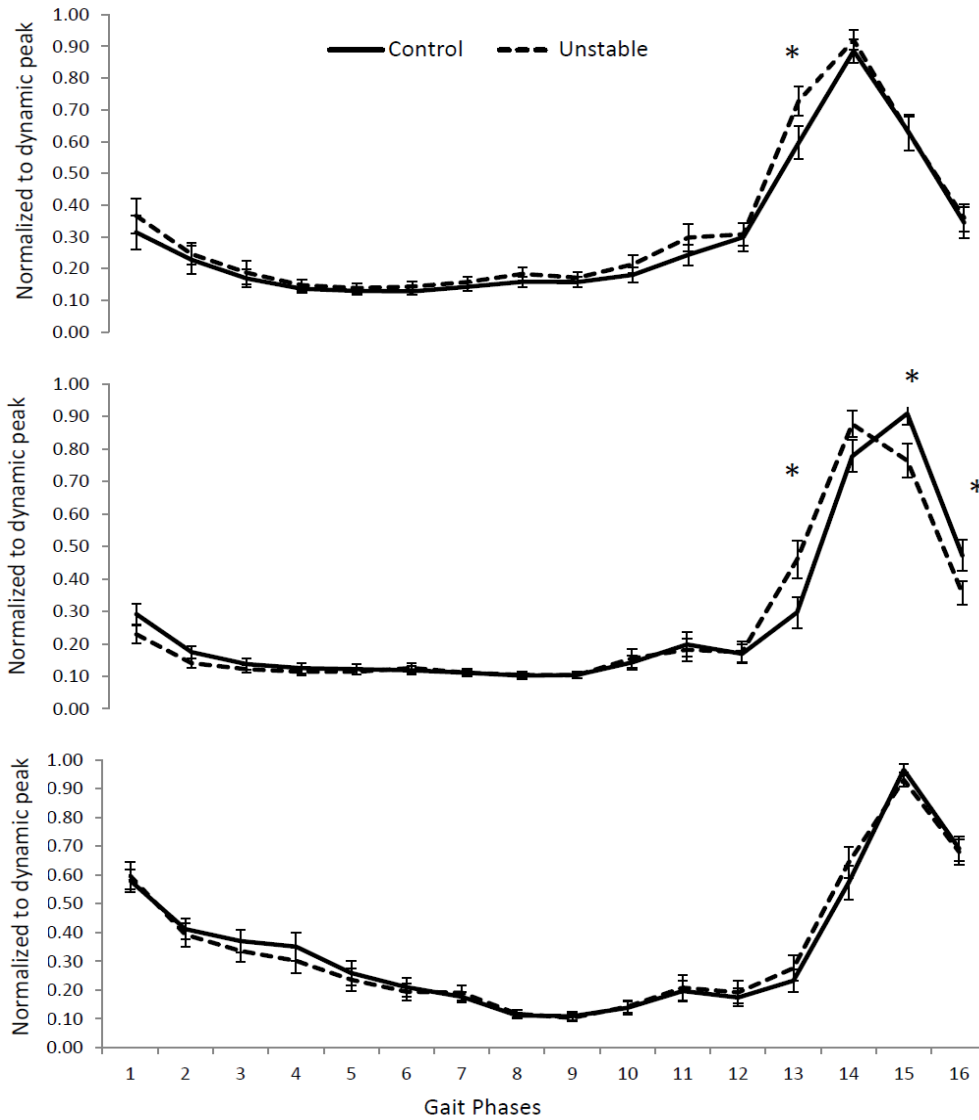


Figure 8. Biceps femoris EMG during (a) Downhill (b) Level (c) Uphill Walking

(vii) Gluteus medius

The analysis showed no main effect for grade but showed significant interaction between shoe type and gait cycle phases ($p=0.000$, $f=7.23$). Tukey post hoc analysis revealed that the EMG amplitude while walking in unstable shoes was lower in phase 2 but higher in phase 16 when compared with stable shoes (fig 9).

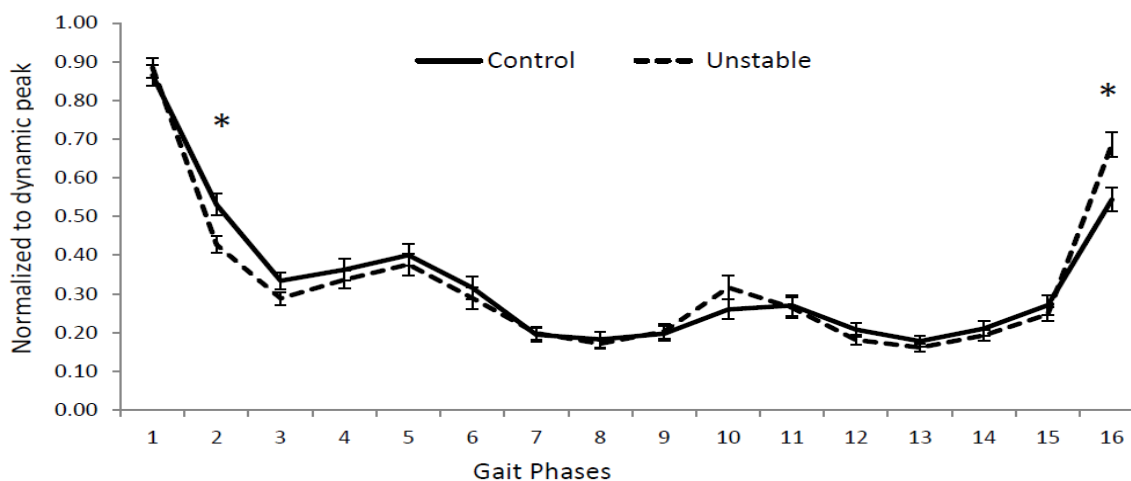


Figure 9. EMG activity of gluteus medius while walking in stable versus unstable shoes

4.2 Oxygen consumption

For both relative and absolute oxygen consumption, there were no differences between the pre (unaccustomed) and post (accustomed) readings. For relative oxygen consumption the analysis showed main effect for grade ($p=0.000$, $f=538.34$) with no other main effects or interactions. Tukey post hoc analysis revealed that relative oxygen consumption was highest while walking uphill with mean of 22.49 ml/kg/min (SE .461), followed by level walking with mean of 12.82 ml/kg/min (SE .260) and lowest for downhill walking which had a mean of 8.79 ml/kg/min (SE .210). There was no impact of shoe type at any grade.

For absolute oxygen consumption there was a main effect for walking grade ($p = .000$, $f = 447.25$) with no other main effects or interactions. Tukey post hoc analysis revealed significant difference in absolute O_2 while walking on all three levels. The absolute oxygen consumption was highest while walking uphill with mean of 1.41 litre/ min and Standard Error (SE) of .029, followed by level walking with a mean of 0.81 litre/min (SE .020) and lowest for downhill walking with a mean of 0.55 litre/min (SE .010). There was no impact of shoe type at any grade. A summary of oxygen consumption findings has been provided in table 4.

	Absolute VO ₂		Relative VO ₂	
	CONTROL	MBT	CONTROL	MBT
Uphill	Mean: 1.40L/min SE: .049	Mean: 1.43L/min SE: .038	Mean: 22.29ml/kg/min SE: .722	Mean: 22.68ml/kg/min SE: .578
Level	Mean: 0.82L/min SE: .020	Mean: 0.80L/min SE: .024	Mean: 13.01ml/kg/min SE: .347	Mean: 12.62 SE: .386
Downhill	Mean: 0.55L/min SE: .016	Mean: 0.55L/min SE: .020	Mean: 8.82ml/kg/min SE: .268	Mean: 8.76ml/kg/min SE: .316

Table 4. Oxygen consumption in stable and unstable shoes

4.3 Borg Scale

There were no differences between pre (unaccustomed) and post (accustomed) readings. The analysis revealed a main effect for grade ($p = .000$, $f = 35.31$) for RPE with no other main effect or interactions. Tukey post hoc analysis showed no significant difference in RPE between downhill and level walking whereas a significant difference was noted between downhill and level RPE scores of 9 and the uphill walking RPE score of 11. There were no differences with respect to shoe type at any grade (table 5).

4.4 Heart Rate

There were no differences between the pre and post readings. The analysis showed main effect for grade only ($p=0.000$, $f=94.76$). Tukey post hoc analysis showed significant differences of HR between all three grades with uphill walking showing highest average HR values (mean: 133 b.p.m, SE 3.68) followed by level walking (mean: 101 b.p.m, SE 2.55) and downhill walking (mean: 92 b.p.m., SE 2.85). No shoe effect was seen on HR response while walking on different grades as seen in table 5.

	HR		RPE	
	CONTROL	MBT	CONTROL	MBT
Uphill	Mean: 129b.p.m SE: 4.07	Mean: 130b.p.m SE: 4.00	Mean: 11 SE: .25	Mean: 11 SE: .24
Level	Mean: 99b.p.m SE: 2.74	Mean: 99b.p.m SE: 2.91	Mean: 9 SE: .24	Mean: 9 SE: .19
Downhill	Mean: 90b.p.m SE: 3.04	Mean: 92b.p.m SE: 3.19	Mean: 9 SE: .23	Mean: 9 SE: .24

Table 5. RPE and HR in stable and unstable shoes

5. Discussion

This is the first study to investigate muscle activity, oxygen consumption, heart rate and RPE in stable and unstable shoes across different grades with normalized shoe weight. Overall, differences were found in lower limb muscle activation during walking in unstable and stable shoes on three different grades suggesting modifications in neuromuscular strategy related to shoe type. However, the majority of differences between shoe type and gait phase occurred during level walking with few during uphill walking and only one noted difference for downhill walking. This suggests that level walking may afford the greatest opportunity to realize differences

between shoe types for changes in lower limb muscle activity. Specifically this study observed important differences between ankle and hip stabilizer activity related to shoe type irrespective of grade. While few differences were revealed during downhill and uphill grades, walking with different shoe types on varied terrain may highlight slight but meaningful functional differences in muscle activation. A detailed explanation of potential functional consequences on lower body muscle activation is outlined below. Further, while there were differences between oxygen cost, rate of perceived exertion or heart rate across walking grades, there were no differences related to shoe type. This would suggest that shoe type may not influence the physiological cost of walking across varied terrains.

5.1 Ankle and hip stabilization modifications due to shoe type

One of the main impetuses for the usefulness of unstable shoes is the proposed challenge to the wearer's equilibrium and balance maintenance (Porcari et al., 2011). It was therefore hypothesised that unstable shoes work as a proprioceptive tool and lead to increased ankle stabilizer activation during standing and walking (Romkes et al., 2006; Nigg et al., 2006). Specifically unstable shoes are suggested to recruit muscles for greater ankle stabilization effort during weight acceptance at heel strike and early stance (Romkes et al., 2006). In the present study, there were grade independent changes in ankle and hip muscle activity related to shoe type. Tibialis anterior activity was significantly higher in the swing phase of walking in unstable shoes as compared to stable shoes for all walking grades. Romkes et al., (2006) functionally associated this heightened activity with noticeably increased dorsiflexion during the swing phases. Also, Nigg et al., (2006) found significant differences in activation of tibialis anterior while standing in unstable shoes. They attributed this heightened activity to larger excursion of centre of pressure

in antero-posterior and medio-lateral direction and the strategies applied to control it. Various factors can be related to increased dorsiflexion during the swing phase. One of the related factors could be greater sole thickness (Koyama et al., 2012) and conscious effort for more ground clearance to avoid tripping. The midsole of the unstable shoe have the greatest thickness as compared to other shoes where the heel is thickest. This difference in thickness at the midsole may require greater dorsiflexion for sufficient ground clearance. It is established that sufficient TA activity is needed during swing phase for ground clearance (Schubert et al., 1997) and hence with a thicker sole, greater dorsiflexion may be required. Additionally, in the present study we found that at heel strike there was lower TA activity in unstable as compared to stable shoes. This may be due to the fact that there is no real heel contact in unstable shoes as a rolling motion occurs at heel strike and there is continuous plantar flexion movement from heel strike to mid-stance (Romkes et al., 2006). Therefore while wearing unstable shoes, there is augmented ankle stabilizer muscle activity, this activity is not during heel strike or weight acceptance where a greater demand to ankle stabilization is assumed to occur due to unstable shoes. Another muscle in the present study that had differential activation related to shoe type, but not grade of walking, was gluteus medius (Fig.9). The analysis showed higher GM activation at terminal swing (phase 16) but lower at early stance (phase 2). Nigg et al., (2006) found an average 16% decrease in gluteus medius activation in one gait cycle. However, the specific phases of the gait cycle where the muscle activity was diminished were not stated. While it is difficult to determine the exact functional consequences of these results, it can be postulated that a decrease in GM activity at heel strike would result in lower hip stabilization during the loading response (Gottschalk, Kourosh, & Leveau, 1989). This finding would therefore be contradictory to the proposed benefits of unstable shoes.

Taken together these results lend some support for the use of unstable shoes to enhance ankle stabilizer muscles but not during load acceptance. Also, we did not find any support increase in activity of hip stabilizer muscle. However since we did not measure all muscles active at these joints or corresponding kinematics this statement is difficult to fully substantiate. It is important to state that there were no differences between walking grades for the results found for both the TA and GM. This would help to support past finding comparing unstable shoes across limited modifications in terrain. That is, while there are differences between stable and unstable shoes in terms of specific muscle activation, certain muscle activation and roles may be unaffected by terrain changes.

5.2 Shoe type modifies neuromuscular strategy across different walking grades

When considering the effect of shoe type on muscle activation during different walking grades, the current literature is lacking where the majority of studies have focused on shoe type comparisons during level walking with very few comparisons on different grades. However, human gait is not limited to level walking at a constant speed, but involves a wide variation and combination of grades, terrain and speed (Wall-Scheffler, Chumanov, Steudel-Numbers, & Heiderscheit et al., 2010). In fact it is well established that training on different terrain can have various beneficial effects in terms of oxygen consumption and muscle strength improvements (Tulloh, 1998). Further, similar to current findings, heart rate and RPE have been found to be higher in uphill running as compared to downhill or level running (Cai et al., 2010) regardless of shoe type. It has been documented that muscle activation during graded walking is significantly different from level walking (Franz & Kram, 2012). Franz & Kram, (2012) found that while walking uphill (9° grade) extensor muscle activity at the hip, knee and ankle were higher than

during level walking whereas while walking downhill (9°) only the activity of knee extensor muscles were significantly increased as compared to level walking. These differences in muscle activation were functionally associated with the recruitment strategies to assist downhill and uphill walking. The authors recorded mean normalized EMG activity for gluteus maximus, biceps femoris, rectus femoris and vastus medialis from heel strike to midstance and medial gastrocnemius and soleus were recorded from midstance to toe off. The results from the current study showed similar muscle activations during the same portions of stance phase. Higher muscle activation was recorded only in knee extensor muscle (vastus medialis) while walking downhill whereas higher muscle activation was recorded in hip (biceps femoris, Fig.8), knee (vastus medialis, Fig.7) and ankle extensors (soleus and gastrocnemius, Fig.4 & 5) while walking uphill as compared to level walking. These results indicate that different muscle recruitment strategies are involved to assist graded walking as compared to level walking.

When considering the effect of shoe types across various inclines the results indicated modifications in neuromuscular strategy caused by shoe type during certain phases of the gait cycle, for all the muscles (Fig.3 to Fig.9) while walking on level surface with significant modifications in neuromuscular strategy for soleus (Fig.4), vastus medialis (Fig.7) and biceps femoris (Fig.8) while walking on different grades. These results emphasize the importance of studying muscle activation on different grades while walking in different shoe types.

5.3 Muscle activation differences during walking on a level surface related to shoe type

In the present study soleus muscle activity was observed to be increased during mid stance (phase 6) but decreased during late stance (phase 8) when walking in unstable shoes on a level surface. Further, Koyama et al., (2012) found higher muscle activation for soleus but the exact

phase of the gait cycle was not documented. The present results also showed lower gastrocnemius activity in late stance (phases 7 and 8). These findings are in contradiction to the findings by Romkes et al., (2006) where the activity of gastrocnemius was found to be higher in initial contact to midstance with differences in other phases. The authors suggested that GT muscle activation along with co-contraction of TA might be able to increase stability at the ankle in the early stance phase to counteract instability caused by the shoe design. Differences noted between the current study and that of Romkes et al., (2006) may be due to variations in study protocol. In the study by Romkes et al., (2006) subjects were given specific walking instructions and training time with a physiotherapist. Details of this training scenario were not disclosed. Since instruction based training was not undertaken in the current experiment, these results may represent only those populations who purchase commercial unstable shoes without instruction or training about their proper use. Briefly, Romkes et al., (2006) also stated that the heightened activity of the gastrocnemius, during terminal swing up to toe off, was due to the continuous plantarflexion movement experienced when using unstable shoes properly. It is possible that the difference in training and instruction as well as the passive rolling plantarflexion enabled by the shoe construction could explain the lower activation in late stance for both soleus and gastrocnemius seen in this study compared to that of Romkes et al., (2006).

Knee extensors recorded higher activation in unstable shoes as compared to stable shoes at terminal swing to stance transition (phase 16) but lower activation at initial contact (phase 2). These findings are different from the findings by Romkes et al., (2006) where the muscle activity for vastus medialis and lateralis was higher from midstance to toe off for unstable shoes. However Nigg et al., (2006) found lower (non significant) vastus medialis activation during the gait cycle in unstable shoes. Again, the lack of specific guidance about the shoe usage can be one

factor behind the difference in the results of the current study and Romkes et al., (2006). One functional possibility in the change in knee extensor activity may be related to the sole construction and foot kinematics in an unstable shoe. That is, in order to keep the rear part of the foot clear during heel strike and properly initiate the plantar-flexion rolling motion, the knee extensors may contract to maintain knee extension thereby presenting a greater heel surface to contact the ground. However, the study done by Romkes et al., 2006, found decreased knee flexion angle at end of terminal swing and refutes this possibility. Since the present study did not include any kinematic data, it is possible that the kinematic data could have supported the current hypothesis. Additionally, the EMG results for knee extensors in the Romkes et al., 2006 study mimicked the knee kinematic results, but were different at terminal swing for the EMG we observed in the current experiment. Moreover, increased step length has been reported while walking in unstable shoes (Koyama et al., 2012) which might be completed by continuous knee extensor activity at the terminal swing in order to delay the foot contact and hence increase the step length. The lower values for knee extensor activation at initial contact (phase 2) may be a compensatory response to the higher knee extensor activation in initial phases and an attempt to gain the required knee flexion which was not gained earlier. This is supported by increased knee flexion reported during stance phase by Romkes et al., (2006). The current results also showed increased activation of biceps femoris in mid to late swing (phase 13) and lower activation for terminal swing (phases 15 and 16) during level walking in unstable shoes. Koyama et al., (2012) found increased but non-significant biceps femoris activation for the whole gait cycle. The higher knee flexor activation in mid-swing may assist TA in providing sufficient ground clearance of the thickened midsole of unstable shoes. This is again different from the kinematic findings of

Romkes et al., 2006, as mentioned above. Further, the lower knee flexor activation in terminal swing may be in preparation for higher knee extensor activation as discussed earlier.

5.4 Muscle activation differences during walking on an uphill surface related to shoe type

Franz & Kram, (2012) found increased muscle activation for hip, knee and ankle extensor while walking uphill as compared to level walking in control shoes. The current study found consistent results to Franz & Kram, (2012) for normal athletic shoes and unstable shoes.

However, there were notable differences in unstable shoes in muscle activation at specific gait phases when compared to normal shoes. Current results display an increase in soleus muscle activation at initial contact (phase 2) while walking in unstable shoes as compared to stable shoes (Fig.4). While walking in unstable shoes higher soleus activation may be required to initiate the plantar-flexion rolling motion uphill to counteract passive dorsiflexion. Also, the results showed higher activity in vastus medialis (Fig. 7) while walking in unstable shoes as compared to stable shoes at terminal swing to stance transition (phase 16) but lower activation at initial contact (phase2). Moreover, it is possible that more knee flexion is required at initial contact (phase 2) to gain more ROM for walking uphill in unstable shoes requiring lower vastus medialis activity in order to facilitate it. Further, higher vastus medialis activation at terminal swing to stance transition (phase16) may be necessary to gain more step length (Koyama et al., 2012).

5.5 Muscle activation differences during walking on a downhill surface related to shoe type

During downhill walking in normal shoes Franz & Kram, (2012) found increase muscle activation for knee extensors. The present study also demonstrated increased knee extensor activation for both shoe types during downhill walking. The results also showed higher biceps

femoris activation during midswing (phase 13) in unstable shoe as compared to stable shoes (Fig. 8). The higher activation of biceps femoris in midswing may be necessary for ground clearance due to higher sole thickness at midsole as mentioned during level walking.

5.6 Oxygen Consumption

Oxygen consumption was significantly different while walking on different inclines, with both unstable and stable shoes. This finding was supported by the results of Minneti et al., (2002) that showed a difference of energy cost of walking at extreme uphill and downhill slopes in regular shoes.

Unstable shoes presumably offer a more oxygen consumption when compared to the use of regular shoes but the findings of this study showed no such effect. Absolute and relative oxygen consumption values, which are important physiological markers of exercise intensity, showed no significant difference between the shoe types while walking. The current results concur with some recent literature. Two studies completed in 2011 (Porcari et al.; Gjovaag et al.) found similar results of having no difference in oxygen consumption when walking in toning shoes or in regular running shoes.

However, some studies have shown an increase in oxygen consumption with the use of unstable shoes. Nigg, (2004) found a 2.5% increase in oxygen cost with unstable shoes when compared with regular walking shoes. Koyama et al., (2012) also reported an increased oxygen cost with unstable shoes over what was found with stable shoes. The authors explained the increase was due to increased step length and increased muscle activity per unit time especially in the calf muscles. However, a major drawback of the study by Koyama et al., (2012) was that the weight of the shoes was not controlled and the unstable shoes were almost 1 kg heavier than the

stable shoes which might have lead to differences in oxygen consumption. Similarly, Nigg, (2004) also did not equalize the shoe weight and thus in that study the unstable shoes also weighed more than stable shoes and probably impacted the measured oxygen cost between the two conditions. Jones et al., (1984) reported oxygen consumption increased by 0.8% per 100 gram increase in shoe weight. They also reported energy expenditure to be significantly influenced by putting up additional mass to the shoes.

The study completed by Koyama et al., (2012) also examined the effect of walking speed on oxygen consumption using unstable versus stable footwear. They found a significant relationship between walking speed and VO₂. Moreover and more relevant to this current study, Koyama et al., 2012 reported greater increase in oxygen consumption with increase in speed in unstable shoes as compared to stable shoes. The current study used a fixed pace and so the effect of speed on oxygen consumption was not compared between the shoes, which can be another reason for the difference in results.

5.7 RPE

RPE is a subjective indicator of exercise intensity. The current study showed a significant difference in perceived exertion rating in downhill and level walking when compared to uphill walking for both shoe types. However RPE showed no significant difference when comparing the shoe types at each grade. Koyama et al., (2012) also reported little change (non significant) in RPE owing to the ease of walking in unstable shoes. In contrast Gjovaag et al., (2011) reported a 25% increase in RPE while walking in unstable shoes which was said to be affected by the shoe type. A study by Porcari et al., (2011) also found out an increase in RPE score with unstable shoes treadmill walking. Again, as with increased oxygen consumption, it is hypothesized that

the heavier weight of unstable shoes as compared to the other shoe used was the probable cause for higher RPE ratings.

5.8 Heart rate

Variations in heart rate during exercise can be associated with intensity of exercise (Karvonen & Vuorimaa, 1988). As expected in this study, HR increased significantly with an increase in grade from downhill walking to level walking to uphill walking regardless of shoe type. However, the current study found no significant difference while walking in unstable shoes when compared with stable shoes irrespective of walking grade. Similarly, Thuesen & Lindahl, (2009) found no significant difference in heart rate while walking on a treadmill with unstable shoes or stable shoes. They refuted the concept of an intense workout being provided by unstable shoes even though the weight of the stable and unstable shoes used was different. In contrast previous researchers have found that heart rate increased by 6.6% during treadmill walking with unstable shoes when compared with stable shoes (Gjovaag et al., 2011). Koyama et al., (2012) also found HR to be higher for unstable shoes than stable shoes.

6. Conclusion

The current study observed the effect of shoe type on muscle activity in lower limbs and physiological variables while walking on different grades. Overall, while there were no differences found between stable and unstable shoes for oxygen consumption, RPE and HR, there were significant phase related differences in muscle activity across grades while walking. This suggest that while there may be no difference in overall fitness benefit of walking in unstable shoes, changes in neuromuscular strategy highlight possible specific muscle strengthening/toning

benefits. Specifically, differences in ankle stabilizer activation irrespective of grade due to shoe type may support the role of unstable shoes in ankle muscle strengthening. However, decreased hip stabilizer activity during the walking loading response in unstable shoes may present a possible detriment to walking performance. Therefore the authors suggest that care must be taken when considering the use of unstable shoes for overall fitness or specific strengthening needs. While the present study highlighted changes in muscle activity for lower limb muscles across different grades future studies are required to analyze kinematics and kinetics alongside muscle activity, while walking at different speeds and grades to fully substantiate functional consequences.

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Appendix

I. Certificate of Approval- Human Research Ethics Board



Human Research Ethics Board
 Office of Research Services
 Administrative Services Building
 PO Box 1700 STN CSC
 Victoria British Columbia V8W 2Y2 Canada
 Tel 250-472-4545, Fax 250-721-8960
 Email ethics@uvic.ca Web www.research.uvic.ca

Certificate of Approval

PRINCIPAL INVESTIGATOR	Avneet Singh Chatha	ETHICS PROTOCOL NUMBER	12-365
UVic STATUS:	Master's Student	ORIGINAL APPROVAL DATE:	11-Sep-12
UVic DEPARTMENT:	EPHE	APPROVED ON:	11-Sep-12
SUPERVISOR:	Dr. Lynneth Stuart Hill	APPROVAL EXPIRY DATE:	10-Sep-13
PROJECT TITLE: Comparison of EMG activity in lower limb, oxygen consumption and RPE in toning versus running shoes on uphill, level and downhill walking			
RESEARCH TEAM MEMBERS: None			
DECLARED PROJECT FUNDING: None			
CONDITIONS OF APPROVAL			
This Certificate of Approval is valid for the above term provided there is no change in the protocol.			
Modifications To make any changes to the approved research procedures in your study, please submit a "Request for Modification" form. You must receive ethics approval before proceeding with your modified protocol.			
Renewals Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.			
Project Closures When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a "Notice of Project Completion" form.			
Certification			
This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.			
			

Certificate Issued On: 11-Sep-12

12-365 Chatha, Avneet Singh

Appendix II: Call for participants



This is an invitation to participate in a research project being conducted by Dr. Lynneth Stuart Hill and Avneet Singh Chatha at the University of Victoria.



Science under your feet

Interested to test its efficiency???

WHO IS INVITED?

- Healthy **FEMALES** aged **25-40 years**
- Must not be under any fitness training.

WHAT?

- ▶ A research study involving 10 minutes treadmill walk to compare toning shoes (MBT) with Athletic running shoes.

WHY?

- No research has looked at the
- This will help to support the need for change in policy and practice.

WHEN?

- ▶ The study begins in August 2012 and participation is welcomed from then.

HOW?

- ▶ Participation in the study involves walking on treadmill for 5 min each wearing toning shoes (MBT) and athletic training shoes.
- ▶ Electromyography (EMG), oxygen consumption and perceived exertion (RPE) will be measured alongside.
- ▶ Participation is voluntary and you may withdraw from the study at any time.



The study is self funded and not by the shoe manufacturers.

Thank you for your time and consideration in participating in this study. If you would like to participate, please contact:



III. Participant consent form

“Comparison of EMG activity in lower limb, oxygen consumption and RPE in toning versus running shoes on uphill, level and downhill walking”

You are being invited to participate in a study entitled “Comparison of EMG activity in lower limb, oxygen consumption and RPE in toning versus running shoes on uphill, level and downhill walking” that is being conducted by Dr Lynneeth Stuart-Hill, Dr Marc Klimstra, Dr Catherine Gaul and Avneet Singh Chatha. Dr Lynneeth Stuart-Hill, Dr Marc Klimstra and Dr Catherine Gaul are professors in the School of EPHE, and can be contacted at lstuhill@uvic.ca, klimstra@uvic.ca and kgaul@uvic.ca respectively. Avneet Singh Chatha is a graduate student in the School of Exercise Science, Physical and Health Education (EPHE) at the University of Victoria, and you may contact him if you have any questions at 778-676-2012 or avneetchatha@gmail.com.

The purpose of this study is to compare toning shoes and athletic running shoes in terms of EMG activity in lower limb, oxygen consumption and RPE while walking on +10%, 0% and -10 % grade on treadmill.

Toning shoes, that we are going to use in the study, are shoes manufactured with an unstable sole. These are supposed to work like barefoot walking. In the early 1990s, it was realised that Masai tribesmen of Africa, who did not wear any kind of shoes while walking, were free from backache. So it was concluded that walking barefoot on the natural soft, uneven ground activates muscles which otherwise get wasted while walking on hard, even surfaces wearing conventional shoes. To replicate this, unstable-soled toning shoes were created.

Our study is an attempt to compare the effects of two different shoes- toning shoes and regular athletic shoes in terms of muscular activity and workout. Muscular activity of the thighs and legs will be quantified whereas workout will be assessed in terms of oxygen consumed while walking and subjective rating of fatigue induced with these shoes.

For this study, you will be provided a new pair of suitably-sized toning shoes and regular athletic shoes each, 3 weeks prior to the final assessment. A base reading will be taken on day one. You will be asked to wear the specialized toning shoes regularly and maximally in order to accommodate to such shoes. After 3 weeks you will be required to visit the research laboratory and walk on treadmill for 5 minutes with those toning shoes on. While walking, various parameters will be calculated and noted. After 5 minutes of treadmill walking with toning shoes, you will be seated to regain the energy for another similar 5 minutes walk on treadmill while wearing regular athletic shoes. The same assessments will be done and recorded. All these procedures will be completed within an hour. After this, you may leave the laboratory. No follow up or further interviewing will be done later.

As mentioned above, your participation will include the monitoring of several variables during the treadmill walk. The variables being measured include: height, weight, heart rate, electrical (EMG) activity of various muscles of lower limb, oxygen consumption and rating of perceived exertion (RPE). Throughout the treadmill walk, heart rate will be monitored continuously using a Polar heart rate monitor.

Muscle activity will be measured using surface electrodes positioned over the skin of thighs and legs. Surface electrodes are flat self-sticking devices that do not give any kind of sensation to the user other than that similar to a bandaid. They are meant to receive signals from muscles and present them on the computer. Oxygen consumption will be assessed by using a metabolic measurement system. The subject will be required to wear a sterilized mask on mouth and breathe normally while walking on the treadmill. The air blown out during expiration will automatically get collected and will be tested for calculating oxygen consumed. Perceived exertion will also be noted at the end of each walk. It will require the subject to just report verbally (on a scale of 6-20) how much tiredness can be felt after the walk with each shoe.

We anticipate that your participation in the study poses no increased risk over the risk of walking on treadmill alone. Before applying electrodes, it will be ensured that skin surface is clean and dry. The skin will be abraded with an abrasive cream, or using an alcohol wipe. The participant might need to shave small areas of the thighs and legs to ensure the electrodes adhere to the skin. If you have ever experienced difficulty walking on treadmill or have been told by a doctor to use any walking aid while walking, then you may not go ahead with the protocol.

In this research, your anonymity during data collection will be maintained. It will be protected by assigning a number to your data so that following data collection your data will be identified only by that number. Your confidentiality and the confidentiality of the data will be protected by storing your coded data on a password protected computer, to which access is limited to the principal researcher. All data will be presented as group averages and individual results will not be given.

The results of the study will be used only for academic thesis. It is anticipated that the results of will be shared with others through presentations during scholarly meetings or through submission to peer-reviewed research publications. The data will be kept for 1 year and then deleted.

By participating in this research, you will benefit by contributing to the knowledge about the fitness shoes, and could contribute to a growing body of research supporting the effectiveness of rocker bottom shoes for fitness as well as rehabilitative purposes.

Participation in this research must be completely voluntary. You may withdraw from the study at any time without any consequences. If you do withdraw from the study, your data will not be used in any data analysis and will be destroyed.

In addition to being able to contact the researchers at the phone numbers listed below, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca)

Please ensure that you understand the above conditions of participation in the study and you have had the opportunity to ask the researcher about any questions or concerns that you may have. Your signature below indicates that you consent to participate in this research project.

Name of Participant

Signature

Date

FINAL DAY OF TESTING

I voluntarily agree to participate in this study. I have had an experience of using the toning shoes for 3 weeks. I did not face any difficulty walking in such shoes. I have no objection to walk on treadmill with toning shoes or the regular athletic shoes.

Name of Participant

Signature

Date

IV. Shoe-weight Equalization

Participant	Right			Left		
	Unstable	Stable	Weight added	Unstable	Stable	Weight added
1	459g	224g	235g (104%)	453g	222g	231g (104%)
2	429	281	148g (53%)	440	290	150g (52%)
3	423	272	151g (55%)	420	280	140g (50%)
4	473	250	223g (89%)	463	250	213g (85%)
5	453	284	169g (60%)	445	282	163g (58%)
6	480	262	218g (83%)	484	258	226g (87%)
7	469	245	224g (91%)	469	238	231g (97%)
8	460	285	185g (65%)	465	290	185g (64%)
9	463	301	162g (54%)	475	304	171g (56%)
10	478	233	245g (105%)	471	230	241g (105%)
11	479	427	52g (12%)	489	436	48g (11%)

V. Total usage of unstable shoes by each participant

Participant	Maximum used in a day	Minimum used in a day	Average of 3 weeks usage
1	8 hours	0 (not used at all for at least one day)	3.09 hours
2	8 hours	0	2.33 hours
3	8 hours	0	2.26 hours
4	6 hours	0	1.53 hours
5	6 hours	0	1.88 hours
5	7 hours	0	2 hours
6	5 hours	0	1.69 hours
8	5 hours	0	1.57 hours
9	4 hours	0	1.65 hours
10	6 hours	0	1.82 hours
11	4 hours	0	1.33 hours

VI. Activity Calendar

Each participant was required to fill this calendar daily for three weeks, documenting hours and activities of using unstable shoes.

<p>13 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>	<p>14 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>	<p>15 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>
<p>16 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>	<p>17 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>	<p>18 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>
<p>19 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>	<p>20 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>	<p>21 December 2012</p> <p>Shoes worn for ___ hours Activities done:</p>

22 December 2012 Shoes worn for ___ hours Activities done:	23 December 2012 Shoes worn for ___ hours Activities done:	24 December 2012 Shoes worn for ___ hours Activities done:
25 December 2012 Shoes worn for ___ hours Activities done:	26 December 2012 Shoes worn for ___ hours Activities done:	27 December 2012 Shoes worn for ___ hours Activities done:
28 December 2012 Shoes worn for ___ hours Activities done:	29 December 2012 Shoes worn for ___ hours Activities done:	30 December 2012 Shoes worn for ___ hours Activities done:

31 December 2012 Shoes worn for ___ hours Activities done:	1 January 2013 Shoes worn for ___ hours Activities done:	2 January 2013 Shoes worn for ___ hours Activities done:
3 January 2013 Shoes worn for ___ hours Activities done:	4 January 2013 Shoes worn for ___ hours Activities done:	5 January 2013 Shoes worn for ___ hours Activities done:
6 January 2013 Shoes worn for ___ hours Activities done:	7 January 2013 Shoes worn for ___ hours Activities done:	8 January 2013 Shoes worn for ___ hours Activities done:

VII. Intensity of walk of each participant on various inclines

Participant	Predicted HR_{max}	Uphill (%)	Level (%)	Downhill (%)
1	191	65	47	43
2	195	60	48	44
3	196	53	42	37
4	193	56	44	39
5	197	65	56	46
6	197	81	60	54
7	195	69	54	49
8	199	72	56	50
9	197	58	44	39
10	195	54	41	38
11	183	73	49	44
Mean	194.36	64.18	49.18	43.9

