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Management

The effect of unstable footwear on trunk muscle electromyography and postural sway in healthy adults

H Frampton, S Potter, N Smith, D Hodgson, J Dixon, CG Ryan*

Abstract

Introduction

Preliminary evidence suggests that unstable footwear is beneficial for back pain. It has been proposed that the effect may be mediated by challenging balance, causing an increase in core stabilising muscle activity. However, no studies have investigated the effects of unstable footwear on core muscle activity. The primary aim of this study was to investigate if trunk muscle activation during quiet two-legged stance was affected by unstable footwear in comparison to usual footwear or on barefoot conditions.

Materials and methods

In this randomised repeated measures design, healthy participants (n = 21) stood on a Kistler™ force platform for 30 seconds three times under three conditions: (1) barefoot, (2) usual footwear and (3) unstable footwear. Under each condition, postural sway and the average intensity of electromyographic activity was collected for three different muscles bilaterally: transversus abdominus (TrA), external obliques (EO) and rectus abdominis (RA).

Results

A repeated measures ANOVA found increased postural sway (centre of pressure velocity) in the unstable footwear condition compared to both the barefoot (4.2 (1.7 – 6.7) mm.s^{-1}) (mean difference, 95 CI) and usual footwear conditions (4.9 (3.2 – 6.7) mm.s^{-1}). However, there was no statistically significant difference in trunk muscle activity between these conditions.

Conclusion

This study found no evidence that unstable footwear can increase/alter trunk muscle activity suggesting that any positive effects of unstable footwear on back pain may be mediated via different mechanisms other than core muscle training effects. However, further investigation with a clinical population over longer time periods, using different functional tasks may be warranted.

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Introduction

Chronic low back pain (CLBP) is associated with trunk muscle dysfunction[1–6]. Deep core stabilisers such as transversus abdominus (TrA) have impaired timing patterns[1,7] and reduced activation levels[5] in individuals with CLBP. Additionally, there is evidence that patients with CLBP are less able to preferentially activate the deeper stabilisers relative to larger superficial muscles such as the rectus abdominus (RA)[2]. Thus, clinically, core stability interventions for individuals with CLBP attempt to selectively activate the deep core stabilisers relative to the larger superficial muscles[8,9]. A number of studies have shown that core stability training can normalise trunk muscle activity[9,10] and improve pain and function in patients with CLBP[11,12].

Within core stability exercise regimes, the use of unstable surfaces may be helpful for increasing trunk muscle activation. Relative to a stable surface, performing abdominal exercises on an unstable surface, such as on a Swiss ball, can increase RA activity and external oblique (EO) activity[13–15]. However, a key problem with these interventions is that they require patient adherence to exercise programmes which can be as low as 36% in patients reporting high pain levels[16]. Adherence to exercise programmes may be improved if the exercise regime, or unstable surface which might challenge balance, could be incorporated into everyday activities of daily living.

One potential way by which issues of non-compliance could be overcome for core stability exercises is the use of unstable footwear by the individual in everyday life. Unstable footwear can increase postural instability in healthy adults as indicated by increased postural sway when compared to usual footwear[17]. This could potentially increase trunk muscle activity during everyday activity. There is preliminary evidence from one RCT that unstable footwear could improve back pain[18]. The authors of the RCT postulate that this effect may have been achieved by 'increased engagement of core muscle groups'[18]. This could relate to increased intensity of activity, altered muscle timing or increased co-contraction. While there is evidence that unstable footwear can increase foot and leg muscle activity in healthy individuals[17,19], the effects of unstable footwear on trunk muscle activity in healthy individuals or individuals with back pain have not yet been investigated.

The aim of this study was to investigate if trunk muscle activation was affected by unstable footwear in comparison to usual footwear or barefoot conditions in healthy individuals.

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Materials and methods

Participants

A convenience sample of healthy university students was recruited. Inclusion criteria were: ≥ 18 years of age, no history of low back pain, no previous medical history which may affect their ability to take part, no previous surgery to the back or abdomen, no history of epilepsy, not currently pregnant or recently given birth, and has the capacity to consent. Exclusion criteria were: history of inner ear problems, history or falls, allergy to the electromyography (EMG) conductance gel, alcohol or recreational drug consumption in the past 24 hours. Ethics approval was granted by the School of Health and Social Care Research Governance and Ethics Committee at Teesside University (reference number: 177/11). Written informed consent was obtained from all participants and all work was conducted in accordance with the Declaration of Helsinki, 1964.

Design

The study used a within-subject experimental design with participants taking part in testing in each of the three conditions: 1) barefoot, 2) usual footwear and 3) unstable footwear (Masai Barefoot Technology, MBT). The order of testing was randomised using a Latin squares design. For each footwear condition, the participant stood on a force plate (Model 9286AA, Kistler, Alton, UK) three times for 30 seconds during which muscle activity was measured using surface EMG. The average integrated EMG was collected for three different muscles bilaterally: TrA, RA and EO. By using surface EMG to measure TrA, it is not possible to distinguish between TrA and internal obliques (IO). Hence, throughout the results of this paper, when TrA activity is described, we are referring to TrA/IO activity[20]. The balance outcome measures were the range and standard deviation of the Centre of Pressure (CoP) displacement in the anterior–posterior and medio–lateral directions (AP range, AP SD, ML range, ML SD respectively, all in mm) and the mean CoP velocity ($mm.sec^{-1}$) in the AP and ML directions, and collectively (the overall mean velocity), during bipedal standing. The CoP displacement variables represent the magnitude of CoP movement (a marker of sway) quantified in the AP and ML directions as the range and SD (average deviation from the mean position). Measures of CoP velocity represent the speed of postural sway in the AP and ML directions, and overall. Increases in all of these parameters are clinically interpreted as poorer sway or postural control. The muscle activity and postural sway were compared between conditions.

Instrumentation

Balance data was obtained from a Kistler™ force platform (Model 9286AA, Kistler, Alton, UK), W 40 × L 60 × H 3.5 cm, sampled at 50 Hz. Surface EMG recordings were collected using a 16-channel Biopac system (Model MP100), using bipolar active surface EMG recording electrodes (type TSD 150B, 11.4 mm diameter, electrode spacing 20 mm), with 3 dB 12–500 Hz band pass and x 330 built-in amplification. After cleaning and shaving the skin, EMG recordings were collected from standardised sites on three muscles bilaterally. Standardisation of electrode placement followed the recommendations of Marshall and Murphy[14,20,21]. Each TrA electrode was located approximately 2 cm medial and inferior to the anterior–superior iliac spine. Each EO electrode was positioned 12–15 cm lateral to the umbilicus, oriented 45° to the horizontal[14]. Each RA electrode was located 3 cm superior to the umbilicus and 2 cm lateral to the midline[20]. All electrodes were positioned while the subjects were standing to eliminate movement over the skin surface when moving from the supine to standing position. A pre-gelled ground reference electrode (Blue Sensor®) was placed at the sternum. The EMG and force plate systems were synchronised.

Unstable footwear

Unstable footwear has a curved or uneven sole construction, which attempts to challenge the balance of the wearer. A number of different companies produce unstable footwear. The unstable footwear used in this study was provided by the company MBT (Masai Marketing and Trading AG, Switzerland) (Figure 1). The specific make of MBT shoes used were Kimondo (for men) and Fora (for women). A range of sizes were available to accommodate the differing foot size of the participants.

Figure 1: The unstable footwear used in this study

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Procedures

All participants carried out standard tests of bipedal quiet standing with eyes open lasting 30 seconds. This is a standard test, commonly used in rehabilitation research for the assessment of balance[22,23]. There were three trials for each condition, making nine trials in total per participant. Each participant carried out all three trials of one condition before testing took place under another condition. The sequence of test condition was randomised using number cards selected by the participant. Due to the unstable nature of the MBT shoes, an acclimatisation period of 10 minutes was permitted prior to the commencement of the MBT condition for participants to become accustomed to the sensation of wearing the shoes. During this 10-minute period, participants were free to stand/walk as much as they wanted within the laboratory.

Participants were instructed to stand with their arms by their side, looking straight forwards and to focus on the middle of a visual target. The feet were spaced approximately 15 cm apart and aligned in an anterior–posterior direction on the force plate.

To enable normalisation of the EMG amplitudes during the balance tests, maximal voluntary contractions (MVCs) were carried out before the standing balance procedure. A maximal resisted sit up contraction while lying supine was used for the RA and EO[13]. A maximal draw-in test in four point kneeling was used to normalise the TrA data[14]. Both of these MVCs consisted of a five second isometric contraction, and participants carried out three trials of each, with practice attempts beforehand for familiarisation. All EMG recordings were stored digitally for later analysis.

Data extraction and analysis

ML and AP range and SD were calculated automatically by the force platform for 30 seconds in each trial, using the Bioware software package[22,23]. Three measures of CoP velocity (AP velocity, ML velocity, overall velocity) were calculated using previous methods[24], after low-pass filtering of the raw data at 10 Hz. The overall mean CoP velocity was calculated using the equations, according to Raymakers et al.[24]:

$$Vd = (\sqrt{((x_i - x_{i\text{-}1})^2 + (y_i - y_{i\text{-}1})^2)})/(t_i - t_{i-1})$$

$$Vm = (\sum Vd)/n$$

where x is the position of the CoP at time t, i is the participant data set and n is the number of paired data points.

CoP velocity was calculated individually for the AP and ML directions using the equations of Raymakers et al.[24]

$$Vd_{AP} = (y_i - y_{i\text{-}1})/(t_i - t_{i-1})$$

$$Vm_{AP} = (\sum |Vd_{AP}|)/n$$

where Vd is the displacement velocity, Vm is the mean velocity, y is the CoP position in millimetres from the origin in the AP direction, and was substituted for x for the ML direction.

To produce a linear envelope, the raw EMG data were processed with a 20 Hz high pass filter and a root mean square moving window of 25 ms using the system's AcqKnowledge software (Version 3.7.3, BIOPAC Systems Inc., Santa Barbara, CA, USA). Any ECG artefacts were cleaned from the traces[9,25]. The average integrated EMG was extracted for each muscle in each balance trial. The EMG values for each muscle were averaged over the three trials for each condition. The EMG amplitudes during the balance testing were then normalised to the MVC levels for each muscle. For normalisation purposes, the whole of each MVC burst was used, onset and cessation being determined visually, and the average of the three MVCs was calculated and used as the reference level. Normalisation was carried out by converting the average EMG value during the balance tests to a percentage of that during the MVCs.

To investigate if the deep core stabilisers were preferentially activated compared to the larger superficial muscles, the EMG ratio between the TrA and the RA was calculated (TrA/RA ratio)[9,14]. To calculate this ratio for each participant, the normalised TrA amplitude was divided by the normalised RA amplitude.

Statistical analysis

Data were analysed using the Statistical Package for Social Sciences (SPSS, Chicago, IL, USA) version 18.0. For each of the variables, repeated measures analysis of variance (ANOVA) was carried out to determine the effects of the test conditions, with alpha set at 0.05. Where the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. Differences between each pair of conditions were evaluated using mean differences and 95% confidence intervals.

Results

Participants

Twenty-two participants volunteered for this study. One participant had a recent episode of LBP and was thus excluded from participating. The remaining 21 participants (age 27 ± 7 years; 13 female, 8 male; BMI 22.9 ± 3.4 kg.m^{-2}) completed the study.

Postural sway

The postural sway data are compared between each condition in Table 1. For all postural sway outcome measures, the MBT footwear produced significantly greater sway (poorer balance) than usual footwear, though the overall ANOVA for ML SD and ML range was not statistically significant ($p = 0.053$ and $p = 0.066$, respectively). Similarly, compared to the barefoot condition MBT footwear produced significantly greater sway in the AP direction (range and SD) and CoP velocity in the AP direction and overall. There was no significant difference in postural sway between barefoot and usual footwear conditions.

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Table 1 Postural sway for each condition during quiet standing (n = 21).							
	BF Mean (SD)	U Mean (SD)	MBT Mean (SD)	ANOVA *p*-value	BF-U Mean (95%CI)	BF-MBT Mean (95%CI)	U-MBT Mean (95% CI)
AP SD (mm)	4.1 (1.5)	4.6 (1.5)	6.7 (2.2)	0.001*gg	0.5 (–0.1 to 1.1)	2.6 (–1.5 to 3.6)*	2.1 (1.2 to 2.9)*
AP range (mm)	22.3 (8.2)	23.4 (7.6)	34.1 (9.3)	0.001*	1.1 (–2.1 to 4.4)	11.8 (6.5 to 17.1)*	10.7 (5.9 to 15.4)*
AP CoP velocity (mm.s^{-1})	8.2 (1.8)	8.3 (1.3)	13.2 (3.2)	0.001*gg	0.1 (–0.7 to 0.9)	5.0 (3.2 to 6.8)*	4.9 (3.4 to 6.5)*
ML SD (mm)	2.7 (1.8)	2.2 (0.6)	3.2 (1.1)	0.053gg	–0.5 (–1.6 to 0.5)	0.5 (–0.7 to 1.7)	1.0 (0.5 to 1.6)*
ML range (mm)	15.1 (9.3)	13.3 (3.2)	18.0 (5.5)	0.066gg	–1.8 (–6.6 to 2.9)	2.9 (–3.2 to 9.0)	4.7 (1.5 to 8.0)*
ML CoP velocity (mm.s^{-1})	14.9 (4.5)	14.1 (3.8)	15.8 (4.2)	0.019*gg	–0.8 (–2.0 to 0.4)	0.8 (–0.8 to 2.5)	1.6 (0.6 to 2.6)*
CoP velocity (mm.s^{-1})	18.7 (4.4)	18.0 (3.6)	22.9 (5.2)	0.001*gg	–0.7 (–2.1 to 0.7)	4.2 (1.7 to 6.7)*	4.9 (3.2 to 6.7)*

*$p < 0.05$, gg = Greenhouse-Geisser correction for sphericity, BF = Barefoot, U = Usual footwear, MBT = Masai Barefoot Technology®, AP = Antero–posterior, ML = Medio–lateral, CoP = Centre of Pressure, SD = Standard Deviation.

EMG

Data for one participant was excluded due to electrical noise. The EMG data are compared between each condition in Table 2. There was no statistically significant difference between conditions for any muscles or for the TrA/RA EMG ratios.

Discussion

The aim of this study was to investigate if trunk muscle activation was affected by unstable footwear in comparison to usual footwear or barefoot conditions. While unstable footwear increased postural sway compared to usual footwear and barefoot conditions, there was no difference between conditions for trunk muscle activity.

In keeping with the findings of this study, previous research has shown that unstable footwear can increase postural sway[17]. Thus, unstable footwear does create instability. However,

Table 2 EMG muscle activity for each condition (n = 20).							
	BF Mean (SD)	U Mean (SD)	MBT Mean (SD)	ANOVA *p*-value	BF-U Mean (95%CI)	BF-MBT Mean (95%CI)	U-MBT Mean (95% CI)
<u>Left side</u>							
TrA (%)	29.5 (20.0)	30.8 (21.5)	31.9 (22.2)	0.103	1.3 (–1.2 to 3.7)	2.3 (–0.9 to 5.6)	1.0 (–1.4 to 3.5)
EO (%)	36.6 (41.0)	35.6 (30.7)	32.5 (22.7)	0.578 gg	–0.9 (–10.5 to 8.5)	–4.0 (–22.9 to 14.8)	–3.1 (–13.1 to 7.0)
RA (%)	8.0 (6.1)	8.6 (7.3)	7.8 (6.5)	0.625 gg	0.6 (–0.8 to 2.0)	–0.2 (–3.7 to 3.2)	–0.8 (–3.8 to 2.2)
TrA/RA ratio	5.2 (4.1)	5.6 (5.0)	6.3 (6.7)	0.247 gg	0.4 (–0.7 to 1.5)	1.1 (–1.2 to 3.3)	0.7 (–0.7 to 2.1)
<u>Right side</u>							
TrA (%)	28.5 (26.3)	28.6 (25.5)	29.8 (27.2)	0.334 gg	0.03 (–2.3 to 2.3)	1.2 (–2.2 to 4.7)	1.2 (–0.5 to 2.9)
EO (%)	37.3 (27.0)	40.6 (28.8)	41.1 (30.6)	0.402 gg	3.2 (–4.4 to 10.9)	3.7 (–7.3 to 14.8)	0.5 (–4.9 to 5.9)
RA (%)	9.3 (10.0)	9.5 (8.3)	10.0 (10.6)	0.611 gg	0.3 (–2.6 to 3.2)	0.7 (–0.3 to 1.7)	0.4 (–2.0 to 2.9)
TrA/RA ratio	4.4 (4.0)	4.5 (4.8)	4.8 (5.5)	0.428 gg	0.1 (–0.7 to 0.9)	0.4 (–0.8 to 1.6)	0.3 (–0.2 to 0.8)

*$p < 0.05$, gg = Greenhouse-Geisser correction for sphericity, BF = Barefoot, U = Usual footwear, MBT = Masai Barefoot Technology®, TrA = Transversus Abdominus, EO = External Obliques, RA = Rectus Abdominus.

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it does not appear that this instability is accommodated by any change in trunk muscle activity. Importantly, it should be noted that this bipedal balance test would not have been very challenging for participants, and the ankle strategy would have been the dominant postural control mechanism. Thus, the possibility remains that wearing these shoes during more demanding tasks could produce effects on the trunk muscles. There is some evidence that unstable footwear increases muscle activity in the foot and lower leg[17,19]. Thus, it is likely that in this study these lower limb muscles accommodated the instability created by unstable shoes rather than the trunk muscles. However, other studies suggest that wearing unstable footwear does not affect lower limb muscle activity[26,27]; hence, it cannot be stated for certain that this occurred.

There is preliminary evidence that unstable footwear may be beneficial for low back pain and it has been postulated that this benefit may have been brought about through enhanced trunk muscle activity[18]. The current study found no evidence that unstable footwear can increase muscle activity, which suggests that any positive effects of unstable footwear on low back pain may be mediated via different mechanisms other than core muscle training effects. However, it is possible that unstable footwear affects core muscle activity timing patterns rather than overall activity levels and further investigation on the effects of unstable footwear on trunk muscle timing is warranted. Additionally, the participants in this study were healthy individuals with no history of low back pain and hence their trunk muscle activity was unlikely to be abnormal. If the study was repeated with low back pain participants, with deficient trunk muscle activity, unstable shoes may have affected muscle activity.

Previous studies comparing core muscle exercises on a stable surface compared to an unstable surface have suggested that unstable surfaces can increase trunk muscle activity[13–15] which is contrary to the findings of this study. One potential reason for this is that the degree of instability imparted by unstable footwear is less than that created by equipment such as Swiss balls and wobble boards. If unstable shoes produced greater imbalance, it may have an effect on core muscle activity, but it would have to be countered by issues of safety, comfort, function etc. It is plausible that quiet bipedal stance, as used in this study, does not maximise the imbalance potential of unstable shoes and greater imbalance may have been created using dynamic tasks, such as walking, or activities of daily living where the centre of mass frequently moves outside the base of support enabling a greater extent of the rollover MBT sole to be used. Further research investigating the effects of unstable footwear during these activities is warranted.

Limitations

This was a small study (n = 21) and there was a risk of type II statistical error. However, the magnitude of confidence intervals were small and showed little indication of any clinically meaningful effect independent of statistical significance. The study only looked at the acute effects of the shoes on muscle activity; there is a need to investigate the long-term effects. All participants were healthy with no history of back pain; there is a need to repeat this study in a clinical population with potentially impaired trunk muscle activity such as individuals with chronic low back pain. The current study only looked at the magnitude of muscle activity and no inferences can be made about the possible effects on important clinical outcomes such as muscle timing. Normalisation contractions may not have elicited maximal activation of all muscles, especially EO, so the percentage values should be interpreted with caution. This study only looked at standing, and the findings cannot be extrapolated to other functional activities such as walking or running. Finally, when using surface EMG, there is risk of cross talk between muscles, especially when attempting to measure the muscle activity of deep muscles such as the TrA. However, the method of surface EMG used in this study has been well validated and is widely used in the literature[14,20].

Prior to the MBT tests, participants wore unstable shoes for 10 minutes to allow the wearer to habituate to the shoe. The reason for doing this was twofold; firstly, to reduce the risk of a fall due to the individual's base of support suddenly becoming less stable, and secondly, to attempt to ensure that any alterations in balance or muscle activity were not simply due to the immediate effects of the unbalanced shoe, which may have worn off within a few minutes of wearing, and thus not have been reflective of everyday use of the shoes. It has been shown that unstable shoes can affect leg muscle function in the immediate term for those who have never worn unstable shoes before[28]. Thus, the results may have been different if the habituation period had not been provided.

Previous or current use of unstable footwear was not one of our inclusion/exclusion criteria, nor was the data recorded. Hence, we cannot be certain that all participants were novice unstable shoe wearers, although none of the participants were wearing unstable footwear in the usual footwear condition. Stoggl and Muller found evidence of different leg muscle EMG activity when wearing MBT's before and after a 10-week habituation period. Thus, it is possible that any habitual wearer may have responded differently to novice users of unstable footwear.

The type of footwear worn in the usual footwear condition was not recorded (beyond the fact that none

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were categorised as unstable shoes). Hence, what effects the type of shoe worn during this condition had on balance/EMG cannot be commented upon beyond the fact that this is the footwear participants usually wore in daily life.

The activity used in this study was quiet bipedal standing. This may not have sufficiently challenged balance in this healthy population, and further study of unstable footwear using more challenging activities may be warranted.

Conclusion

The aim of this study was to investigate the effects of unstable shoes on trunk muscle activity compared to usual footwear and barefoot conditions. Unstable shoes increased postural sway, but had no statistically significant effect on trunk muscle activity. This study does not support the hypothesis that unstable footwear can increase core muscle activity in healthy individuals, though further work in clinical populations may be warranted.

Conflict of interests

The unstable footwear used in this study was MBT®'s, provided by Masai Marketing and Trading AG to Teesside University for research and teaching purposes. Teesside University funded all other costs associated with the project. However, the company had no input on the content of the article. The authors declare no other conflicts of interest.

Abbreviations list

ANOVA, analysis of variance; CLBP, chronic low back pain; EMG, electromyography; EO, external obliques; IO, internal obliques; MVC, maximal voluntary contraction; RA, rectus abdominis; TrA, transversus abdominus;

References

1. Hodges PW, Richardson CA. Inefficient muscular stabilisation of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdomins. Spine (Phila Pa 1976). 1996 Nov;21(22):2640–50.
2. O'Sullivan P, Twomey L, Allison G, Sinclair J, Miller K, Knox J. Altered patterns of abdominal muscle activation in patients with chronic low back pain. Aust J Physiother. 1997;43(2):91–8.
3. Evans C, Oldreive W. A study to investigate whether golfers with a history of low back pain show a reduced endurance of transversus abdominis. J Man Manip Ther. 2000;8:162–74.
4. Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: effect and possible mechanisms. J Electromyogr Kinesiol. 2003 Aug;13(4):361–70.
5. Ferreira PH, Ferreira ML, Hodges PW. Changes in recruitment of the abdominal muscles in people with low back pain: ultrasound measurement of muscle activity. Spine (Phila Pa 1976). 2004 Nov;29(22):2560–6.
6. Hodges PW. Pain and motor control: From the laboratory to rehabilitation. J Electromyogr Kinesiol. 2011 Apr;21(2):220–8.
7. Marshall P, Murphy B. Delayed abdominal muscle onsets and self-report measures of pain and disability in chronic low back pain. J Electromyogr Kinesiol. 2010 Oct;20(5):833–9.
8. Richardson CA, Jull GA. Muscle control - pain control. What exercises would you prescribe? Man Ther. 1995 Nov;1(1):2–10.
9. O'Sullivan PB, Twomey L, Allison GT. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. J Orthop Sports Phys Ther. 1998 Feb;27(2):114–24.
10. Tsao H, Hodges PW. Persistence of improvements in postural strategies following motor control training in people with recurrent low back pain. J Electromyogr Kinesiol. 2008 Aug;18(4):559–67.
11. Ferreira ML, Ferreira PH, Latimer J, Herbert RD, Hodges PW, Jennings MD, et al. Comparison of general exercise, motor control exercise and spinal manipulative therapy for chronic low back pain: a randomised trial. Pain. 2007 Sep;131(1–2):31–7.
12. Macedo LG, Maher CG, Latimer J, McAuley JH. Motor control exercise for persistent, nonspecific low back pain: a systematic review. Phys Ther. 2009 Jan;89(1):9–25.
13. Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. Phys Ther. 2000 Jun;80(6):564–9.
14. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. Arch Phys Med Rehabil. 2005 Feb;86(2):242–9.
15. Imai A, Kaneoka K, Okubo Y, Shiina I, Tatsumura M, Izumi S, et al. Trunk muscle activity during lumbar stabilisation exercises on both a stable and unstable surface. J Orthop Sports Phys Ther. 2010 Jun;40(6):369–75.
16. Sluijs EM, Kok GJ, Van der Zee J,. Correlates of exercise compliance in physical therapy. Phys Ther. 1993 Nov;73(11):771–82.
17. Landry SC, Nigg BM, Tecante KE. Standing in an unstable shoe increases postural sway and muscle activity of selected smaller extrinsic foot muscles. Gait Posture. 2010 Jun;32(2):215–9.
18. Nigg BM, Davis E, Lindsay D, Emery C. The effectiveness of an unstable sandal on low back pain and golf performance. Clin J Sport Med. 2009 Nov;19(6):464–70.
19. Romkes J, Rudmann C, Brunner R. Changes in gait and EMG when walking with the Masai barefoot technique. Clin Biomech (Bristol, Avon). 2006 Jan;21(1):75–81.
20. Marshall P, Murphy B. The validity and reliability of surface EMG to assess the neuromuscular response of the abdominal muscles to rapid limb movement. J Electromyogr Kinesiol. 2003 Oct;13(5):477–89.
21. Marshall PWM, Murphy BA. Increased deltoid and abdominal muscle activity during swiss ball bench press. J Strength Cond Res. 2006 Nov;20(4):745–50.
22. Hatton AL, Dixon J, Martin D, Rome K. The effect of textured surfaces on postural stability and lower limb muscle activity. J Electromyogr Kinesiol. 2009 Oct;19(5):957–64.
23. Hatton AL, Dixon J, Rome K, Martin D. Standing on textured surfaces: effects on standing balance in healthy older adults. Age Ageing. 2011 May;40(3):363–8.
24. Raymakers JA, Samson MM, Verhaar HJJ. The assessment of body sway and the choice of the stability parameter(s). Gait Posture. 2005 Jan;21(1):48–58.
25. Kamei K, Kumar DK, Polus BI. Reliability and validity of surface electromyography (SEMG) to study the functional status of lumbar paraspinal muscles during

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execution of unsupported sitting posture. Chiropractic J Aust. 2007;37:30–7.
26. Demura T, Demura S. The effects of shoes with a rounded soft sole in the anterior-posterior direction on leg joint angle and muscle activity. Foot (Edinb). 2012 Sep;22(3):150–5.
27. Sacco ICN, Sartor CD, Cacciari LP, Onodera AN, Dinato RC, Pantaleao Jr E, et al. Effect of a rocker non-heeled shoe on EMG and ground reaction forces during gait without previous training. Gait Posture. 2012 Jun;36(2): 312–5.
28. Branthwaite H, Chockalingam N, Pandyan A, Khatri G. Evaluation of lower limb electromyographic activity when using unstable shoes for the first time: A pilot quasi control trial. Prosthet Orthot Int. 2013 Aug; 37(4): 275–81.

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