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Original Research

Electromyographic analysis of balance exercises in single-leg stance using different instability modalities of the forefoot and rearfoot

Martin Alfuth [a,*], Markus Gomoll [b]

[a] Niederrhein University of Applied Sciences, Faculty of Health Care, Therapeutic Sciences, Reinarzstr. 49, 47805 Krefeld, Germany
[b] German Sport University Cologne, Department of Further Education, Am Sportpark Müngersdorf 6, 50933 Cologne, Germany

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ABSTRACT

Purpose: To investigate the activity of lower extremity muscles in response to single-leg stance on a training device, destabilizing the forefoot while the rearfoot stands on a fixed plate and vice versa compared with a balance pad and the floor.
Design: Cross-sectional study.
Setting: University's laboratory.
Participants: Twenty-seven healthy adults.
Methods: Surface electromyography and 2D video analysis were used to record the activity of lower extremity muscles and to control sagittal knee joint angle during single-leg stance trials under one stable control condition and five unstable conditions.
Results: The majority of lower extremity muscles were significantly more active when the forefoot was destabilized while the rearfoot remained stable compared with the stable condition and the conditions where the forefoot was stable and the rearfoot unstable ($p < 0.001$). Mean change of knee joint angle was significantly increased under the conditions rearfoot stable/forefoot unstable ($p = 0.001$). The soleus muscle activation was significantly increased when balancing on the balance pad ($p < 0.001$).
Conclusions: Increased activity in the majority of lower extremity muscles and sagittal knee joint angles indicate that destabilizing the forefoot while the rearfoot remains stable is the most challenging balance task. Soleus muscle activation increased when performing ankle plantarflexion on the soft balance pad.

1. Introduction

Sensorimotor/balance exercises are commonly used for the treatment of chronic ankle instability (Eils & Rosenbaum, 2001; Sefton, Yarar, Hicks-Little, Berry, & Cordova, 2011) or other sports-related injuries that are associated with impaired proprioception and neuromuscular control (Culvenor et al., 2016; Hatton et al., 2016). They aim at decreasing sensorimotor deficits (Freeman, 1965) and restore neuromuscular activation that allows for active joint stability (Wolburg, Rapp, Rieger, & Horstmann, 2016). Balance exercises are usually performed in double- or single-leg stance on devices with different stability properties. Single-leg stance is used for training and testing because poor balance during single-leg stance might predict an increased risk of ankle sprain (McGuine, Greene, Best, & Leverson, 2000; McKeon & Hertel, 2008; Trojian & McKeag, 2006). During these tasks within a long time interval, feedback from joint mechanoreceptors can be usually used by the sensorimotor subsystems, indicating that closed-loop control mechanisms are involved to control the ankle and foot joint movements (Collins & De Luca, 1993; Gutierrez, Kaminski, & Douex, 2009; Mitchell, Collins, De Luca, Burrows, & Lipsitz, 1995).

Several therapy devices, such as balance boards and pads, soft mats, air cushions or tilting platforms (De Ridder, Willems, Vanrenterghem, & Roosen, 2015; Pfusterschmied et al., 2013; Verhagen et al., 2004) are incorporated into balance exercises. These devices might primarily address stabilization of ankle motion coupled to talocrural and subtalar articulations. According to Freeman (Freeman, 1965) a sprained ankle generates a varus instability of the talus in the ankle mortise, probably resulting in chronic subtalar instability (Pisani, Pisani, & Parino, 2005). Numerous patients reported a feeling of instability without showing clinical or radiological abnormality (Freeman, 1965), however, subtalar instability is often caused by damage of the

* Corresponding author.
E-mail address: martin.alfuth@hs-niederrhein.de (M. Alfuth).

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calcaneofibular and interosseous ligaments creating increased rearfoot inversion (Choisne, Hoch, Bawab, Alexander, & Ringleb, 2013; Hintermann, 1996). Therefore, it is central to consider rearfoot biomechanics in the treatment of ankle instability (Hintermann, 1996).

Ankle sprains predominantly occur during sudden unexpected ankle supination (Podzielny & Hennig, 1997), where the sensorimotor subsystems mainly operate without feedback (open-loop control mechanisms) to control the ankle-foot complex (Collins & De Luca, 1993; Mitchell et al., 1995). Morey-Klapsing et al. (Morey-Klapsing, Arampatzis, & Bruggemann, 2005) found that ankle and foot kinematics consistently differ during sudden medial and lateral ankle tilts in single-leg stance and concluded that it is not sufficient to only focus on one joint to understand the behavior of the ankle-foot complex. The human ankle-foot complex includes six independent functional segments (De Mits et al., 2012), more than 30 articulations, allowing mostly for 6 degrees of freedom of movement (Morrison & Kaminski, 2007). Passive, active and neural subsystems are intertwined to ensure structure and control of the foot (McKeon & Fourchet, 2015; McKeon, Hertel, Bramble, & Davis, 2015). Pronated and supinated foot types (Cote, Brunet, Gansneder, & Shultz, 2005; Hogan, Powden, & Hoch, 2016; Tsai, Yu, Mercer, & Gross, 2006) as well as cavus, rectus and planus foot types (Hertel, Gay, & Denegar, 2002) might influence postural stability. Injury of the midfoot and forefoot occur frequently and can be a comorbidity in lateral ankle sprain and chronic ankle instability (Fraser, Feger, & Hertel, 2016). Therefore, balance training devices that address the stabilization of the movement between forefoot and rearfoot, occurring in the transverse tarsal joint (calcaneocuboid joint) around two separate axes of rotation (Manter, 1941), during single-leg stance might be of great importance for the prevention and in the rehabilitation of ankle sprains.

The muscles of the lower leg contribute to ankle and foot control during single-leg standing (Konradsen, Ravn, & Sorensen, 1993). Muscle activity changes while standing on devices with different properties (Strom et al., 2016; Wolburg et al., 2016). Balance training on different unstable devices is used to restore function of muscles after injury, because during balance exercises muscle activity is increased (Borreani et al., 2014; Braun Ferreira et al., 2011). Increased muscle activity is a worthwhile resource in the sensorimotor recovery of the ankle (Braun Ferreira et al., 2011). Especially the peroneus longus muscle seems to play an important role, because it is the major evertor of the ankle-foot complex and therefore might withstand the inversion moment during the typical injury mechanism (Konradsen, Olesen, & Hansen, 1998). However, it has to be considered that reflex reaction to sudden inversion appears too slow to protect the ankle (Konradsen, Voigt, & Hojsgaard, 1997).

Single-leg stance is primarily characterized by an inter-joint coordination, where axial rotation between the ankle and hip joints, and between ankle inversion/eversion and hip axial rotation are crucial (Liu et al., 2012). Knee joint kinematics may differ when balancing on devices with different stability properties (Pfusterschmied et al., 2013). Particularly, the corrective action of the knee joint became increasingly important when a single-leg balance task became more challenging, e.g. from firm to foam surface (Riemann, Myers, & Lephart, 2003). Therefore, the analysis of knee kinematics might be important when single-leg stance with increasing levels of instability is performed.

There is a lack of information about how muscles react and sagittal knee kinematics change on a training device (ARTZT vitality® Mini Stability Trainer, Ludwig ARTZT GmbH, Dornburg, Germany) that selectively destabilizes the forefoot while the rearfoot stands on a fixed plate and vice versa. The aims of the study were to investigate activity of lower extremity muscles and sagittal knee joint kinematics in response to single-leg stance on the Mini Stability Trainer (MST), a) while destabilizing the forefoot with the rearfoot standing on a fixed plate and b) while destabilizing the rearfoot with the forefoot fixed, compared with a common unstable balance pad (BP) and the floor. It was hypothesized that single-leg stance using the MST results in increased activity of selected distal and proximal lower extremity muscles and increased sagittal knee joint range of motion compared with the floor and the BP.

2. Methods

2.1. Participants

Twenty-seven healthy participants - 11 female and 16 male - volunteered to participate in the study. Participants were recruited from the local university and local sport clubs and selected using a self-constructed questionnaire. None of the participants had a history of a traumatic injury or surgery of the lower extremity, the pelvis, and/or trunk within the past twelve months. No subject reported a chronic ankle instability according to the recommendations of the 'International Ankle Consortium' (Gribble et al., 2013) or any other chronic disorder of the lower extremity. Participants were also excluded if they had acute pain, dysfunction or pathological foot deformities. The mean (SD) age, height, body mass, and body mass index of included participants was 25.5 ± 4.2 years, 177.0 ± 10.0 cm, 69.7 ± 10.2 kg, and 22.2 ± 1.8 kg/m^2, respectively. An a priori sample size calculation on the basis of $\alpha < 0.05$ and a moderate effect size of $dz = 0.5$ from dependent t-tests comparing pilot measurements using mean EMG (μV) of the peroneus longus muscle under different test conditions revealed that a sample size of $n = 27$ was needed to obtain a test power of >80%. All of the participants provided written informed consent prior to participation.

2.2. Procedures

After a 2-min warm-up, participants were asked to perform three single-leg quiet stance trials on the randomly allocated leg under one stable control (floor) and 5 different unstable balance conditions. Therefore, two different unstable devices were used:

1. The MST consists of different plates with different surface structures on the bottom side of the plates (Fig. 1 and Table 1) that can be combined to separately induce instability of the forefoot or the rearfoot in single-leg stance. The green plate has two parallel, peripheral half rolls at the bottom side (Fig. 1, a) and a flat surface at the top side, ensuring a stable stance of the respective part of the foot. The blue plate has a central half roll at the bottom side (Fig. 1, b) and a flat surface at the top side, inducing medial or lateral tilting of the respective part of the foot. The red plate has a central hemisphere at the bottom side (Fig. 1, c) and a flat surface at the top side, inducing multidirectional tilting of the respective part of the foot.
2. The BP (ARTZT vitality® Stability Trainer, Ludwig ARTZT GmbH, Dornburg, Germany) consists of soft material with horizontal grooves at the top side (Fig. 1, d and Table 1) and a flat surface at the bottom side, inducing instability of the ankle in all directions.

At first, each participant completed the trials on the floor. The 5 unstable conditions were (Fig. 1 and Table 1):

- MST [forefoot stable (a)/rearfoot unstable (b), inducing an excursion of the rearfoot in the frontal plane]