ELECTROMYOGRAPHIC ANALYSIS OF BALANCE EXERCISES IN SINGLE-LEG STANCE USING DIFFERENT INSTABILITY MODALITIES OF THE FOREFOOT AND REARFOOT

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Purpose of this study was to investigate 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. Twenty-seven participants performed three single-leg quiet stance trials under one stable (floor) and 5 different unstable balance conditions. Surface electromyography was used to record activity of 6 muscles of the lower extremity. Sagittal knee joint angles were controlled using 2D video analysis. The majority of lower extremity muscles were significantly more active when the forefoot was destabilized while the rearfoot remained stable compared with the stable and the other unstable conditions. Sagittal knee joint angles were significantly increased under the same conditions, indicating an altered strategy to maintain equilibrium.

KEYWORDS: electromyography, destabilization, forefoot, balance training.

INTRODUCTION: Balance exercises are commonly used for the prevention of ankle sprains, the treatment of chronic ankle instability or other sports-related injuries that are associated with impaired proprioception and neuromuscular control (Eils et al., 2010; McKeon & Hertel, 2008). These exercises aim at restoring neuromuscular activation and mechanical stiffness of involved tendons that allow for active joint stability (Wolburg et al., 2016) and are usually performed in single-leg stance on training devices with different stability properties. As ankle and foot kinematics consistently differ during sudden medial and lateral ankle tilts in single-leg stance it was concluded that it is not sufficient to only focus on one joint to understand the behavior of the ankle-foot complex (Morey-Klapsing et al., 2005). Devices that may address the stabilization of movement between forefoot and rearfoot may be of great importance. There is a lack of information of how muscles react on a device that selectively destabilizes the forefoot while the rearfoot stands on a fixed plate and vice versa. Purpose of this study was to investigate activity of lower extremity muscles in response to single-leg stance on the Mini Stability Trainer [MST (Ludwig ARTZT GmbH, Germany)], destabilizing the forefoot while the rearfoot stands on a fixed plate and vice versa compared with a common unstable device (balance pad) and the floor.

METHODS: Twenty-seven healthy participants in the mean age of 25.5 (±4.2) years volunteered to participate in the study. They were asked to perform three single-leg quiet stance trials on the randomly allocated leg under one stable control condition (floor) and 5 different unstable balance conditions [2 with the forefoot stable and the rearfoot unstable, 2 with the rearfoot stable and the forefoot unstable (MST) and 1 on a balance pad]. At first, each participant completed the trials on the floor. The order of balance conditions was assigned at random using concealed envelopes to minimize potential systematic effects of fatigue or habituation. Each trial lasted 20 s with 30-s rest periods between trials. Surface electromyography (EMG) was used to record activity of the tibialis anterior (TA), peroneus longus (PL), soleus (SOL), medial gastrocnemius (GM), long head of the biceps femoris (BF) and vastus medialis (VM) muscles. EMG signals were recorded using the Desktop DTS EMG System (Noraxon, USA) with a sampling frequency of 1500 Hz. Data were collected and processed using MR 3.9.37 software (Noraxon). All EMG signals were filtered. Furthermore, they were rectified and smoothed using a root mean square (RMS) algorithm (150 ms). Data from second 5 to second 15 were used for further analysis. For each trial, the mean and peak EMG amplitude over the 10-sec period were calculated. Ensemble averages out of the 3 trials for each condition were computed and used for further evaluation. Individual differences between the 5 unstable conditions and the control condition were determined. Absolute effects were calculated to normalize data from the unstable conditions to the data from the control condition. The knee angle [°] at the beginning of the balance task and the change of knee angle [°] in sagittal plane were captured using 2D video analysis (Noraxon) after attaching reflective markers to anatomical landmarks of the participant's supporting leg. Data were recorded and markers were automatically tracked over the 10-sec. period. The average of the knee angle at the beginning of the balance task and of the change of the knee angle over the 10-sec. period out of 3 trials was determined for each condition and used for further analysis. Significance of differences between the measurements was determined using Friedman tests ($p \leq 0.05$). If a significant difference was found the Wilcoxon signed-rank test ($p \leq 0.05$) was applied for post hoc pair-wise comparisons of the conditions with appropriate Bonferroni adjustment.

RESULTS: The TA, PL and BF muscles showed significantly higher mean activities under the condition BP and under both MST- conditions rearfoot stable/forefoot unstable compared with the control condition ($p<0.001$) (Fig. 1). The PL muscle demonstrated a significantly higher mean activity under the condition forefoot stable/rearfoot unstable in frontal plane ($p=0.001$). The SOL muscle was only significantly more active while balancing on the balance pad ($p<0.001$). Muscle activity of the VM was significantly increased under both conditions, where the rearfoot remained stable and the forefoot was unstable ($p<0.001$). All muscles showed a significantly increased peak activity on the BP and under both conditions where the forefoot was unstable while the rearfoot remained stable compared with the control condition ($p<0.001$). Peak activity of the BF muscle was significantly increased under the condition forefoot stable/rearfoot unstable in frontal plane ($p=0.001$). The average knee angle at the beginning of the balance task ranged from 15.7 (±6.0)° under the control condition to 18.3 (±7.1)° on the BP. The mean change of knee angle in sagittal plane was significantly higher under both conditions, where the forefoot was unstable, while the rearfoot remained stable as compared with the other conditions ($p \leq 0.001$) (Table 1).

Table 1
Inter-quartiles of mean change of knee angle in sagittal plane [°] for the stable control condition and the unstable conditions of MST and balance pad. FP = Frontal plane; MD = multidirectional. *p≤0.001.

	Mean change of knee angle in sagittal plane [°]				
Condition	**Minimum**	**25th percentile**	**Median**	**75th percentile**	**Maximum**
Control (floor)	0.3	2.5	3.3	3.9	8.2
Forefoot stable/ rearfoot unstable (FP)	0.4	2.0	3.2	4.2	7.9
Forefoot stable/ rearfoot unstable (MD)	0.3	2.1	3.3	5.6	9.8
Rearfoot stable/ forefoot unstable (FP)	0.8	3.8	6.1*	7.4	21.8
Rearfoot stable/ forefoot unstable (MD)	1.0	3.9	5.9*	7.5	11.1
Balance Pad	1.1	1.6	2.1	2.4	4.6

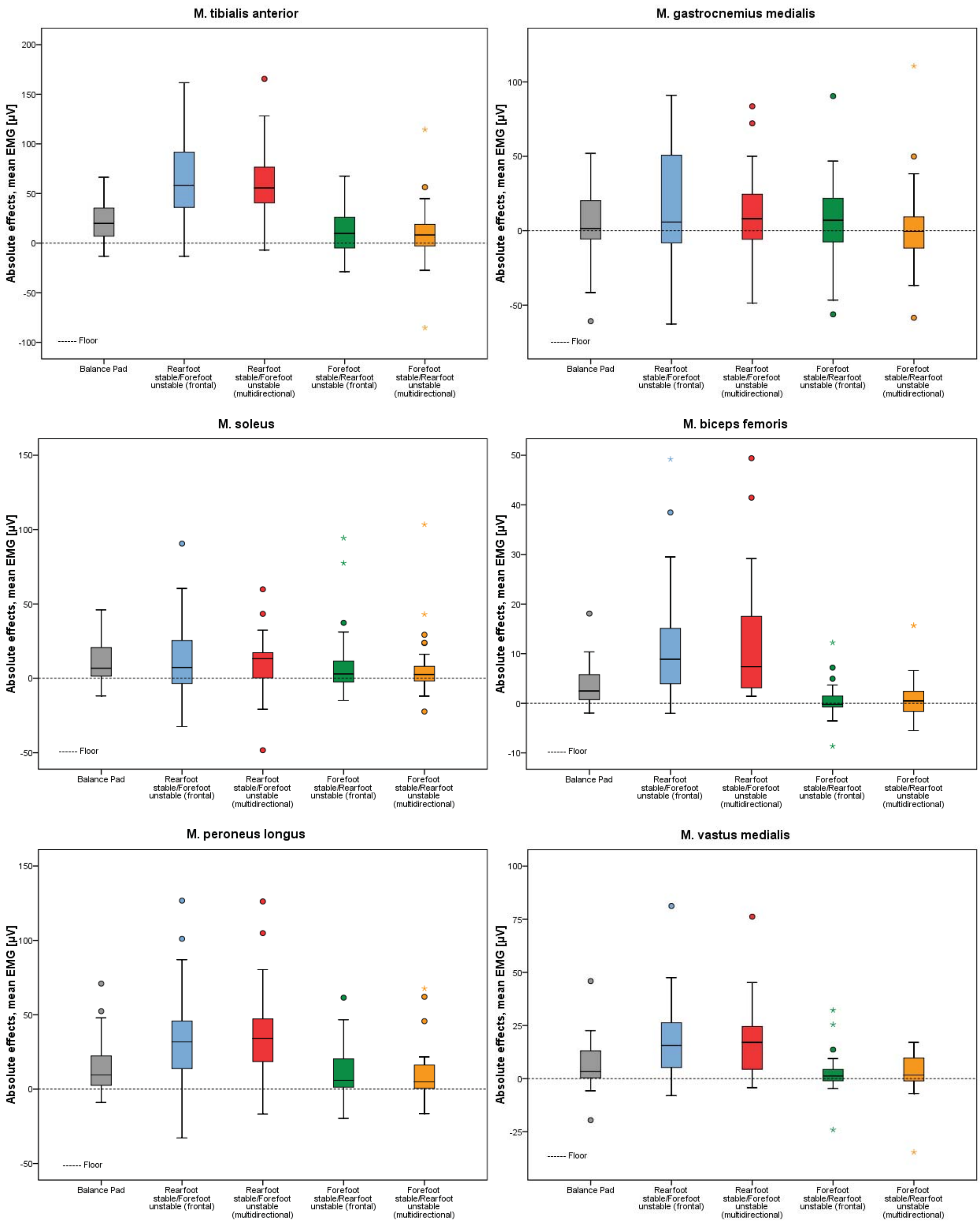

Figure 1: Absolute effects (median along with quartiles) of mean muscle activity (µV) of six muscles of the lower extremity normalized to the control condition (floor). Dots represent moderate outliers, asterisks represent extreme outliers.

DISCUSSION: The main finding of the present study was that single-leg stance with the rearfoot on a stable and the forefoot on an unstable plate demonstrated the highest effects for mean and peak muscle activation of the lower extremity muscles TA, PL, BF and VM compared with the other unstable conditions when normalized to the stable control condition. Only destabilizing the rearfoot in frontal plane while the forefoot remained stable induced an effect of increased mean muscle activity for the PL and of increased peak muscle activity for the BF. Therefore, destabilizing the forefoot seems to be the most challenging balance task for the neuromuscular system. The increased mean change of knee angles for these conditions underlines this assumption. In balance tasks where the whole body center of mass may nearly run perpendicularly through the center of rotation of the ankle joint, i.e. within the conditions where the rearfoot was destabilized, it might have been easier for the neuromuscular system to generate torques that resulted in an appropriate stabilization of the ankle itself as well as the joints proximal to the ankle, i.e. the knee in the present study. When the center of rotation shifts forward, i.e. within the conditions where the forefoot was destabilized, the whole body center of mass may not run nearly perpendicular through the center of rotation of the respective joint, resulting in increased excursions/external torques of involved joints. Increased ankle angle lead to linearly increased gravitational torque on the center of mass of the body (Morasso & Schieppati, 1999; Winter et al., 1998). Thus, the increased flexion of the knee might have been a result of joint relocation to compensate for the shifted course of the center of mass. The majority of lower extremity muscles had to increase activity to ensure stability of the ankle and knee joint. For the SOL muscle there was only an effect of increased mean activation using the BP, indicating that this muscle is only more active when the forefoot subsides into the pad while performing a plantarflexion movement in order to generate sufficient ankle torque against loss of equilibrium due to forward body tilting. The activation of the triceps surae is important to avoid a forward collapse of the body (Loram & Lakie, 2002), which may increasingly occur on a soft balance pad compared with rigid devices, i.e. plates.

CONCLUSION: The majority of lower extremity muscles seems to be significantly more active when the forefoot is placed on an unstable plate while the rearfoot stands on a stable plate during single-leg stance. The activation of the SOL muscle appears to be only increased when the forefoot has to perform a flexion movement, i.e. when balancing on the soft balance pad. The differences in sagittal knee joint kinematics indicate that participants used an altered balance strategy during destabilization of the forefoot in order to maintain postural control. Results may serve to specifically activate lower extremity muscles during single-leg balance training in the prevention and rehabilitation of ankle sprains.

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