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Original Research

Muscle activity of leg muscles during unipedal stance on therapy devices with different stability properties

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ABSTRACT

Objectives: To test the hypotheses that less stable therapy devices require greater muscle activity and that lower leg muscles will have greater increases in muscle activity with less stable therapy devices than upper leg muscles.
Design: Cross-sectional laboratory study.
Setting: Laboratory setting.
Participants: Twenty-five healthy subjects.
Main outcome measures: Electromyographic activity of four lower (gastrocnemius medialis, soleus, tibialis anterior, peroneus longus) and four upper leg muscles (vastus medialis and lateralis, biceps femoris, semitendinosus) during unipedal quiet barefoot stance on the dominant leg on a flat rigid surface and on five therapy devices with varying stability properties.
Results: Muscle activity during unipedal stance differed significantly between therapy devices ($P < 0.001$). The order from lowest to highest relative muscle activity matched the order from most to least stable therapy device. There was no significant interaction between muscle location (lower versus upper leg) and therapy device ($P = 0.985$). Magnitudes of additional relative muscle activity for the respective therapy devices differed substantially among lower extremity muscles.
Conclusions: The therapy devices offer a progressive increase in training intensity, and thus may be useful for incremental training programs in physiotherapeutic practice and sports training programs.

1. Introduction

Proprioceptive and sensorimotor training therapies are successful in treating sport-related disorders and injuries that are linked to deficits in proprioceptive regulation and muscular imbalances (Ergen & Ulkar, 2008; Jerosch, Pfaff, Thorwesten, & Schoppe, 1998; van Ochten, van Middelkoop, Meuffels, & Bierma-Zeinstra, 2014). Frequently, proprioceptive training programs utilize therapy devices with varying stability properties: less stable therapy devices pose a greater challenge on the neuromuscular system (Hupperets, Verhagen, & van Mechelen, 2009). Therapy devices include unstable mats, spinning tops, balls, tilt platforms, and oscillating devices. It is generally accepted that the training stimulus in training sessions should be gradually increased (Holm, Fosdahl, Friis, Risberg, Myklebust, & Steen, 2004; Hupperets, Verhagen, & van Mechelen, 2008). In therapeutic practice, this is usually achieved by combining different motor tasks such as balancing while catching a ball. This method requires greater cognitive attention and consequently higher neuromuscular activation. Frequently, the tasks are not performed simultaneously but rather successively, and it remains unclear if this method will impose a greater stimulus to specific regions such as the ankle joint complex. Therefore, increasing a controlled stimulus to the affected anatomical structure is desirable and might be achieved by increasing the difficulty of the balancing task by using successive therapy devices with decreasing stability properties.

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Two main mechanisms contribute to stabilizing the joints of the lower extremities and thus protect against injury. First, anatomical congruity of the joint facilitates passive mechanical stability and is especially effective at high axial loads. This congruent system is supported and guided by the capsule-ligament system (Hintermann, 1996; Scheuffelen, Rapp, Gollhofer, & Lohrer, 1993). Second, neuromuscular activation and the mechanical stiffness of associated tendons enable active joint stability. Specifically, coordinated neuromuscular activation of antagonistic and agonistic muscles stabilizes the ankle joint both voluntarily and involuntarily through reflex mechanisms (Solomonow & Krogsgaard, 2001). In addition, postural control strategies are characterized primarily by muscle activation patterns and body kinematics, and early activation of dorsal ankle muscles followed by activation of dorsal thigh and trunk muscles during perturbations are indicators for an ankle strategy (Horak & Nashner, 1986; Wang, Molenaar, Challis, Jordan, & Newell, 2014).

Despite the common use of therapy devices, to date information on their effects on muscular coordination is scarce. Van Ooteghem et al. (Van Ooteghem, Frank, Allard, Buchanan, Oates, & Horak, 2008) described that young participants improved their balance control in response to continuous, variable amplitude motion of a translating platform by shifting from an ankle strategy toward a multi-segmental control strategy. A similar change in balance control strategy has been reported for a task with versus without visual information (Wang et al., 2014). While those results imply that ankle muscles may be involved in maintaining balance while standing on an unstable surface, these conclusions were based on kinematic data only. Greater insight into neuromuscular effects of balance training with therapy devices is necessary for improving the efficacy of training interventions aimed at treating and preventing sport-related disorders and ankle injuries.

The objective of this study was to quantify the effects of therapy devices with different stability properties on muscle activity of lower extremity muscles during unipedal stance. We hypothesized that less stable therapy devices require greater muscle activity and that lower leg muscles will have greater increases in muscle activity with less stable therapy devices than upper leg muscles.

2. Methods

A convenience sample of 25 healthy subjects (22 men, 3 women; mean ± 1SD; age: 25.2 ± 4.5 years; body mass: 75.3 ± 9.9 kg; height: 178.4 ± 6.9 cm) participated in this study after providing informed consent. All subjects were active in different sport activities between 1 and 4 h per week. Exclusion criteria of this study were: cerebral or neurological conditions or balance difficulties, joint related functional limitations, muscle related functional limitations of the dominant leg, physiotherapy or surgery of the dominant leg in the preceding 12 months and post-exercise fatigue on the day of testing. This study was approved by the University's ethics review board and conducted in accordance with the Declaration of Helsinki.

2.1. Experimental procedure

Subjects were asked to perform unipedal quiet stance trials on their dominant leg. For all trials, subjects were barefoot with their eyes open and arms folded behind their back. Subjects balanced for 15 s on each of six surfaces: a flat rigid surface and five surfaces with varying stability properties, respectively (Fig. 1). The therapy devices with different stability properties were a Therapy Top (TT, Thieme Sport, Grasleben, Germany), three different deformable balance pads (Thera Band stability trainer™, Hygenic Corporation, Akron, OH) and an Airex mat (Airex AG, Sins, Switzerland). The different stability properties were achieved by different material properties and structural design (Table 1).

All subjects first balanced on the flat rigid surface. This condition served as baseline measurement (control condition). Data for three trials with 10-s breaks between trials were collected for the control condition. To minimize potential systematic fatigue effects, the therapy devices with different stability characteristics were tested in randomized order immediately after the control condition by choosing consecutive orders from a randomization table. Data for three trials with 10-s breaks between trials were collected for each of the device conditions.

2.2. Data recording

Muscle activity was recorded using surface electromyography (EMG). Bipolar surface electrodes were placed according to the proposals of the SENIAM project group (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles; www.seniam.org) on the vastus medialis, vastus lateralis, biceps femoris, semitendinosus, gastrocnemius, soleus, tibialis anterior and peroneus longus muscles. The recording area was shaved, and fine-grained sand paper was used to remove the top layer of skin to reduce skin impedance. The electrodes (Ambu Blue Sensor, Ambu A/S, Ballerup, Denmark Denmark) were fixed over the muscle body along the fiber direction with a 2-cm inter-electrode distance. EMG signals were recorded using the MyoSystem 2000™ (Noraxon U.S.A. Inc., Scottsdale, AZ) with 1000 Hz recording frequency. We confirmed that there was no crosstalk between muscles by computing cross-correlations between raw signals. Signals were preprocessed with a 10 Hz low pass and a 500 Hz high pass filter. Further signal processing was performed in MyoResearch XP™ (Version 1.06.05; Noraxon U.S.A. Inc., Scottsdale, AZ). All EMG signals were rectified, and the mean EMG amplitude over the 15-sec interval was calculated. Values for each trial were normalized to the average value of the control condition and expressed as percent control condition. Ensemble averages of the three trials for each condition were used for further analysis.

2.3. Statistical analysis

All statistical tests were performed in SPSS Statistics version 19.0.0 (IBM Corporation, Somers, NY). Data are presented as means and 95% confidence intervals. Multivariate analysis of variance (MANOVA) was used to detect an overall difference in muscle activation between the test surfaces. One-way analyses of variance (ANOVAs) were used to detect differences in muscle activity between the test surfaces for each muscle. A mixed factor ANOVA was used to detect differences in lower versus upper leg muscle activity between the test surfaces. The significance level was set a priori to $\alpha = 0.05$. Paired t-tests were used for posthoc analyses with Bonferroni adjustment ($\alpha = 0.005$).

3. Results

Muscle activity for all muscles was higher for all therapy devices than for the control condition, except that of the peroneus longus muscle for the Therapy top and the green Thera Band stability trainer (Fig. 2). However, the increase in muscle activity during unipedal balancing differed significantly between therapy devices (Table 2). All muscles required the highest muscle activity for the black Thera Band stability trainer ($P < 0.001$ compared to all other devices; Fig. 2). The greatest amounts of additional relative muscle activity were observed for the tibialis anterior muscle (Fig. 2). The amount of additional relative muscle activity required corresponded mostly to the stability properties of the