Gait & Posture 38 (2013) 894–899

Contents lists available at SciVerse ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Unilateral balance training enhances neuromuscular reactions to perturbations in the trained and contralateral limb

Anderson Souza Castelo Oliveira [a,b], Priscila Brito Silva [a], Dario Farina [c], Uwe Gustav Kersting [a,*]

[a] Center for Sensory-Motor Interaction, Department of Health Science and Technology, Aalborg University, Aalborg, Denmark
[b] The CAPES Foundation, Brazilian Education Ministry, Brasilia, Brazil
[c] Department of Neurorehabilitation Engineering, Bernstein Focus Neurotechnology Göttingen, Bernstein Center for Computational Neuroscience, University Medical Center Göttingen, Georg-August University, Göttingen, Germany

ARTICLE INFO

Article history:
Received 20 August 2012
Received in revised form 17 April 2013
Accepted 18 April 2013

Keywords:
Balance training
Cross-education
Perturbations
Standing

ABSTRACT

The aim of this study was to investigate the effect of unilateral balance training on the reactive recovery of balance for both trained and untrained limbs. Twenty-three subjects were randomly assigned to either a control group (CG) or a training group (TG). The latter performed six weeks of balance training for the right leg. The pre- and post-training measurements were based on single leg standing posture on a moveable force platform which moved 6 cm anteriorly. TG subjects were tested on the trained (TR) and untrained leg (UTR), whereas CG subjects were tested on the right leg (CTR). The center of pressure trajectory length (CP_{LEN}) and average speed (CP_{SPD}) as well as onsets of muscular activation and time to peak (EMG_{TP}) from lower limb muscles were calculated and compared by a 2-way ANOVA (three legs × two training status). Muscular onsets were reduced after training for TR ($\sim$19 ms, $p < 0.05$) and UTR ($\sim$17 ms, $p < 0.05$) with no significant changes for CTR. No effects of training for CP_{LEN} and medial–lateral CP_{SPD} were found. Furthermore, the EMG_{TP} of UTR was predominantly greater before training ($\sim$17 ms, $p < 0.05$). However, after training the EMG_{TP} was similar among limbs. These results suggest that concomitant with improved balance recovery and neuromuscular reactions in TR, there is also a cross-education effect in UTR, which might be predominantly related to supraspinal adaptations shared between interconnected structures in the brain.

1. Introduction

The ability of reacting to unexpected perturbations to balance relies on the interaction between reflexes (modulated by spinal and supraspinal pathways), automatic responses and voluntary responses [1,2]. These mechanisms have essential implications for avoiding falls and assuring safe locomotion during daily life. Inefficient balance recovery strategies after perturbations during standing/walking are directly related to fall incidence [3]. Therefore, the use of perturbations in order to challenge balance skills and train postural control has been proposed [4–6]. Balance training (also called neuromuscular training) has been proven to reduce lower limb injury incidence and falls incidence. The use of simple devices such as wobble boards (also called ankle discs) for training purposes may reduce the injury incidence in athletes by over 50% [7–9]. Balance training has been effective in altering muscular reaction time (or muscle/electromyographic (EMG) onsets) to perturbations [8,10–13], improved joint positioning sense, hamstring/quadriceps ratio and joint stiffness [10,11], as well as postural sway while standing on a force platform [8,14]. In addition, recent investigations have shown that short-term balance training is effective in enhancing neuromuscular coordination of postural muscles, as well as neural adaptations on spinal and cortical levels [6].

Despite the fact that balance can be trained for both lower extremities, it remains to be shown whether adaptations to unilateral balance training can be transferred to the untrained limb by a cross-education effect [15]. This phenomenon has been extensively described in the literature concerning strength and resistance training [16,17], in which the untrained limb also shows positive gains in strength elicited by training stimuli. Possible explanations to the cross-education effect range from peripheral to supraspinal levels (see Carrol et al. [15] for a detailed review). Recent investigations suggested that supraspinal commands play an important role for adaptations to balance training [18,19], therefore, neural adaptations from unilateral balance training may

* Corresponding author at: Center for Sensory-Motor Interaction, Department of Health Science and Technology, Aalborg University, Fredrik Bajers Vej 7 D3, DK-9220 Aalborg, Denmark. Tel.: +45 99408094; fax: +45 98154008.
E-mail address: uwek@hst.aau.dk (U.G. Kersting).

0966-6362/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.gaitpost.2013.04.015

be transferred to the untrained limb via superior levels of the CNS. However cross-education after balance training has been poorly addressed in the literature [8].

Understanding cross-education from balance training may have significant implications in neurophysiology and sports medicine. Therefore, the aim of the present study was to verify whether six weeks of unilateral balance training could enhance reactive recovery of balance during single-leg stance perturbations for the trained leg and also for the untrained leg. To achieve this aim, surface EMG and ground reaction forces were measured to determine muscle onsets and center of pressure (CoP) displacement during single leg standing perturbations. The main hypothesis was that balance training could enhance balance recovery from unexpected perturbations for the trained leg and also for the untrained leg. The optimized balance control provided by balance training could improve neuromuscular properties (muscle onsets, burst durations and magnitudes) and also be reflected in altered reactive CoP displacements, reducing its length and average speed.

2. Methods

2.1. Subjects

Twenty-three healthy men volunteered for the experiment. These subjects were randomly assigned to a training group (TG, $n = 13$, age, 28 ± 4 years; body mass, 69 ± 8 kg; body height, 173 ± 5 cm) or a control group (CG, $n = 10$, age, 25 ± 3 years; body mass, 72 ± 8 kg; body height, 172 ± 3 cm). All subjects were right-dominant as determined by a kicking test. Exclusion criteria included history of knee or ankle ligament injury, current lower-extremity injury, recent (within six months) low back injury, or vestibular dysfunction. All subjects provided written informed consent before participation and the procedures were approved by the ethical committee of Northern Jutland (N-20100042).

2.2. Experimental setup

Pre-training and post-training measurements consisted of single-leg stance perturbations to balance. Both left and right limbs were tested in a random order in TG, in one single session while for CG only the right limb was tested (Fig. 1).

The subjects were asked to stand still on a moveable force platform with their knee slightly flexed while looking straight forward at a fixed target located on a wall 4 m away. The free leg had to be elevated at least 5 cm above the platform while the hands were kept akimbo. The platform delivered forward and backward sudden perturbations to balance (6 cm length, 80 ms duration, average speed 75 cm/s). The target perturbation was the forward displacement, however, perturbations backward were included to assure unpredictability but were not analyzed. Lower limb and trunk muscle EMG and CoP displacement were recorded from 500 ms before the perturbation onset until 1 s after. A few practice trials were allowed for each direction before measurements. After habituation, 12 perturbations forward and 12 perturbations backwards were delivered in random order, with a rest interval of 10–15 s between them. A longer rest interval (2 min) was provided after 12 perturbations to avoid fatigue effects.

The training protocol consisted of six weeks of balance exercises for the right limb. There were four sessions/week (24 sessions of training of 25 min duration each). The exercises were based on single leg stance performed initially on the floor and progressively increasing difficulty for balance maintenance by using foam pads, dyna discs and wobble boards (see Table 1 for exercise progression). No training stimuli were allowed for the left leg during the whole training period. Subjects of the control group were asked to maintain normal daily life activities during the 6-week training program in between the two measurements.

2.3. Kinetics

A three-dimensional force platform (AMTI, OR6-5, Watertown, MA) mounted to a hydraulic system [20] provided perturbation stimuli and simultaneous measures of vertical (Fz), anterior–posterior (Fy) and medial–lateral (Fx) ground reaction forces and moments (Mx, My and Mz). Custom-made software (MrKick II, Aalborg University, Aalborg, Denmark) was used for force recordings (1024 Hz). Using an electronic feedback circuit, the software triggered force plate movements. Ground reaction forces and moments were recorded and sampled by a kinematic tracking system (Qualisys Track Manager, Qualisys, Gothenburg, Sweden) at 256 Hz. Signals were digitally low-pass filtered with a 4th order zero-lag Butterworth filter (8 Hz cut-off). Displacement of the center of pressure (CoP) was calculated as $(x,y) = (x0 + My/Fz,\ y0 + Mx/Fz)$, where $(x0,\ y0)$ was the geometrical center of the force plate. The effects of platform movements during perturbations on the forces and moments were taken into account. A series of identical platform movements (the same delivered during the experiment) were recorded with no loads over it, in order to determine the forces and moments generated only by moving the device. Subsequently, these inertial forces and moments were subtracted from the real forces and moments used to determine the CoP.

2.4. Electromyography

Surface EMG signals were recorded in bipolar configuration with pairs of Ag/AgCl electrodes (Ambu Neuroline 720 01-K/12; Ambu, Ballerup, Denmark) with 22 mm of center-to-center spacing. The EMG signals were amplified with a gain of 2000 (EMG-USB, LISiN; OT Bioelettronica, Turin, Italy), A/D converted (12 bit), sampled at 2048 Hz and band-pass filtered (second-order Butterworth, 10–500 Hz). A reference electrode was placed at the right wrist. The EMG signals of the right limb were recorded from tibialis anterior (TA), rectus femoris (RF), vastus lateralis (VL) and biceps femoris (BF) according to Hermens et al. [21]. EMG signals were synchronized to the ground reaction force by the trigger signal to the perturbation onset.

2.5. CoP analysis

CoP data were analyzed for each trial from the perturbation onset to 1000 ms after it, a period in which it is possible to regain stability after a similar perturbation

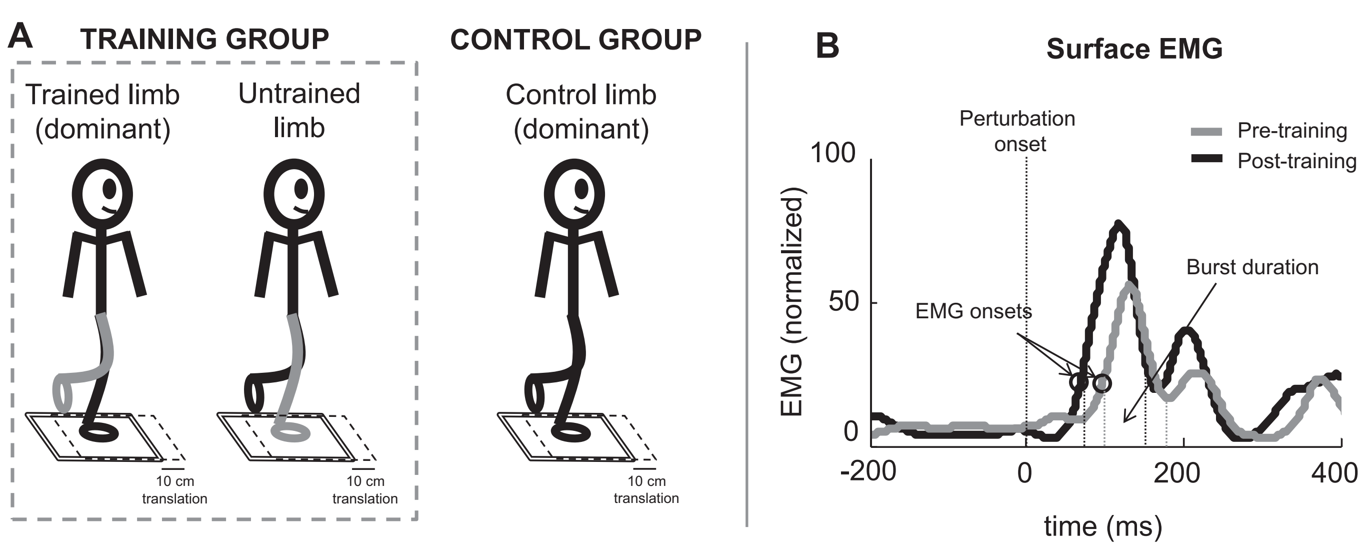

Fig. 1. Illustrative experimental design. (A) Subjects from the training group were tested on both trained (dominant) and untrained legs, whereas subjects from the control group were tested only in the dominant leg. The test consisted in perturbations to balance that elicited backward displacement of the center of mass (10 cm translation). (B) Surface electromyography was recorded from the perturbations and the perturbation onset, as well as burst duration and other variables were calculated before (gray) and after balance training (black).