Gait & Posture 40 (2014) 291–296

Contents lists available at ScienceDirect

Gait & Posture

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

Improved postural control in response to a 4-week balance training with partially unloaded bodyweight

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ARTICLE INFO

Article history:
Received 20 December 2013
Received in revised form 6 March 2014
Accepted 8 April 2014

Keywords:
Sensorimotor training
Partial weight-bearing
H-reflex
Neuromuscular
Rehabilitation

ABSTRACT

Balance training (BT) is successfully implemented in therapy as a countermeasure against postural dysfunctions. However, patients suffering from motor impairments may not be able to perform balance rehabilitation with full body load. The purpose of this study was to investigate whether partial unloading leads to the same functional and neuromuscular adaptations. The impact on postural control of a 4-week BT intervention has been compared between full and partial body load.

32 subjects were randomly assigned to a CON (conventional BT) or a PART group (partially unloaded BT). BT comprised balance exercises addressing dynamic stabilization in mono- and bipedal stance. Before and after training, centre of pressure (COP) displacement and electromyographic activity of selected muscles were monitored during different balance tasks. Co-contraction index (CCI) of soleus (SOL)/tibialis (TA) was calculated. SOL H-reflexes were elicited to evaluate changes in the excitability of the spinal reflex circuitry.

Adaptations in response to the training were in a similar extent for both groups: (i) after the intervention, the COP displacement was reduced ($P < 0.05$). This reduction was accompanied by (ii) a decreased CCI of SOL/TA ($P < 0.05$) and (iii) a decrease in H-reflex amplitude ($P < 0.05$).

BT under partial unloading led to reduced COP displacements comparable to conventional BT indicating improved balance control. Moreover, decreased co-contraction of antagonistic muscles and reduced spinal excitability of the SOL motoneuron pool point towards changed postural control strategies generally observed after full body load training. Thus, BT considering partial unloading is an appropriate alternative for patients unable to conduct BT under full body load.

1. Introduction

It is well known that balance training (BT) improves postural skills [1,2] and subsequently reduces the incidence of lower limb injuries [3,4] as well as decreases the risk of sustaining a fall [5,6]. As a consequence, BT is used in therapy to counteract circumstances where postural and motor control are compromised [7,8]. However, people suffering from motor impairments or reduced mobility (e.g. post-surgery, neurological diseases, the elderly) may not be able to bear their full bodyweight and thus are potentially not capable of participating in conventional intervention programmes. It could be expected that these patient groups may be able to perform BT with partially unloaded bodyweight. Partial unloading of the bodyweight is already routinely applied in gait therapy to counteract neurological disorders during early stage of rehabilitation [9]. Therefore, partial body load conditions during BT could provide early recovery of the functional and neuromuscular properties as static and dynamic balance control are essential skills for daily activities [10].

It is well documented that improvements in balance performance in response to conventional BT (full bodyweight) evoke adaptations within the central nervous system (CNS, [11]). Current findings show that improved postural skills in general are associated with the plasticity of the CNS [12] and it is emphasized that spinal [13,14] and supraspinal [15,16] adaptations in particular may be responsible for the enhancement in postural control. Studies investigating the spinal reflex circuitries by means of peripheral nerve stimulation suggest that BT reduces the excitability of spinal reflexes [13,14]. The decreased spinal excitability is supposed to diminish involuntary postural oscillations and thus is believed to

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http://dx.doi.org/10.1016/j.gaitpost.2014.04.186
0966-6362/

result in a distinct enhancement in balance performance [11]. From a functional perspective regarding the interaction between agonist and antagonist muscle groups, the enhancement in balance performance was shown to be accompanied by a decreased co-contraction [17]. More particular, a reduced co-contraction is considered to play an important role when an accurate and specific balance control is required within a demanding postural task. Taken together, adaptations of neuromuscular properties (i.e. decreased spinal excitability combined with a reduction in simultaneously activated antagonistic muscles) imply a more efficient motor control and thus are supposed to substantially contribute to the improved postural skills.

From a biomechanical point of view, BT under partial unloading conditions must not necessarily evoke similar functional and neuromuscular adaptations compared to full body load BT [18]. For that purpose, this study aimed to compare adaptations of a four-week BT intervention in two subgroups training either under full or partial body load conditions. Particular interest was given in understanding the possible group specific functional and neuromuscular adaptations. It was hypothesized that (a) improvements in balance control are accompanied by (b) a decrease in co-contraction of antagonistic muscles and (c) a reduction in H-reflex amplitudes; however the improvements are expected to be more pronounced in the group that performed conventional BT.

2. Materials and methods

2.1. Subjects

32 healthy subjects (18 females, 15 males, mean age 24 ± 2 years) participated in this study. All subjects provided written informed consent for the experiment, which was approved by the ethics committee of the University Freiburg and was in accordance with the Declaration of Helsinki. The participants were randomly assigned to either the group performing partially unloaded BT (PART, n = 16, 9 female, 8 male, age 24 ± 2years, height 175 ± 7 cm, weight 69 ± 11 kg) or to the control group performing conventional BT with full body load (CON, n = 16, 9 female, 7 male, age 24 ± 2years, height 173 ± 10 cm, weight 70 ± 13 kg).

2.2. Experimental design

A four-week training study design was chosen to evaluate the influence of partial bodyweight unloading during BT on postural control. Centre of Pressure (COP) displacement, electromyographic activity (EMG) and H-reflex amplitudes were assessed before and after the intervention in three different test conditions which display a gradual level of difficulty from simple to complex postural tasks: bipedal stance (BS, control condition for normalization), monopedal stance (MS) on a stable surface and monopedal stance on an instable surface (MIS, spinning top). Three trials of 30 s were performed for each condition.

2.3. Training intervention

All participants performed a visual feedback-based BT for a period of four weeks, with two training sessions per week separated by minimum one day rest. One session lasted 35 min and consisted of 5 min warm up, 10 min static BT and 20 min dynamic BT. During static BT subjects stood on their left leg keeping their COP (displayed on a screen, distance 2 m) as still as possible. During dynamic BT, subjects stood on both legs and traced a circled line as accurately as possible by shifting their COP in the predefined directions. Each task was performed for durations of 30 s with pauses of 30 s. The volume of BT was kept equal for both groups. The CON group performed BT with full bodyweight, whereas the PART group trained with a 60% unloading of the body's mass [19]. Unloading was achieved by means of a bodyweight-support harness system consisting of elastic straps connected to a ceiling-mounted height-adjustable system (Fig. 1).

2.4. Outcome measures

2.4.1. Postural sway

Total (COP_{total}), anterior–posterior (a–p, COP_{ap}) and medial–lateral (m–l, COP_{ml}) COP displacement was determined on a force plate (AMTI, Watertown, USA) (Fig. 2). 3D ground reaction forces were sampled at 50 Hz. The participants were barefoot, placed their hands akimbo, directed their head and eyes forward and were asked to stand as still as possible. Prior to measurements each subject practiced 10 min to adapt to the instable surface.

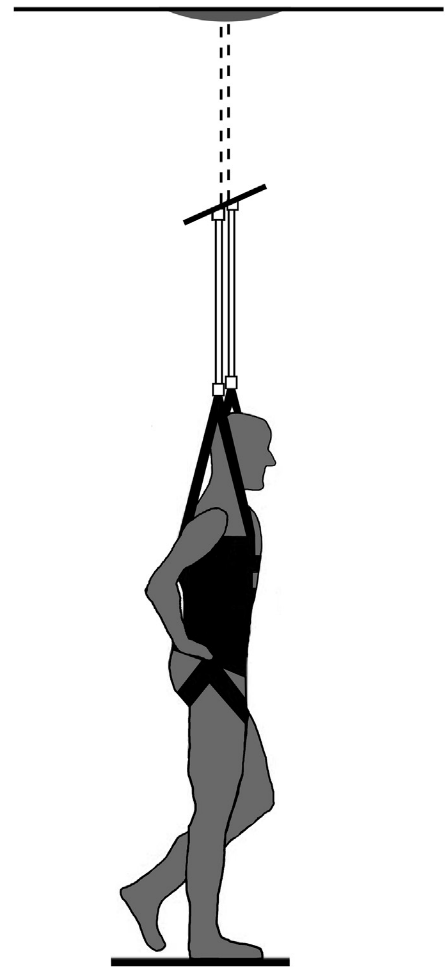

Fig. 1. Partial unloading system: elastic straps were fixed to the subject via a climbing harness. The height-adjustable system was ceiling-mounted and extended over 7 m. The unloading of the subjects was adjusted to 40% of the bodyweight by weighing them on a scale.

2.4.2. EMG recording

EMG data was obtained by placing surface electrodes (∅9 mm, Ag/AgCl, Ambu Blue Sensor P, Ballerup, Denmark) over m. soleus (SOL), tibialis anterior (TA) and peroneus longus (PER). Electrodes were placed in line with the direction of the underlying muscle fibres with a centre-to-centre distance of 25 mm. By shaving and light abrasion of the skin interelectrode resistance was kept below 5 kΩ. Signals were amplified (1000×) and recorded with 1 kHz (band-pass filter 10 Hz to 1 kHz).

2.4.3. Peripheral nerve stimulation

Modulation in spinal excitability of SOL was assessed by eliciting H-reflexes. The posterior tibial nerve was stimulated with 1 ms square-wave pulses using an electrical stimulator (Digitimer®, DS 7). The anode was fixed underneath the patella and the cathode was placed in the popliteal fossa. Prior to measurements, H/M-recruitment curves were recorded during upright stance detecting the maximal H-reflex and M-wave (Mmax) [14]. For data collection, the stimulation current was adjusted to elicit H-reflexes with the size of 25% Mmax. Electrical stimulation was triggered to occur every four seconds resulting in 20 H-reflexes in each stance condition (Fig. 2).

2.4.4. Kinematics

Ankle and knee angles were recorded by monoaxial electrogoniometers (Biometrics®, Gwent, UK). One goniometer was placed over the medial epicondyle of the femur (endplate attached to the shank aligned to the medial malleolus) and the other to the thigh (aligned to the greater trochanter). The second goniometer was fixed at the medial aspect of the ankle (ends attached to the axis of the foot and leg). Signals were recorded with 1 kHz and band-pass filtered (10 Hz to 1 kHz).

2.4.5. Data processing

COP_{ap} and COP_{ml} was assessed and COP_{total} was calculated corresponding to the Pythagoras theorem $COP_{total} = \Sigma D_i$, $i = [0;\ 1500]$ with D_i = [(Displacement in a–p