Journal of Electromyography and Kinesiology 24 (2014) 682–688

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

The effect of six weeks endurance training on dynamic muscular control of the knee following fatiguing exercise

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ARTICLE INFO

Article history:
Received 26 June 2013
Received in revised form 23 May 2014
Accepted 10 June 2014

Keywords:
Endurance training
Centre of pressure
Muscle fatigue

ABSTRACT

The aim of the study was to examine whether six weeks of endurance training minimizes the effects of fatigue on postural control during dynamic postural perturbations. Eighteen healthy volunteers were assigned to either a 6-week progressive endurance training program on a cycle ergometer or a control group. At week 0 and 7, dynamic exercise was performed on an ergometer until exhaustion and immediately after, the anterior–posterior centre of pressure (COP) sway was analyzed during full body perturbations. Maximal voluntary contractions (MVC) of the knee flexors and extensors, muscle fiber conduction velocity (MFCV) of the vastus lateralis and medialis during sustained isometric knee extension contractions, and power output were measured. Following the training protocol, maximum knee extensor and flexor force and power output increased significantly for the training group with no changes observed for the control group. Moreover, the reduction of MFCV due to fatigue changed for the training group only (from 8.6% to 3.4%). At baseline, the fatiguing exercise induced an increase in the centre of pressure sway during the perturbations in both groups (>10%). The fatiguing protocol also impaired postural control in the control group when measured at week 7. However, for the training group, sway was not altered after the fatiguing exercise when assessed at week 7. In summary, six weeks of endurance training delayed the onset of muscle fatigue and improved the ability to control balance in response to postural perturbations in the presence of muscle fatigue. Results implicate that endurance training should be included in any injury prevention program.

1. Introduction

Maintaining balance is the ability to maintain the body's centre of mass over the base of support during quiet standing and movement. These body oscillations are measured by the displacement of the COP resulting from centre of gravity movements of the individual (Winter, 1995). Balance involves multiple sensory systems (visual, vestibular, and somatosensory), the motor system, and requires central nervous system integration (Punakallio, 2005). The task of maintaining balance is achieved without much difficulty during daily life. However, in the event of either an external perturbation (e.g., being pushed or nudged, walking on a compliant/slippery surface, changes in lighting) or an internal perturbation (e.g., muscle stiffness, musculoskeletal injury, fatigue), there is a tendency for postural sway to increase (Dickin and Doan, 2008) which, in the case of fatigue, may reduce static and dynamic regulation of balance.

It has been well established that lower limb muscle fatigue may impair the proprioceptive and kinesthetic properties of joints (Miura et al., 2004) by increasing the threshold of muscle spindle discharge, disrupting afferent feedback, and subsequently altering conscious joint awareness (Gribble and Hertel, 2004) leading to decreased functionality of the proprioceptive muscle receptor system (Forestier et al., 2002). Therefore, altered somatosensory input due to muscle fatigue could result in deficits in neuromuscular and postural control around the joint (Gribble and Hertel, 2004), thereby making joint structures more susceptible to injury (Gollhofer et al., 1987). Studies have shown that fatigue reduced postural control measured using Star Excursion Balance Performance (SEBT) (Gribble and Hertel, 2004) and reduced EMG responses of the lower limbs when perturbed (Hedayatpour et al., 2011; Hassanlouei et al., 2012).

Endurance training results in numerous adaptations within the skeletal muscle that may be significant for exercise performance,

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http://dx.doi.org/10.1016/j.jelekin.2014.06.004
1050-6411/

including increases in sodium–potassium pump concentration (Jones and Carter, 2000), lactate transport capacity (McCullagh et al., 1996) and possibly myoglobin concentration (Harms and Hickson, 1983). Endurance training is also associated with a reduction in the degree of lactacidaemia for any given absolute or relative exercise intensity and has been dominantly used to increase the resistance to fatigue (Gibbons et al., 1983; Gaesser and Poole, 1988). Longitudinal studies show that as few as three sessions of practice of a sustained submaximal isometric contraction of the elbow flexors enable sedentary subjects to prolong their time to exhaustion (Hunter and Enoka, 2003) by an increased energy metabolic potential (Green et al., 1999), and reducing the accumulation of metabolic by-products during exercise. Training has also been shown to enhance postural control during static or dynamic perturbations (Myer et al., 2006a, 2006b). However, such studies have been conducted on individuals in an un-fatigued resting state. There is no knowledge on whether endurance training would counteract the increased postural sway observed during perturbations in the presence of fatigue.

Therefore, the purpose of this study was to investigate the effects of six weeks endurance training on dynamic postural control following exercise-induced muscle fatigue. Maximum voluntary contractions of the knee flexors and extensors, maximal power output and muscle fiber conduction velocity (MFCV) of the vastus medialis and vastus lateralis muscles during sustained isometric knee extension contractions can be used as indicators of muscle fatigue and with that to confirm the efficacy of a training program. This knowledge may be useful to design exercise training to improve postural stability and prevent skeletal muscle injuries in sports.

2. Materials and methods

2.1. Subjects

Eighteen healthy sedentary men (age, mean ± SD, 26.5 ± 4.5 year, body mass, 74.4 ± 7.3 kg, height, 1.8 ± 0.38 m), with no history of lower limb disorders, participated and were randomly assigned to either a 6-week endurance training program ($n = 10$) or a control group (no intervention; $n = 8$). All subjects were right leg dominant assessed by asking for the leg they would prefer to kick a ball with. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee (N-20100045). Subjects provided informed written consent before participation in the study.

2.2. Procedure

The subjects attended two laboratory sessions; immediately before (session 1 – week 0), and after completion of the 6-week training period (session 2 – week 7), with no strenuous exercise or training for at least 48 h prior to testing to assure the experiments were executed in a rested state. In both sessions, three maximal voluntary contractions (MVC) of knee flexion and extension were conducted before and immediately after dynamic fatiguing exercise. Muscle fibre conduction velocity was recorded from the vastus medialis and vastus lateralis during isometric contractions following the fatiguing exercise. Moreover, COP displacements were measured during full body postural perturbations. The same order of the test was followed for the two sessions (Fig. 1).

2.2.1. Training protocol

Endurance training was performed on a bicycle ergometer, and the exercise intensity was prescribed based on the percentage of the heart rate reserve (HRR). The lower and upper limits of HRR [target heart rates (THR)] were calculated with the Karvonen method [(maximal heart rate − resting heart rate) × % intensity + resting heart rate] (Karvonen et al., 1957). The use of % HRR has been recommended for prescribing exercise intensity in cycling activities since it provides accurate target workloads, especially for individuals with a low fitness level. To maintain the exercise intensity within the required THR, each subject used a pulse meter during the training sessions. From week 1 to week 2, the THR was set between 50% and 60% of the HRR, and each training session lasted 20–30 min. On weeks 3 and 4, the duration of the sessions was 30–40 min and THR was 60–70% of the HRR. For the last 2 weeks, the time per session increased to 40–45 min and the THR was maintained at 65–75% of the HRR. Three sessions were completed each week. All training sessions were supervised by the principal investigator (HH).

2.2.2. Maximal power output

Maximal power output was determined using the ramping test to evaluate the performance of the participants. The starting power output was 100 W, with a ramp rate of 15 rev min^{-1}. Visual feedback from a computer display enabled participants to maintain pedal cadence between 75 and 80 rev min^{-1}. The participants ended the test voluntarily when they could no longer maintain the required pedal cadence. Maximal power output was defined equal to the final power output reached in the test.

2.2.3. Fatiguing exercise

Dynamic exercise was performed on a SRM bicycle (SRM, Germany). After adjusting the saddle and handle-bar height to match each subject's leg and arm lengths (comfortable cycling height), subjects commenced with a 10 min warm up that consisted of light cycling followed by a ramping protocol until exhaustion. Starting at 100 W, the workload was increased by 15 W·min^{-1}. A pedal frequency meter was used by the subject to maintain the cadence between 75 and 80 rev min^{-1}. A consistent level of strong verbal encouragement was provided to motivate subjects for maximum output throughout the exercise at both pre and post training sessions. Each exercise test was terminated either: (1) voluntarily by the subject, (2) when pedaling cadence could not be maintained at 75 rev·min^{-1}.

2.2.4. Maximal voluntary force

Knee extension (quadriceps) and flexion (hamstrings) MVCs were measured during isometric contractions before and after the exercise protocol with a load cell strapped to the subject's ankle 5 cm above the malleoli of the right leg. The subject was seated on an adjustable chair with the hip and knee in 90° flexion and the ankle in a neutral position. Straps were applied around the subject's hips and chest. Visual feedback of the force produced was provided on a screen positioned 50 cm in front of the subject. The subject was asked to perform three maximal contractions for both knee extension and flexion (5 s in duration) in a random order with 2 min rest between each contraction. Verbal encouragement was provided to encourage maximal effort and the highest value of the three efforts was defined as the MVC.

2.2.5. Muscle fibre conduction velocity

Adhesive linear arrays of eight equi-spaced electrodes (bar electrodes 5-mm long, 1-mm diameter, 5-mm inter-electrode distance Spes Medica, Salerno, Italy) were used to detect surface EMG signals from the vastus medialis (VM) and vastus lateralis (VL) muscles of the right leg (Fig. 2). The arrays were located between the most distal innervation zone and the distal tendon region of the muscles. Innervation zone and tendon regions were non-invasively identified in preliminary test contractions with the use of a dry array as previously described (Masuda and De Luca, 1991). The