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Time to task failure influences the postural alteration more than the extent of muscles fatigued

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A B S T R A C T

The aim of this study was to compare the effects of unilateral and bilateral muscle fatigue on monopedal postural control. Nineteen subjects completed bilateral fatiguing contractions and unilateral fatiguing contractions of the quadriceps femoris until the torque output for both exercises dropped below 30% of the measured peak torque (the time to task failure was measured) for three consecutive contractions (independently measured for each leg). Postural control was evaluated by using a force platform which recorded center of foot pressure (COP) and was measured before and after the completion of both fatiguing tasks. Spatio-temporal COP parameters were used to evaluate postural control. The unilateral contractions affected monopedal postural control more than the bilateral fatiguing contractions ($p < 0.05$). Moreover, the time to task failure was significantly longer for the unilateral contractions than for the bilateral contractions ($p < 0.05$). The greater alteration of postural control for the unilateral fatiguing contractions compared to the bilateral fatiguing contractions could be related to a longer time to task failure which could provoke greater disturbances of the postural system in terms of sensory input and motor output.

1. Introduction

Acute activity has different impacts in terms of fatigue of the muscles involved in a task (i.e. the reduction of their maximal voluntary contraction-MVC) depending on whether sustained submaximal muscle contractions are unilateral or bilateral. Indeed, the time to task failure and the reduction of the MVC differ between the completion of unilateral fatiguing contractions and bilateral fatiguing contractions [1]. Nevertheless, there is no evidence that unilateral fatiguing contractions differently affect neuromuscular control compared to bilateral fatiguing contractions. Yet, muscle fatigue disturbs movement control such as range of motion and movement velocity [2]. Even very localized muscle fatigue, i.e. involving few muscle groups, is sufficient to degrade postural control [3]. Fatigue of the unilateral lower-limb muscles deteriorates postural control during monopedal stance [4–14]. Evidence suggests that bilateral fatigue for the same muscle group also deteriorates monopedal postural control [15].

In the context of localized muscle fatigue, an exercise that involves antagonist ankle muscles such as plantarflexors and dorsiflexors impaired postural control more than an exercise involving either plantarflexors or dorsiflexors [16]. Boyas et al. [16] reported that the greater the number of fatigued muscles, the higher the postural disturbance and suggested that the greater the number of fatigued muscles, the greater the alteration of the postural system in terms of motor output and sensory input. The previous relationship persists with general muscle fatigue which shows that exercise applied to few muscles, but very localized such as heel raises, affected postural control less than exercise soliciting a greater number of muscles involving the whole body such as squat thrusts or rowing movements [17,18]. Furthermore, fatigue of muscles even not directly involved in the postural regulation (i.e. muscles non extensor of the lower limb, trunk or head) such as the shoulder muscles is sufficient to disturb postural control [19]. The global number of muscle fatigued could have a cumulative effect on the postural control disturbance. Hence, one can postulate that for a given muscle chain, the disturbing effects of bilateral fatigue on monopedal postural control should be greater than those induced by unilateral fatigue.

In addition, the effects of cross-over fatigue are sufficient to disturb postural control of the contralateral limb [12]. According to Paillard et al. [12], the deterioration of contralateral monopedal postural control obviously emanates from central changes. This could result from the altered activity of the motor units of the

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ipsilateral quadriceps femoris. Changes in spinal reflexes of the ipsilateral limb can disturb the drive of the homologous motor units of the contralateral quadriceps femoris [20] and modify the contralateral motor pathway [21]. Hence, bilateral fatigue of lower-limb muscles could disturb monopedal postural control more than unilateral fatigue since the contralateral and ipsilateral fatiguing effects could be cumulative.

On the basis of the data referred to above, bilateral muscle fatigue could accentuate the disturbance of monopedal postural control compared to unilateral muscle fatigue. To our knowledge, no study has compared the effects of unilateral fatigue with those of bilateral fatigue on monopedal postural control. The aim of this study was to compare the effects of unilateral and bilateral fatiguing contractions of the quadriceps femoris performed at the same relative level of force on monopedal postural control and neuromuscular activities (MVC and central activation level) whose changes are able to influence the motor output of the postural system.

2. Materials and methods

2.1. Subjects

Nineteen healthy male sports science students who practiced competition sport participated in the study (age 20.8 ± 3.4 years; height 176.5 ± 5.9 cm; body weight 75.7 ± 10.9 kg). Exclusion criteria included a documented postural control disorder or a medical condition that might affect postural control, a neurologic or a musculoskeletal impairment in the past 2 years, or current injury making the subjects unable to participate. The participants avoided strenuous activity before the data collection session. This experimental procedure received the approval of the local committee for the protection of human subjects and all subjects gave informed consent to participate in the experiment in accordance with the Declaration of Helsinki.

2.2. Protocol

The experiment consisted of examining the possible modifications of postural control and neuromuscular activities induced by two different fatiguing exercises: unilateral voluntary muscular contractions (UNI exercise) and bilateral voluntary muscular contractions (BI exercise) of the quadriceps femoris muscle. Isometric MVC, central activation ratio (CAR) and monopedal postural control were measured before (pre-fatigue or PRE condition) and after (post-fatigue or POST condition) the completion of the two fatiguing muscle exercises involving a drop below 30% of the measured peak torque. The completion of each exercise (UNI and BI) was separated by a period of 7–15 days for all the participants. The effects of each fatiguing exercise were assessed in a randomized order. For each exercise, the subjects successively performed a postural test (PRE condition), a 15-min warm-up on a cycle ergometer, MVC and CAR tests, a fatigue protocol, MVC and CAR tests and a postural test (POST condition).

2.3. Postural test

The subjects were asked to stand barefoot, on one leg, as still as possible for 25 s on a force platform, with their arms along side the body (PostureWin, Techno Concept, Cereste, France; 40 Hz frequency, 12 bit A/D conversion). The force platform recorded the displacements of the center of foot pressure (COP) with three strain gauges. The supporting leg was the dominant leg, i.e. the one used when kicking a ball. The foot was placed according to precise landmarks with respect to the *X* and *Y* axes of the platform. The other leg was raised and flexed 90° at the knee-level. The two hips were placed in a neutral position (0° of flexion). COP signals were smoothed using a second-order-Butterworth filter with a 10 Hz low-pass cut off frequency.

The spatio-temporal parameters of COP displacements analyzed were the COP surface area (mm^2), the COP_X and the COP_Y velocity (the total COP displacement divided by the total period on the medio-lateral axis or *X* axis and the antero-posterior axis or *Y* axis respectively, mm s^{-1}). The COP surface is an indicator of the postural stability, the smaller the COP surface area, the better the stability [22]. The COP_X and COP_Y velocity were used to specify the postural control on the axes *X* and *Y*, the smaller the COP velocity the better the postural control [22].

2.4. Measurement of maximal voluntary contraction

The MVC of the quadriceps of the dominant leg and the MVC of the non-dominant leg were both measured on an ergometer (Leg extensor, Panatta Sport^{TM}, Apiro, Italia) for both conditions (PRE and POST). This device was equipped with two force sensors (Model SSM Series, PM Instrumentation^{TM}, Courbevoie, France; 200 Hz sampling frequency) attached to the subjects' ankles. The subjects sat with a 100° knee flexion and a 100° hip flexion. The back of the seat was inclined 10° backwards and the depth of the seat was fitted to the length of the subjects' thighs. Subjects were stabilized with straps positioned across the chest and pelvis. The arms were crossed on the chest. A period of familiarization was established before this test period. During the test for the PRE and POST conditions, subjects were asked to perform their MVC (in Newtons) for 5 s, with a 10-s rest between the dominant leg and the non-dominant leg actions. The subjects received verbal encouragements without having any visual and verbal feedback about their performance.

2.5. Evaluation of central activation ratio

To quantify central activation failure during each MVC, an electrical stimulation (ES) was triggered manually after force plateaued (i.e. after 3 s), for 2 s. Central activation ratio was calculated according to the following equation [23,24]:

$$\mathrm{CAR} = \frac{\mathrm{MVC}}{\mathrm{MVC} + \mathrm{ES}}$$

where MVC + ES = voluntary + stimulated forces. In the case where there was no increase in force during the electrical stimulation, CAR = 1.0 and voluntary activation was considered as complete. Central activation ratio was evaluated on the dominant leg for both exercises.

ES was completed with a portable stimulator (CefarTM Rehab 4 Pro®, Lund, Sweden). Four rectangular self-adhesive conducting electrodes (Stimrode®, 50 mm × 89 mm, Sweden) were placed over the vastus medialis, vastus lateralis and rectus femoris muscles. Three electrodes were longitudinally placed over the motor point of the vastus medialis, rectus femoris and vastus lateralis muscles and one electrode was placed on the proximal part of the quadriceps across the vastus lateralis and rectus femoris. Muscles were stimulated using a biphasic symmetrical rectangular wave (pulse duration 450 μs, 70 mA, frequency 80 Hz).

2.6. Fatiguing exercise

Two minutes after the MVC and CAR tests (in the PRE condition), the subjects began the fatigue protocol which was completed with only the dominant leg for the UNI exercise and with both legs for the BI exercise. Each isometric knee extension lasted 5 s. Two seconds separated each contraction. The subjects received feedback from a computer screen so that they could