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Walking kinematics and kinetics following eccentric exercise-induced muscle damage

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ABSTRACT

The goal of this investigation was to investigate how walking patterns are affected following muscle-damaging exercise by quantifying both lower limb kinematics and kinetics. Fifteen young women conducted a maximal isokinetic eccentric exercise (EE) muscle damage protocol (5×15) of the knee extensors and flexors of both legs at 60°/s. Three-dimensional motion data and ground reaction forces (GRFs) were collected 24 h pre-EE while the participants walked at their preferred self-selected walking speed (SWS). Participants were asked to perform two gait conditions 48 h post-EE. The first condition (COND1) was to walk at their own speed and the second condition (COND2) to maintain the SWS (±5%) they had 24 h pre-EE. Walking speed during COND1 was significantly lower compared to pre-exercise values. When walking speed was controlled during COND2, significant effects of muscle damage were noticed, among other variables, for stride frequency, loading rate, lateral and vertical GRFs, as well as for specific knee kinematics and kinetics. These findings provide new insights into how walking patterns are adapted to compensate for the impaired function of the knee musculature following muscle damage. The importance to distinguish the findings caused by muscle damage from those exhibited in response to changes in stride frequency is highlighted.

1. Introduction

It is widely accepted that unaccustomed exercise of high intensity or duration can result in muscle damage. Exercise-induced muscle damage manifests itself as soreness, stiffness, reduction in the force-producing capability of the muscle and elevated intramuscular proteins in blood (Byrne et al., 2004). The severity of damage and the extent of discomfort are exacerbated over time and can last for several days. Most damage occurs when the exercise bout involves eccentric actions (Byrne et al., 2004).

Eccentric "muscle-damaging" actions are not limited to sport-specific movements but also appear frequently during everyday activities, such as downhill walking and step descending. Walking, in particular, provides a healthful form of physical activity that is accessible to most individuals regardless of age, sex, or physical condition and is the preferred mode of exercise for many population groups, including hikers, backpackers and the elderly population (Lee and Buchner, 2008). Intensive and long marches are also carried out during military training. It is generally acknowledged that many participants experience soreness of their lower-limbs after walking long distances. However, there is not much information available about the basis for these complaints and could partially be due to the occurrence of muscle damage. Indeed, it has been documented that excessive downhill walking, which involves repetitive eccentric actions, results in delayed onset muscle soreness (DOMS) and/or muscle damage (Howatson et al., 2011). In order to prevent from severe muscle damage that could lead to serious musculoskeletal injury, it is essential to address how individuals respond mechanically during walking when their locomotor system is stressed due to muscle damage.

Yet, there are only few studies available on how exercise-induced muscle damage affects walking biomechanics. These studies observed significant effects of localized damage of knee flexors and/or extensors after isokinetic (Paschalis et al., 2007; Tsatalas et al., 2010) or isotonic (Lanier et al., 2009) eccentric exercise (EE) on walking kinematic parameters. However, very little is known about the underlying mechanisms by which muscle damage influences these parameters. A relevant study examined the neuro-mechanical strategies that take place during walking after exhaustive stretch-shortening cycle exercise (SSC) of the lower limbs, based on EMG

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and kinematic measurements (Morio et al., 2011). It was reported an anticipatory pain protective strategy 48 h following SSC, but the compensatory neural adjustments within the triceps surae muscle group were sufficient to preserve walking kinematics. Moreover, evidence of a protective mechanism designed to decrease EMG activity of the sore muscle (biceps femoris) while increasing the activity of a synergistic muscle (gastrocnemius) during walking was provided after EE-induced damage of knee flexors (Dover et al., 2012). To our knowledge, there is no study available that investigated what kinetic adaptations healthy adults make to successfully negotiate the demands of walking following muscle damage.

Understanding the adaptations in gait dynamics could provide new insights into how muscle damage affects walking patterns. Furthermore, it could guide the development of interventions aimed at avoiding more severe musculoskeletal injury, especially among older adults who may be more susceptible to exercise-induced muscle injury than younger adults (Faulkner et al., 1995). A first step in this direction is to establish these adaptations for healthy young adults. Therefore, the goal of this investigation was to investigate how walking patterns are affected following muscle-damaging exercise by quantifying both lower limb kinematics and kinetics.

2. Materials and methods

2.1. Participants

Fifteen healthy physically active women (22.9 ± 3 years; 164 ± 7 cm; 54.3 ± 5 kg) volunteered to participate in this study. Most of them were students in our sports science department, participating no more than three times per week in low- to moderate-intensity and short- to moderate-duration physical education classes and various recreational activities. They were informed of the purpose and potential risks of their involvement and gave written informed consent. Participants had not experienced any EE training or other activities with large eccentric component for at least 6 months before the study. They were also requested to abstain from strenuous exercise activities and not take anti-inflammatory drugs for the duration of the investigations. The study was conducted according to the Declaration of Helsinki and approved by the institutional review board.

2.2. Experimental design

Upon entering the gait laboratory during the first-visit (72 h pre-EE), the participants received instructions regarding the test procedure with a visual demonstration of the walking and the isokinetic dynamometer tests. Thereafter, the individual self-selected walking speed (SWS) of each participant was determined. SWS was assessed from the interval required to pass between two infrared light timing gates located in the middle of the 10 m laboratory walkway. Baseline walking kinematics and kinetics were collected during the second-visit (24 h pre-EE), while muscle-damaging isokinetic EE was conducted in the third-visit (0 h). Taking into consideration that muscle damage symptoms peak 24–72 h post-exercise (Byrne et al., 2004), follow-up walking kinematics and kinetics were captured 48 h post-EE (fifth-visit). Evaluated muscle damage indicators included DOMS, isometric average peak torque and serum creatine kinase (CK) activity. DOMS was evaluated pre-exercise (third-visit), 24 h (fourth-visit), 48 h (fifth-visit) and 72 h (sixth-visit) post-exercise. Isometric average peak torque was assessed pre-exercise (third-visit), immediately after (third-visit), 24 h (fourth-visit), 48 h (fifth-visit) and 72 h (sixth-visit) post-exercise. CK was examined pre-exercise (third-visit) and 72 h post-exercise (sixth-visit).

2.3. Muscle damage protocol

A Cybex Norm isokinetic dynamometer (Ronkonkoma, NY) was used to induce muscle damage. Exercise was performed in a seated position (100° hip angle) and the trunk, waist, and thighs were stabilized with straps. The chair position was modified until the knee axis of rotation was aligned with the axis of rotation of the dynamometer's attachment arm. The range of motion (ROM) at the knee was set at 0–100° (0° = full knee extension). Gravitational corrections were also employed. The muscle damage protocol consisted of 5 × 15 eccentric maximal voluntary actions of the knee flexor and extensor muscle groups in sequence at 60°/s (Tsatalas et al., 2010, 2013). Each of the five sets was separated by 3 min of rest. EE was conducted randomly on one side of the body and then repeated on the contralateral leg after a 5 min recovery between the two bouts. The volunteers were given visual feedback of their performance (i.e. knee extensor and flexor torque/time plots) on the computer screen attached to the isokinetic dynamometer and were thoroughly instructed to act as forcefully as possible through the whole range of motion.

2.4. Indicators of muscle damage

A 10-cm visual analog scale, labeled with end points on the left (no pain) and right (extremely painful), was used to assess DOMS. Participants were asked to mark their perceived soreness level on the scale while the investigator palpated the muscle belly and distal region of all their quadriceps and hamstrings with the muscles relaxed. Participants performed three 3 s maximal voluntary isometric actions of knee extensors and flexors of both legs at 65° and 30° of knee flexion, respectively (Kellis and Baltzopoulos, 1996). A 2 min rest period was given between efforts to avoid fatigue effects. The peak value for each 3 s contraction was recorded and the average of the three contractions was defined as isometric average peak torque. Blood samples were drawn from an antecubital vein into plain evacuated test tubes. The blood was allowed to clot at room temperature for 30 min and centrifuged at 1500*g* for 10 min. The serum layer was removed and frozen at −30 °C until analyzed. CK was determined spectrophotometrically (Spectronic-401; NY) in duplicate using a kit (Spinreact, Spain).

2.5. Walking tests

Participants were asked 24 h pre-EE to walk barefoot across the 10 m long gait laboratory walkway within 5% of their SWS determined during the first-visit. A photocell system displayed their walking speed in real time. Trials were performed until at least five complete gait cycles were obtained with a clean foot landing on the force platform located in the middle of the walkway for both left and right sides. Walking trials were repeated in the fifth-visit, but this time participants were required to walk at two gait velocity conditions. During the first condition (COND1), they were instructed to walk at their own comfortable speed. During the second condition (COND2), they were required to maintain their SWS (±5%) recorded 24 h pre-EE to minimize the effect of walking speed on the data.

2.6. Data collection and analysis

Kinematic data were acquired using a 10-camera 3-D analysis system (Vicon-MX40+, UK), operating at 100 Hz. A force platform (Bertec 4060-10, OH) embedded in the laboratory floor captured GRFs at 1000 Hz synchronized with the kinematic data. Twenty-four reflective spherical markers were placed bilaterally over selected landmarks on the pelvis and lower extremities of each subject, according to the model described in a previous study