Gait & Posture 38 (2013) 62–67

Contents lists available at SciVerse ScienceDirect

Gait & Posture

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

Biomechanics of sit-to-stand transition after muscle damage

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ARTICLE INFO

Article history:
Received 21 February 2012
Received in revised form 16 October 2012
Accepted 23 October 2012

Keywords:
Muscle damage
Eccentric exercise
Sit-to-stand
Motion analysis

ABSTRACT

The purpose of the study was to examine the effects of exercise-induced muscle damage on the biomechanics of the sit-to-stand transition (STST). Seventeen volunteers participated in an intense, eccentric based, muscle damage protocol of knee flexors and extensors via an isokinetic dynamometer. Kinematic and kinetic data were collected using a 10-camera optoelectronic system and a force plate 24 h before and 48 h after exercise. Statistical analysis showed significant differences in kinematic and kinetic parameters after exercise. Forty-eight hours after exercise, the strategy did change and the knee joint relative effort level increased significantly. Pelvic and hip kinematics, in conjunction with the knee extension joint moment, provided an efficient mechanism to support the participants' locomotor system during the STST. These results may be of great significance in designing supportive devices, as well as composing rehabilitation programs for young or elderly individuals, with various musculoskeletal pathologies.

1. Introduction

The shift between the seated position and locomotion is usually referred to as the sit-to-stand transition (STST). STST involves an unstable movement from a static and stable position to a quasi-static position. This is thought to be one of the most mechanically demanding tasks performed during daily living. The challenges of STST are exemplified by the welfare issue of elderly people being unable to rise from a chair due to loss of muscle strength. The inability to perform the STST can lead to impaired functioning and mobility in activities of daily living [1].

Many researchers have investigated the mechanics of STST in healthy young and elderly people [2] as well as in various pathological cases such as stroke [3], Parkinson's disease [4], hemiplegia [5], obesity [6], osteorthritis and after hip–knee arthroplasty [7]. Moreover, other researchers have studied STST with loading on the back or weighted garments on lower limbs to understand strategy changes of the musculoskeletal system by artificially stressing the muscles [8,9].

Muscle damage is very common to those undergoing acute concentric or eccentric muscle contractions after long periods of inactivity. Generally, any unaccustomed exercise of high intensity or long duration can lead to muscle damage [10]. It is important to note that any exercise consisting of eccentric contractions induces muscle damage in all ages [11]. Elderly people are more vulnerable and can experience muscle damage even from mildly repetitive every day movements such as stair descent or lowering to a chair, which involves eccentric quadriceps and gluteus maximus action [12]. Muscle damage affects the peak joint torque; range of motion (ROM) and 48 h after activity it creates delayed onset muscle soreness (DOMS) accompanied by pain [10]. To date there is no research on the effects of muscle damage on the biomechanics of STST.

Although understanding of the above factors will certainly be helpful to improve function in activities of daily living, the key point for real independence is the load/capacity ratio. This ratio, referred to by some investigators as "relative effort" [13–16], is affected by the different demands of various movements (load) as well as the strength of the individual (capacity). The immediate changes in this ratio have only been investigated through increased loading (additional weights) on STST alone [8,9]. Capacity has been investigated only as a function of aging [13,15]. An increase in this ratio, resulting from a reduction in capacity, will challenge the locomotor system by making the movement more demanding [8]. Exercise-induced muscle damage alters this ratio by dramatically decreasing capacity [10,17] thus introducing stress to the locomotor system. Cross sectional studies have suggested that strength is the most important determinant for an unsuccessful STST [14,18]. Moreover, the limited strength of elderly people without any comorbidities lead them to perform activities of daily living closer to their maximum capability [13].

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0966-6362/$ – see front matter
http://dx.doi.org/10.1016/j.gaitpost.2012.10.013

Since the load/capacity ratio plays an important role on STST, the aim of our study was to investigate the subsequent (48 h) effects of reduced muscle strength (lower strength capacity) in a healthy population, introduced by muscle damage on the mechanics of STST. We hypothesized that lower strength capacity will lead to important changes in the strategy of STST.

2. Methods

2.1. Participants

Seventeen physically active women (23.1 ± 3 years; 165 ± 7 cm; 54.6 ± 5 kg), without any musculoskeletal injury or other pathology volunteered to participate in this study after signing an informed consent form approved by the University's ethics committee. Most of them were students in our sports science department, participating not more than three times per week in low- to moderate-intensity and short- to moderate-duration physical education classes and various recreational activities. This was confirmed by filling a questionnaire.

2.2. Time frame

All participants visited the laboratory six times within a one-week period. The first visit, 72 h before the eccentric protocol (Time −72 h) was dedicated to anthropometric measurements, isokinetic dynamometer familiarization and collection of baseline isometric peak torque data. Baseline kinematic data for the STST task were captured during the second visit, 24 h before the eccentric exercise protocol (Time −24 h). Eccentric exercise took place during the third visit (Time 0). Blood sampling, pre-exercise isometric average peak torque, and post eccentric exercise isometric average peak torque were also measured at Time 0. At the forth visit (Time 24 h), DOMS and isometric average peak torque were collected. Muscle damage symptoms peak 24–72 h post-exercise thus, post kinematic STST data, DOMS and isometric peak torque were collected during the fifth visit, 48 h after eccentric exercise (Time 48 h). Finally, at the sixth visit (Time 72 h) blood sampling, DOMS and isometric average peak torque were collected.

2.3. Isokinetic exercise protocol

A warm up protocol of 10 min, including cycling at 50 W (Monark, Sweden) and stretching of the major muscle groups of the lower limbs, was applied before isokinetic testing. Eccentric exercise was conducted on an isokinetic dynamometer (Cybex-Norm, Ronkonkoma, NY). Participants were securely seated at 100° hip flexion angle. The knee range of motion (ROM) was set at 0-100°. Gravitational correction at 45° was also performed. 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 [21]. Both legs were exercised randomly in two separate bouts with a 5-min recovery between them and a 3-min rest interval was given between each of the five sets.

2.4. Muscle damage indices and relative effort

Muscle damage indices included average isometric maximum torque at 70° and 30° of knee flexion, measurement of pain through DOMS using a visual analog scale ranging from 0 (no soreness) to 10 (extremely painful) and creatine kinase. These parameters are clearly described in a previous study [21].

The angle of 70° for maximum isometric knee extension was selected because it is very close to the angle of maximum torque during STST. The maximal knee joint extension moment during the STST was normalized to the maximum isometric knee extension creating a relative effort ratio for knee extensors.

2.5. Data collection

Pelvic and lower extremities kinematic and kinetic data were collected via, a 10 camera optoelectronic system (Vicon-T40, Oxford, UK), sampling at 100 Hz and a BERTEC (4060-15) forceplate sampling at 1000 Hz. A functional calibration model with twenty-four retro-reflective markers attached to the pelvis and lower extremities was employed. The position of the markers was marked with permanent pen (lasting 5–7 days) in order to decrease test–retest variability. In this model, the joint centers and axes of rotation are calculated in two stages: static and dynamic. In the static stage, the standard Davis model is used to define the initial position of joint centers and axes of rotation [22]. The subject is then asked to rotate the lower limb joints and the new positions are refined based on a mathematical optimization procedure. Kinetic data were normalized to body mass.

2.6. STST protocol and phases

Participants were asked to perform five STST tasks barefoot at self-selected speed. An armless and backless seat fixed at the standard height of 43 cm was used [9]. Feet were positioned at pelvic width and hands were crossed on the chest initially and throughout the STST task. Each subject's feet were placed on the ground with the ankles slightly dorsiflexed close to the neutral position.

STST was studied in three phases according to Seven et al. model. The first phase starts at the point that the force-plate signal appears to be twice the standard deviation over zero level to all three axes and ends at hip off. Hip off was set at the time when the vertical velocity of the hip joint had a positive value on the vertical axis. The end of the first phase up to maximal dorsiflexion defined the second phase. The third phase was set from maximum dorsiflexion until the subject balanced to a standing position. These three phases will be referred to as: Phase one: flexion-momentum phase, Phase two: momentum-transfer phase, Phase three: extension phase.

2.7. Statistics and data analysis

Paired *t*-tests between left and right side kinematic measurements showed no significant differences. Thus, the right side was used for analysis. The average of five trials per subject was used in data analysis. Paired *t*-tests were used to investigate the pre and 48 h after the exercise for all data. Two-way ANOVA (4 times $\times$ 2 muscle groups) was used to analyze DOMS and two-way ANOVA (5 times $\times$ 2 muscle groups) was used to analyze isometric average peak torque. Significant interactions and main effects were further investigated using Bonferroni post hoc analysis for multiple group comparisons. The level of significance was set to $p < 0.05$.

3. Results

3.1. Muscle damage indices

Table 1 shows that significant differences appeared in all muscle damage indices following eccentric exercise confirming that muscle damage did occur. DOMS increased and isometric average peak torque decreased ($p < 0.05$) at all-time points after muscle damage. Strength reduction of knee extensor muscles was significantly lower compared to flexors only 24 h after eccentric exercise. Serum CK activity was significantly elevated 72 h post exercise.