Gait & Posture 52 (2017) 15–21

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Muscle activation patterns of the lumbo-pelvic-hip complex during walking gait before and after exercise

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ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form 3 November 2016
Accepted 7 November 2016

Keywords:
Core
Fatigue
Performance

ABSTRACT

The lumbo-pelvic-hip core complex consists of musculoskeletal structures that stabilize the spine and pelvis, however fatigue may affect muscle recruitment, active muscle stiffness and trunk kinematics, compromising trunk stability. The purpose of this study was to compare trunk muscle activation patterns, and trunk and lower extremity kinematics during walking gait before and after exercise. Surface electrodes were placed over the rectus abdominis, external oblique, erector spinae, gluteus medius, vastus lateralis, and vastus medialis of twenty-five healthy inidviduals. Means and 95% confidence intervals for muscle amplitude, muscle onsent and kinematics for 0–100% of the gait cycle were compared before and after exercise. Mean differences (MD) and standard deviations were calculated for all significant differences. The amplitude increased in the rectus abdominis during loading (MD = 0.67 ± 0.11), midstance (MD = 0.75 ± 0.04), terminal stance (MD = 0.58 ± 0.04), and late swing (MD = 0.75 ± 0.07) after exercise. Amplitude also increased during swing phase in the erector spinae (MD = 0.92 ± 0.11), vastus lateralis (MD = 1.12 ± 0.30), and vastus medialis (MD = 1.80 ± 0.19) after exercise. There was less trunk and hip rotation from initial contact to midstance after exercise. Neuromuscular fatigue significantly influenced the activation patterns of superficial musculature and kinematics of the lumbo-pelvic-hip complex during walking. Increased muscle activation with decreased movement in a fatigued state may represent an effort to increase trunk stiffness to protect lumbo-pelvic-hip structures from overload.

1. Introduction

The lumbo-pelvic-hip complex, often defined as the "core," consists of musculoskeletal structures that are responsible for stabilizing the spine and pelvis as well as facilitating the movements of distal limbs [1]. Optimal function of lumbo-pelvic-hip muscles have been thought to enhance trunk stability and muscle coordination and, in theory, reduce risk of injury [2,3]. Core stability research often focuses on the function of deep local stabilizing muscles, such as the transverse abdominis and multifidus, however, the role of the more superficial global movers such as the rectus abdominis, external obliques, and erector spinae are less studied. These superficial muscles contribute to trunk stability [4], often activating before limb movement [5,6]. Although stability has many definitions in exercise science, stability in this context is defined as the ability to maintain equilibrium of the lumbo-pelvic-hip complex despite the presence of kinematic or motor-control disturbances [7]. Stability of the lumbo-pelvic-hip complex is an important consideration because it is largely related with injury prevention, by transferring force from the lower extremities to the pelvis and spine [8,9] and stabilizing the pelvis during activities [3].

Trunk and abdominal strength of the superficial musculature is compromised in patients with low back pain. These patients often demonstrate increased muscle activation in the rectus abdominis, erector spinae, and external oblique and decreased variability of trunk rotation during activities of daily living such as standing and walking [10–12]. Despite these muscular and biomechanical alterations to increase trunk stiffness, which contributes to trunk stability and is defined by increased antagonistic muscle recruitment [13], patients with low back pain are often encouraged to engage in more physical activity to decrease pain [14,15]. However, stability of the lumbo-pelvic-hip complex may be further compromised when these superficial muscles become fatigued.

Neuromuscular fatigue results in physiological changes at both central and peripheral levels, and is often defined as a decreased force output, which leads to a temporal delay in the onset of

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http://dx.doi.org/10.1016/j.gaitpost.2016.11.016
0966-6362/

muscle activity and altered muscle activation patterns [16–18]. Isolated muscular fatigue, such as fatiguing a certain muscle or muscle group, adversely changes muscular strength, postural control, and quality of movement in the lumbo-pelvic-hip complex [19–22]. Fatigue also affects motor control and coordination in healthy and pathologic populations, and is often associated with increased stiffness and a constrained neuromusculoskeletal system to reduce degrees of freedom [23–25]. The acute effects of exercise on the global movers of the lumbo-pelvic hip complex and lower extremity musculature are unclear.

Therefore, the purpose of the study was to compare trunk and lower extremity joint kinematics and muscle activation patterns and onset of the rectus abdominis, external oblique, erector spinae, gluteus medius, vastus lateralis, and vastus medialis during walking gait in healthy individuals before and after fatiguing exercise. We hypothesized that muscle amplitude would increase after exercise and there would be delayed activation during gait. We also hypothesized that there would be decreased kinematic movement after fatiguing exercise.

2. Methods

2.1. Design

This was a descriptive laboratory study using a repeated measures design. The independent variable was time (pre and post-fatiguing exercise). The dependent variables were the amplitudes of muscle activation over the entire gait cycle, the time of onset activation for the rectus abdominis, external oblique, erector spinae, gluteus medius, vastus lateralis, and vastus medialis, and trunk and lower extremity kinematics.

2.2. Subjects

Twenty-five recreationally active individuals (16 female, 9 male, 20.0 ± 1.7 years, 171.0 ± 10.0 cm, 69.0 ± 13.1 kg) without history of lower extremity, abdominal, or trunk injury or surgery volunteered to participate in this study. All subjects provided written informed consent approved by the university's institutional review board for health sciences research.

2.3. Instrumentation

A wireless electromyography (EMG) system (Trigno Sensor System, Delysis Inc., Natick, MA, USA: interelectrode distance = 10 mm, 80 dB common mode rejection rate) was used to capture muscle activity of rectus abdominis, external oblique, erector spinae, gluteus medius, vastus lateralis, and vastus medialis. EMG data were sampled at 2000 Hz.

A 12-camera motion capture system (Vicon Motion Systems, Inc., Lake Forest, CA, USA) was used during collection. Kinematic data were sampled at 250 Hz. Ground reaction forces were collected using an instrumented treadmill (Bertec, Columbus, OH, USA) and sampled at 1000 Hz. All data were synchronized and exported using MotionMonitor software (Innovative Sports Training, Chicago, IL). A heart rate monitor (Polar T31 Transmitter, Polar Electro Inc., Lake Success, NY) was fitted below the pectoral muscles against the skin.

2.4. Procedures

Subjects reported to the laboratory for a single session wearing athletic shoes and athletic clothing. EMG electrodes were placed over the muscles of interest on the subject's dominant side. Dominant side was defined as the subject's preferred kicking leg. The skin was shaved, debrided, and cleaned with alcohol in preparation for EMG placement. The electrode for the rectus abdominis was placed 3 cm lateral to the navel [26]. The electrode for the external oblique was placed lateral to the rectus abdominis above the anterior superior iliac spine, halfway between the iliac crest and the ribs [26]. The electrode for the erector spinae was placed 3 cm, 2 finger width lateral to the spinous process of L1 [27]. The gluteus medius electrode was placed halfway between the iliac crest and the greater trochanter [21]. The electrodes for the vastus lateralis and medialis were placed on the distal third of the muscle belly [27]. Each EMG sensor was affixed directly to the skin using adhesives and tape to stay in place throughout the testing session. Eight clusters of retroreflective markers were attached to upper back, sacrum, bilaterally over the lateral mid thigh, lateral mid calf, and forefoot (Fig. 1) for the entire collection. The medial and lateral malleoli, medial and lateral knee joint lines, L5/S1, T12, C7/T1, and the right and left anterior superior iliac spine were digitized to identify joint centers.

Subjects walked on the treadmill at 1.3 m/s to acclimate to the treadmill and testing materials. Pre-exercise data were recorded for 20 s once the subject was comfortable. The exercise protocol consisted of six series each consisting of five minutes of treadmill walking at 1.3 m/s and one minute of 10 jump squats and 10 alternating lateral hops [28]. During walking phases, the treadmill incline increased by 1%/min and stopped increasing when the treadmill reached a 15% incline. During the final 30 s of each bout of walking, the participants were asked to rate their level of perceived exertion (RPE) using the Borg Scale [29] and heart rate (bpm) was recorded. Immediately after exercise completion, subjects walked on the treadmill at 1.3 m/s for 20 s for post-exercise data collection.

2.5. Data processing

The raw EMG data were filtered and exported using Motion-Monitor software, with a bandpass filter (10–500 Hz), a 60 Hz notch filer and 50 ms window, moving average, root mean square algorithm. EMG data were normalized to quiet standing. Kinematic and EMG data were reduced to 101 data points representing 0–100% (heel strike to ipsilateral heel strike) of the gait cycle. The stance phase of the gait cycle was defined as 0–60% of the gait cycle, whereas 61–100% was defined as the swing phase of gait [30]. Heel strike was defined as the point when vertical ground reaction forces were greater than 20 N. Eight consecutive strides were extracted before and after exercise for each individual.

The onset of muscle activation was calculated for each subject before and after exercise using the following threshold formula [31].

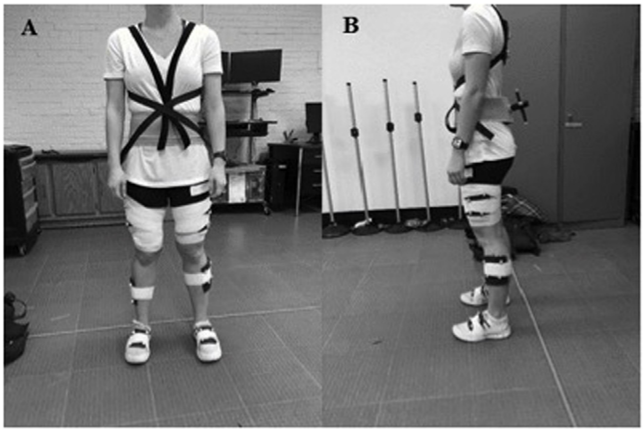

Fig. 1. Frontal view (A) and sagittal view (B) of the eight cluster sets attached to the upper back, sacrum, thighs, calves, and feet.