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Biomechanical adaptations during running differ based on type of exercise and fitness level

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ABSTRACT

Lower extremity injuries are most common in more active and fit individuals, suggesting that adaptations from neuromuscular fatigue may differ depending on type of exercise and fitness level. The purpose of this study was to compare changes in gait in highly fit and recreationally active individuals before and after two exercise protocols. Lower extremity kinematics and kinetics were measured on the dominant leg during running before and after two exercise protocols (walking/sport) from 0 to 100% of gait in 24 healthy individuals divided into higher ($n = 13$) and lower fitness ($n = 11$) groups. Change scores were calculated for each point of the gait cycle with 95% confidence intervals. There were no differences between groups in knee or hip kinematics and kinetics in response to the walking exercise protocol, however the higher fit group increased trunk extension and the lower fit group increased trunk lateral flexion after walking exercise. After the sport exercise, the higher fit group increased knee extension, knee valgus, trunk extension, knee flexion moment, knee varus moment, knee abduction moment, knee internal rotation moment, and hip flexion moment compared to the lower fit group. The lower fit group increased hip extension, hip abduction, hip internal rotation, trunk lateral flexion, trunk rotation, and knee external rotation moment compared the higher fit group after sport exercise. Greater between group differences were found with sport exercise compared to walking exercise. It is important to consider type of exercise and fitness level when assessing altered movement patterns in response to fatiguing exercise.

1. Introduction

Over 80% of musculoskeletal injuries are from participation in recreational physical activity or sport, with injuries to the lower extremity accounting for 60% of all musculoskeletal injuries [1]. Neuromuscular fatigue has been theorized as a contributing factor associated with lower extremity musculoskeletal injury in athletes because injuries are most common at the end of games [2]. In order to better understand the neuromuscular effects of fatigue, often defined as a decline in force or power production [3], the effects of exercise on movement patterns during functional tasks has been well-studied, however exercise protocols used to induce fatigue vary widely.

Several laboratory-based exercise protocols exist, most often inducing fatigue using controlled and isolated repetitive movements until task failure [4]. There is some advantage to isolating muscle fatigue with controlled, uni-planar exercises, however overall generalization to sport environment is limited [4]. Other exercise protocols utilize a combination of anaerobic exercises, such as squat jumps and short sprints, or single leg landings and squats [5]. These protocols result in fatigue using exercises that simulate movements experienced during sport and activity, however do not incorporate the aerobic component of prolonged sport participation. Graded treadmill exercise has been used to test cardiopulmonary fitness [6] and is commonly used to induce neuromuscular fatigue due to the fatiguing aerobic component [7].

Although this exercise may induce fatigue, it does not stimulate the demands of sport. In college soccer, for example, walking only makes up approximately 15–20% of games [8] and most lower extremity injuries occur during high-speed movements [9], suggesting that exercise protocols including high-speed activities and simulate the demands of sport may be best suited for assessing fatigue-related adaptations that are more generalizable to highly active athletes participating in prolonged and intense sport environments.

Along with type of exercise, demands of exercise required to illicit

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fatigue may differ based on fitness level. Current research investigating the influence of neuromuscular fatigue often group all participants together, assuming that all individuals respond similarly to fatiguing exercise, however injuries to the lower extremity are most common in more fit and physically active individuals [1], with injury risk increasing for high-level athletes [10]. High level athletes have increased strength compared to recreational athletes [11], and may require different sport-specific demands to evaluate fatigue-related biomechanical adaptations that may increase injury risk in more fit athletes [1,12]. Therefore, the purpose of this study was to compare changes in running gait before and after walking exercise and sport-specific exercise between different fitness levels.

2. Methods

2.1. Design

This was a descriptive laboratory study with a repeated measures design. The independent variable in this study was fitness level (2 levels: higher fit and lower fit). The dependent variables included pre-post change in sagittal, frontal, and transverse plane knee, hip, and trunk kinematics and internal knee and hip moments.

2.2. Subjects

Twenty-four individuals (15F/9M, 19.7 ± 0.9 yrs, 172.8 ± 9.1 cm, 70.5 ± 10.2 kg) without history of lower extremity or trunk surgery or lower extremity or trunk injury within the previous 12 months volunteered to participate in this study. Subjects were divided based on fitness level into a higher fit and lower fit group based on the group median for maximal oxygen uptake during aerobic exercise (Table 1). All subjects provided written informed consent approved by the university's institutional review board for health sciences research (IRB-HSR #18468).

2.3. Instrumentation

Maximal oxygen uptake (VO_2max) was collected using a metabolic cart (Vmax Encore Metabolic Cart, Becton, Dickinson and Company, Franklin Lakes, NJ). Flow, volume, and gas concentrations were calibrated before each test. A heart rate monitor (Polar T31 Transmitter, Polar Electro Inc., Lake Success, NY) was fitted below the pectoral muscles during metabolic testing and the exercise protocols. A 6–20 Borg Scale was used for rating of perceived exertion (RPE) during metabolic testing and both exercise protocols [13]. A 12-camera motion capture system (Vicon Motion Systems, Ltd, UK) and a split-belt instrumented treadmill (Bertec, Columbus, OH) were used to collect kinematic and kinetic data. Kinematic data were sampled at 250 Hz and ground reaction forces were sampled at 1000 Hz. Data were synchronized, exported, and filtered using a zero-lag fourth-order Butterworth filter at 14.5 Hz using MotionMonitor software (Innovative Sports Training, Inc., Chicago, IL) [14]. Kinematic and kinetic data were calculated in MotionMonitor. The FITLIGHT Trainer™ reactive light system (FITLIGHT Sports Corp., Aurora, Ontario) was used during the exercise session.

Table 1
Subject demographics for higher fit and lower fit groups with standard deviations.

	High Fit (N = 13)	Low Fit (N = 11)
Sex (M/F)	(6M/7F)	(3M/8F)
Age (yrs)	19.8 (0.9)	19.5 (0.9)
Height (cm)	174.3 (11.1)	171.1 (6.1)
Mass (kg)	70.9 (9.9)	70.0 (11.0)
Godin Leisure-Time	127.6 (48.1)	112.8 (27.9)
Marx Activity	11.3 (4.1)	8.8 (5.2)
Maximum Heart Rate (bpm)	186.2 (11.2)	184.0 (13.4)
VO2max (mL/kg/min)	56.1 (4.7)	46.6 (2.9)

2.4. Procedures

Subjects reported to the laboratory for three sessions separated by at least 48 h. All subjects completed the Godin Leisure-Time Exercise Questionnaire [15] and the Marx Activity Scale [16]. The first session included an incremental treadmill test to determine VO_2max. The second and third sessions included assessment of running biomechanics before and after 30 min of exercise and in counterbalanced order.

2.5. VO_2max testing

Initial treadmill velocity was a comfortable running velocity for each subject and velocity was increased by 0.22 m/s (0.5 mph) every 2 min (the duration of each stage) until volitional fatigue. Heart rate and RPE were recorded at the end of every stage and volitional fatigue. VO_2max data were averaged every 60 s and normalized to mass. The highest mL/kg/min value was recorded as the subject's VO_2max and was confirmed based on either a respiratory exchange ratio greater than 1.15 or RPE $\geq$ 17 [17].

2.6. Gait analysis

Subjects wore their own athletic shoes appropriate for running, shorts, and a t-shirt. Eight clusters of retro-reflective markers were attached to the thorax, sacrum, bilaterally over the lateral mid-thigh, lateral mid-calf, and forefoot for the entire collection [18]. The medial and lateral malleoli, medial and lateral knee joint lines, L5, T12, C7, and bilateral anterior superior iliac spine were digitized to identify joint centers. Subjects walked and ran on the treadmill for five minutes to acclimate to the environment. Twelve capture periods of two-seconds each were collected for each subject during running at 3.33 m/s (7.5 mph) before and after exercise. The two-second capture periods were used to increase the number of included strides in analyses and randomize stride selection during the run.

2.7. Exercise protocols

The walking exercise session included five repeated cycles of treadmill walking at 1.34 m/s (3.0 mph) for 5 min immediately followed by 1 min of jumping exercises (repeated bouts of 10 squat jumps and 10 lateral hops). The treadmill incline increased by 0.5°/min during walking phases and stopped increasing at 8.5° (15%) incline (Fig. 1). The sport exercise session included five repeated cycles of treadmill walk, jog, and run intervals and one minute of agility exercises using a reactive light system. Each 5-min treadmill interval included 15-s of walking at 1.34 m/s (3.0 mph), 25-s of jogging at 2.68 m/s (6.0 mph), and 20-s of running at 3.33 m/s (7.5 mph). The velocities and durations of intervals were designed based on GPS data collected from a men's collegiate soccer team during matches over an entire season [8] to mimic a sport environment. Eight reactive lights were set up in a semicircle, each positioned 3.5 m from the subject and illuminated in a random order. The subject was instructed to run to touch the illuminated light as quickly as possible and backpedal to the starting position when another light illuminated (Fig. 2). Subjects were instructed to touch as many lights as possible in one minute and encouragement was provided to ensure maximal effort. Heart rate and RPE were recorded during the final 15 s of each treadmill bout for both exercise protocols and immediately after exercise completion.

2.8. Data processing and statistical analyses

Kinematic data were reduced to 101 points to represent 0–100% of the gait cycle (heel strike to ipsilateral heel strike). Heel strike was