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The effect of lower extremity fatigue on shock attenuation during single-leg landing

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Abstract

Background. The forces that are imposed on the body due to landings must be attenuated primarily in the lower extremity. Muscles assist in the absorption of these forces, and it has been shown that a fatigued muscle decreases the body's ability to attenuate shock from running. The purpose of the study was to determine the effect of lower extremity fatigue on shock attenuation and joint mechanics during a single-leg drop landing.

Methods. Ten active male participants were recruited (eight used for analysis). Each participant took part in a fatigue landing protocol. This protocol included cycles of a drop landing, a maximal countermovement jump, and five squats, repeated until exhaustion. Accelerometers attached to the skin measured tibia and head accelerations. Lower extremity kinematics were collected using an electromagnetic tracking system and kinetics were collected using a forceplate. A repeated-measures ANOVA ($P < 0.05$) was performed on each of the dependent variables across the cycles of the fatigue protocol.

Findings. Fatigue was induced, however there was no significant change in shock attenuation throughout the body. Hip and knee flexion increased and ankle plantarflexion decreased at touchdown with fatigue. Hip joint work increased and ankle work decreased.

Interpretation. This change in work distribution is thought to be a compensatory response to utilize the larger hip extensors that are better suited to absorb the mechanical energy of the impact. The results suggested that the lower extremity is able to adapt to fatigue though altering kinematics at impact and redistributing work to larger proximal muscles.

Keywords: Joint kinetics; Muscle; Injury; Energy

1. Introduction

Mechanical shock during landing from a height must be attenuated by the musculoskeletal system, and when the external loads become too great for the body to adequately attenuate, the probability of injury increases (Dufek and Bates, 1990). Injuries due to landings are prevalent in sports such as basketball, netball, volleyball, football, gymnastics and aerobic dance (Dufek et al., 1991). In animal studies it has been shown that impulsively loading the knee joints for short daily intervals over the space of only a few weeks caused changes in knee joints consistent with those of joint degeneration (Radin et al., 1973; Simon and Radin, 1972). Similar trabecular microfractures are also thought to propagate in humans whose lower extremities are subjected to continual sub-maximal loading. It has also been observed in a study of sheep that prolonged walking on hard surfaces caused significant degenerative changes to occur in joint structures and cartilage (Radin et al., 1982). Microfractures, medial tibial stress syndrome, spinal injuries and other degenerative changes in joint and articular cartilage in humans also have been suggested to be significantly influenced by the body's ability to attenuate the associated shock from continual impacts (Light et al., 1980; McMahon et al., 1987).

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The shock experienced by the body due to landings must be attenuated by several structures and mechanisms in the body including bone, synovial fluids, cartilage, soft tissues, joint kinematics and muscular activity (Lafortune et al., 1996b; Nyland et al., 1994). Passively, shock attenuation is achieved by soft tissues and bone. Actively, shock attenuation is achieved through eccentric muscle action. This active mechanism is thought to be far more significant than the passive mechanism in attenuating shock (Mizrahi and Susak, 1982). Since muscles are thought to play a primary role in energy and shock absorption during landing, it has been hypothesized that reduced muscular function, through fatigue, decreases the shock absorbing capacity of the body and subsequently can lead to an increased chance of injury (Radin, 1986;Verbitsky et al., 1998; Voloshin et al., 1998). Fatigue has been defined as 'any reduction in the force generating capacity of the total neuromuscular system regardless of the force required in any given situation' (Bigland-Ritchie and Woods, 1984). In studies of running it has been shown that the human musculoskeletal system becomes less capable of handling heel strike-induced shock waves when the muscles are significantly fatigued. Several studies have reported significant decreases in shock attenuation with fatigue during running (Derrick et al., 2002; Mercer et al., 2003; Verbitsky et al., 1998; Voloshin et al., 1998). These studies concluded that there is a relationship between fatigue and increased heel strike-induced shock waves. It is thought that a fatigued muscle will be less able to protect the body effectively from impact forces and thus the body will be predisposed to overuse impact-related injuries. This loss in protection may be due to a variety of changes that occur with fatigue, including both central (neural drive) and peripheral (contractile machinery) mechanisms.

Previous landing protocols that have investigated joint mechanics and shock attenuation have generally used a two-legged landing paradigm. These studies have found that while the hip generally has the greatest joint moment and power during two-legged landings, the knee has the greatest joint excursion and performs the greatest amount of work (Decker et al., 2003; DeVita and Skelly, 1992; Zhang et al., 2000). Decker et al. (2003), for instance, reported for their male participants ranges of motion of 50°, 63°, and 41.6° for the hip, knee, and ankle respectively, and the associated work contributions were 30%, 41%, and 29%. In contrast, Madigan and Pidcoe (2003) reported that hip and knee joint ranges of motion that were smaller for single-leg landings (hip = 10°, knee = 34°), but displayed greater ankle motion (55°). While the majority of studies have utilized a two-legged landing, many of the activities that these data are compared against (running, cutting, landing during play) occur on a single leg. Based on the relative lack of data regarding single-leg landings, it is unclear how the joints of the lower extremity act to absorb landings. Single-leg landings may be far stiffer and the distribution of work may be different. It may not simply be a case of scaling of the two-legged landing mechanics.

Previous studies reporting shock attenuation did not relate the ability of the musculoskeletal system to attenuate shock to specific joint kinematic or kinetic adaptations. This is particularly relevant with the onset of fatigue, because the discrepancies in the literature regarding the effect of fatigue on shock attenuation may be related to compensatory changes in joint mechanics. Therefore, the purpose of this study was to determine the effect of lower extremity fatigue on shock attenuation, and assess how joint mechanics relate to shock attenuation during a single-leg drop landing. It was hypothesized that lower extremity fatigue would cause a decrease in the shock attenuation capacity of the musculoskeletal system in addition to altering joint mechanics as compared to a non-fatigued state during a drop landing.

2. Methods

Ten male participants were recruited from a mid-western US college population which was determined to be sufficient based on a sample size estimation calculated for shock parameters. However, data for two subjects were later excluded due to technical difficulties. The age, mass, and height of the remaining eight subjects were 23.8 (SD 2.4) years, 81.6 (SD 6.8) kg, and 1.84 (SD 0.07) m, respectively. All participants had feet within size ranges 9–12 in order to fit into the standard running shoes (Saucony Jazz Original) worn for the study. Participants were physically active for at least 30 min, most days of the week and had no history of lower extremity injury in the previous 6 months leading up to the testing. All participants signed a written informed consent in accordance with university regulations.

During the initial practice session an OR6-5 force platform (AMTI, Watertown, MA, USA) was used to record ground reaction forces (GRF's) for a series of jumps. These data were collected at 1000 Hz. For the data collection session, GRF's were obtained from a non-conducting force platform (Type 4060-NC, Bertec Corporation, Columbus, OH, USA). Accelerations of the tibia (distal anteromedial aspect) and forehead (frontal bone) were captured using two light-weight (1.7 g) quartz shear piezoelectric accelerometers (model 353B17, PCB Piezoelectronics, Inc., Depew, NY, USA). A MotionMonitor electromagnetic tracking system (version 4.10, Innovative Sports Training, Inc., Chicago, IL, USA) was used to capture kinematic data from the landing leg. Three-dimensional position and rotation sensor data were sampled at a rate of 100 Hz, and all analog data (accelerometer and force platform data) were recorded synchronously at 1000 Hz.

During the practice session subjects were asked to perform a series of jumps on a force plate. Three two-leg and three single-leg (for each leg) maximum effort countermovement jumps (CMJ) were collected. Jump height for each jump was calculated by utilizing the takeoff velocity determined from the net impulse (Luhtanen and Komi, 1978), and the average power output was based on the