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Soldier-relevant loads impact lower limb biomechanics during anticipated and unanticipated single-leg cutting movements

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ABSTRACT

This study quantified how body borne load impacts hip and knee biomechanics during anticipated and unanticipated single-leg cutting maneuvers. Fifteen male military personnel performed a series of single-leg cutting maneuvers with three different load configurations (light, ~6 kg, medium, ~20 kg, and heavy, ~40 kg). Subject-based means of the specific lower limb biomechanical variables were submitted to repeated measures ANOVA to test the main and interaction effects of body borne load and movement type. With body borne load, stance time ($P<0.001$) increased, while larger hip ($P=0.027$) and knee flexion ($P=0.004$), and hip adduction ($P<0.001$) moments, and decreased hip ($P=0.002$) and knee flexion ($P<0.001$), and hip adduction ($P=0.003$) postures were evident. Further, the hip ($P<0.001$) and ankle ($P=0.024$) increased energy absorption, while the knee ($P=0.020$) increased energy generation with body borne load. During the unanticipated maneuvers, the hip ($P=0.009$) and knee ($P=0.032$) increased energy generation, and peak hip flexion moment ($P=0.002$) increased relative to the anticipated movements. With the body borne load, participants adopted biomechanical patterns that decreased their locomotive ability including larger moments and reduced flexion postures of the lower limb. During the single-leg cut, participants used greater energy absorption from the large, proximal muscles of the hip and greater energy generation from the knee with the addition of load. Participant's performance when carrying a range of loads was not compromised by anticipation, as they did not exhibit the hip and knee kinetic and kinematic adaptations previously demonstrated when reacting to an unplanned stimulus.

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1. Introduction

Locomotive ability – capacity to walk, run and cut – is related to both the time spent in stance (Weyand et al., 2000) and capability of the musculoskeletal system to support the body during that period (Miller et al., 2012). During military activities, soldiers rely on their musculoskeletal system to support their body and additional body borne load during locomotion. For soldiers, body borne loads can start at 20 kg and may exceed 45 kg during dismounted operations (Task Force Devil Combined Arms Assessment Team, 2003). Heavy loads, however, are detrimental to soldiers' physical performance, decreasing their ability to walk, run and cut (Harman et al., 2008), and may stem from increased hip and knee flexion posture (Majumdar and Pal, 2010; Simpson et al., 2012) during locomotion. While hip and knee flexion help maintain stability (Kinoshita, 1985), the flexed posture may attenuate the elevated ground reaction forces (Birrell et al., 2007) and lower limb joint moments (Quesada et al., 2000) exhibited during load carriage. As a result of the altered hip and knee biomechanical profiles, soldiers increase stance time (Birrell and Haslam, 2009), an adaptation that restricts their locomotive ability. Maintaining locomotive ability is important to the soldier because the battlefield requires highly mobile troops, and any reduction in the capacity to walk, run and cut can decrease their survivability.

To successfully execute a dynamic movement, such as a single-leg cut, lower limb musculature must generate and absorb energy to accelerate, decelerate, and/or change the direction the center of mass is moving. Experimental evidence suggests that energy production of the lower limb does not change during unloaded (Farris and Sawicki, 2012) or loaded (Brown et al., 2014) steady-state locomotion, as neither potential nor kinetic energy change

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from step to step. However, dynamic tasks that involve a change of kinetic energy require a substantial increase in lower limb joint power (Van Caekenberghe et al., 2013). Dynamic movements with body borne load may require large modifications in joint power and the lower limb biomechanical profile to successfully redirect the center of mass, potentially further decreasing locomotive ability.

Dynamic, single-leg cutting maneuvers exhibit substantial modifications in the lower limb biomechanical profile (Besier et al., 2001b; Malinzak et al., 2001; McLean et al., 1998). When performing a single-leg cut, participants use significantly greater knee joint motions (McLean et al., 1998), and exhibit large frontal and transverse plane knee joint loads (Besier et al., 2001b). Because these kinematic and kinetic adaptations are consistent with mechanisms proposed to increase knee joint loading (McLean et al., 2005), researchers have extensively studied the effect sex (Malinzak et al., 2001; Pollard et al., 2004), technique (Dempsey et al., 2007) and cutting angle (Imwalle et al., 2009) have on lower limb biomechanics, particularly at the hip and knee. To date, however, it is not understood how body borne load impacts hip and knee biomechanical profiles during single-leg cutting.

Single-leg cutting maneuvers are further altered when an individual has to perform an unanticipated movement, such as reacting to an external, unplanned stimulus (Besier et al., 2001a; Borotikar et al., 2008; Brown et al., 2009). Previous researchers found unanticipated movements result in a significant reduction in hip flexion posture (Brown et al., 2009) and larger frontal plane hip and knee motions and loads (Besier et al., 2001a; Borotikar et al., 2008; Brown et al., 2009; Landry et al., 2007; McLean and Samorezov, 2009), as compared to anticipated movements. Besier et al. (2001a) found lower limb joint loads during unanticipated movements were up two times greater than during similar anticipated maneuvers. Elevated joint loads, particularly large frontal plane hip and knee moments, are thought to be a hazardous biomechanical response (Besier et al., 2003), which adversely affect joint stabilization, increasing strain on the musculoskeletal system, and decrease locomotive ability (Borotikar et al., 2008). Currently, however, it is unclear if body borne load further compromises the ability to perform an unanticipated single-leg cut. Therefore, the purpose of the study was to quantify how body borne load impacts hip and knee biomechanics during anticipated and unanticipated single-leg cutting maneuvers. We hypothesized that body borne load would increase hip and knee flexion motions and loads, and increase energy generation and absorption of the lower limb. We also hypothesized that during the unanticipated movements, greater frontal plane hip and knee joint motions and loads, and lower limb energy generation and absorption would be present compared to the anticipated maneuvers; and the hip and knee adaptations of unanticipated maneuvers would substantially increase with addition of body borne load.

2. Methods

An a priori power analysis of unanticipated maneuvers suggests 13 participants are needed to achieve 80% statistical power with alpha level of 0.05 (Borotikar et al., 2008). Fifteen male (age: 20.9 ± 3.1 yrs, height: 1.8 ± 0.1 m and mass: 75.6 ± 11.6 kg) military personnel who self-reported the ability to safely carry loads up to $\sim$43 kg were recruited to participate. Those who reported: current pain or recent injury to the back or lower extremity (previous 6 months), history of back or lower extremity injury or surgery, and/or any known neurological disorder were excluded from participation. Prior to testing, all participants gave written consent and research approval was obtained from the local institutional review board.

Participants completed three test sessions. A different soldier-relevant body borne load configuration (light, medium, or heavy) was tested at each session (Fig. 1A–C). For the light configuration ($\sim$6 kg), participants wore a helmet and carried a mock rifle. For the medium configuration ($\sim$20 kg), participants wore body armor with a fabric ammo panel attached on the anterior abdomen in addition to the light load. For the heavy configuration ($\sim$40 kg), participants wore a military backpack in addition to the medium load. The testing sequence for the body borne load configurations was randomly assigned to each participant from a 3×3 Latin Square, prior to beginning the study.

During each test session, participants performed a series of dynamic maneuvers, while synchronous three-dimensional (3D) joint (hip, knee and ankle) kinematic and kinetic data were recorded. For all trials, a force platform (AMTI Optima, Advanced

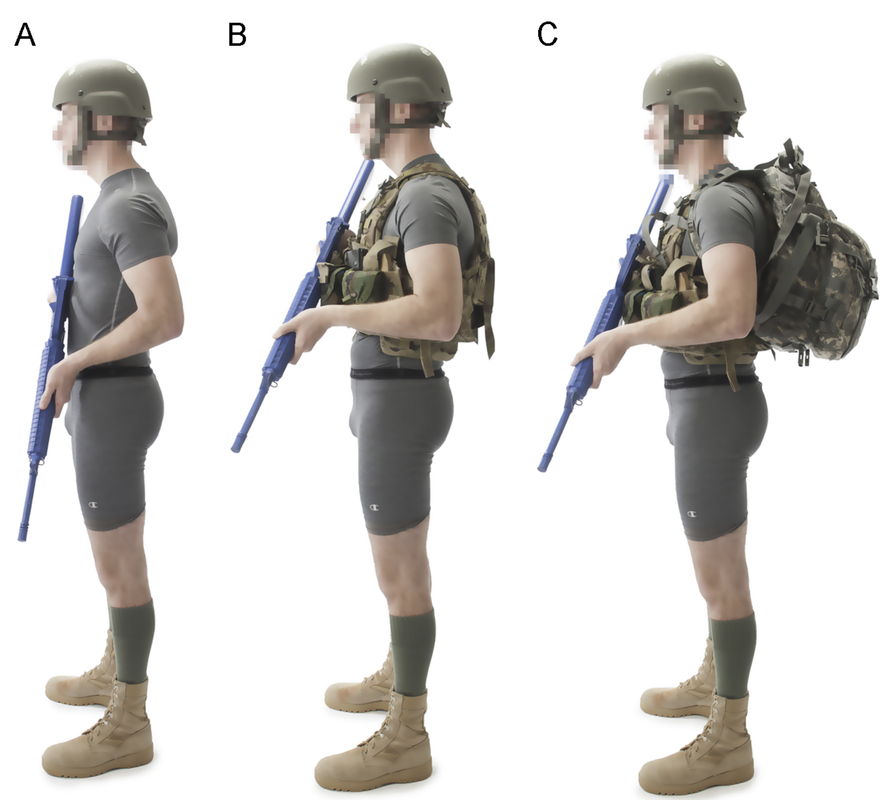

Fig. 1. Equipment for the light (A), medium (B), and heavy (C) body borne load configurations are presented.