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Lower limb flexion posture relates to energy absorption during drop landings with soldier-relevant body borne loads

T.N. Brown [a, b, *], M. O'Donovan [b], L. Hasselquist [b], B. Corner [b], J.M. Schiffman [b, c]

[a] Oak Ridge Institute for Science and Education (ORISE), Belcamp, MD, USA
[b] U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, USA
[c] Liberty Mutual Research Institute for Safety, Hopkinton, MA, USA

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ABSTRACT

Fifteen military personnel performed 30-cm drop landings to quantify how body borne load (light, ~6 kg, medium, ~20 kg, and heavy, ~40 kg) impacts lower limb kinematics and knee joint energy absorption during landing, and determine whether greater lower limb flexion increases energy absorption while landing with load. Participants decreased peak hip ($P = 0.002$), and knee flexion ($P = 0.007$) posture, but did not increase hip ($P = 0.796$), knee ($P = 0.427$) or ankle ($P = 0.161$) energy absorption, despite exhibiting greater peak hip ($P = 0.003$) and knee ($P = 0.001$) flexion, and ankle ($P = 0.003$) dorsiflexion angular impulse when landing with additional load. Yet, when landing with the light and medium loads, greater hip ($R^2 = 0.500$, $P = 0.003$ and $R^2 = 0.314$, $P = 0.030$) and knee ($R^2 = 0.431$, $P = 0.008$ and $R^2 = 0.342$, $P = 0.022$) flexion posture predicted larger knee joint energy absorption. Thus, military training that promotes hip and knee flexion, and subsequently greater energy absorption during landing, may potentially reduce risk of musculoskeletal injury and optimize soldier performance.

1. Introduction

Musculoskeletal injury is a serious military issue (Kaufman et al., 2000) that often leaves soldiers medically unable to perform their duties (Jones et al., 2010). Besides the detrimental short-term impact on soldiers' health, musculoskeletal injuries have a high prevalence of reoccurrence (Hauret et al., 2001), which increasingly result in long-term disability and discharge from the military (Gilchrist et al., 2000). Most musculoskeletal conditions, such as soft-tissue or bony disorders, are training-related overuse injuries (Jones et al., 2010) that result from the cumulative effects of repetitive sub-maximal loads that impact the body during physical activity (Hauret et al., 2010). The military is particularly interested in musculoskeletal injury because physical training with body borne loads – such as basic or advanced military training – has been suggested to further elevate the risk of sustaining these injuries (Knapik et al., 2011; Jones et al., 1994). In fact, during military training activities, 82% of musculoskeletal-based disabilities occur in the lower extremity (Almeida et al., 1999), with a majority at the knee joint (Kaufman et al., 2000; Hauret et al., 2010; Shaffer et al., 1999). Knee injuries, such as soft-tissue sprain, strain or rupture, reportedly occur during landing and pivoting maneuvers (Olsen et al., 2004), the same movements that are prevalent during a variety of military training activities (Johnson, 2003). Thus, military training may lead to musculoskeletal injury leaving soldiers unable to perform their duty.

During landing without body borne loads, the human body typically experiences ground reaction forces between two and five times body weight (Zhang et al., 2000), but can reach 14 times body weight (Panzer et al., 1987), and vary depending on landing height (Fathallah and Cotnam, 2000; McNitt-Gray, 1993) or demand (Dempsey et al., 2014). During drop landings with a light body borne load (10% and 18% of body weight, respectively), there is a significant increase in maximal vertical ground reaction force and demand placed on the musculoskeletal system (Sell et al., 2010; Kulas et al., 2008). However, to date, little is known about how the body borne loads, between 20 kg and 40 kg, that soldiers commonly carry during military activities increase the ground reaction force and demand place on the musculoskeletal system

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* Corresponding author. Natick Soldier RD & E Center, Department of Army, 15 Kansas St, Natick, MA 01760, USA.
E-mail address: tyler.n.brown4.civ@mail.mil (T.N. Brown).

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during drop landings (Task Force Devil Combined Arms Assessment Team, 2003).

To prevent musculoskeletal injury of the knee during these drop landings, the neuromuscular system must safely dissipate the loading of the passive tissues (Devita and Skelly, 1992) surrounding the joint by actively absorbing the kinetic energy of landing with eccentric contractions of the hip, knee and ankle musculature (Mizrahi and Susak, 1982). While the knee joint and associated musculature are the major contributors to energy absorption during landing (Zhang et al., 2000; Decker et al., 2003), their contributions can be influenced by a variety of factors. Energy absorption during landing is substantially impacted by gender (Schmitz et al., 2007), landing height (Zhang et al., 2000) and landing technique (Devita and Skelly, 1992). For instance, using greater knee flexion reportedly increases energy absorption and decreases ground reaction force during landing (Devita and Skelly, 1992; Kulas et al., 2008). Energy absorption also increases as demand of landing (Zhang et al., 2000; McNitt-Gray, 1993), such as the addition of a light body borne load (10% of body weight) (Kulas et al., 2008), increases. Yet, the energy absorption by the knee musculature purportedly increases at a relatively slower rate than the demand (Yeow et al., 2009), and it is currently unknown if energy absorption increases when landing with soldier-relevant body borne loads.

Landing with body borne load increases the demand placed on the musculoskeletal system (Sell et al., 2010; Kulas et al., 2008), but improving the biomechanical profile of lower extremity, such as using more knee flexion during landing, may increase the amount of energy the knee can safely absorb and decrease the risk of musculoskeletal injury – e.g., ligamentous sprain or rupture. Considering both recreationally active (Kulas et al., 2008) and military (Sell et al., 2010) participants exhibit greater knee flexion while landing with light body borne loads, increasing knee flexion when landing with soldier-relevant body borne loads should be an attainable goal to increase energy absorption and decrease the risk of musculoskeletal injury. But, to date, it remains unanswered how landing with body borne loads, especially soldier-relevant load configurations, increases the demand on the knee musculature, and whether greater knee flexion during such landings translates to greater energy absorption.

The primary purpose of the study was to examine how soldier relevant body borne loads impact lower limb biomechanics, particularly sagittal plane posture, angular impulse and energy absorption of the hip, knee and ankle, during the deceleration phase of a drop landing. We hypothesized that participants would exhibit significantly greater lower limb flexion posture and angular impulse, and energy absorption with the 20-kg and 40-kg as compared to the 6-kg body borne load during the deceleration phase of landing. Understanding whether greater flexion posture during drop landings with body borne load promotes energy absorption of the knee joint may provide an avenue to reduce both risk of musculoskeletal injury and the incidence rate of these debilitating injuries with future training methodologies. Therefore, a second purpose was to determine whether active (greater) lower limb flexion during the deceleration phase of loaded drop landings relates to increased energy absorption by the knee musculature. We hypothesized that greater flexion motion of the lower limb would relate to larger energy absorption at the knee.

2. Methods

2.1. Participants

An *a priori* power analysis of knee joint biomechanics exhibited during similar dynamic landing task suggests 13 participants are needed to achieve 80% statistical power with alpha level of 0.05 (Herman et al., 2009). As such, fifteen male military personnel participated in this study. Only male participants were recruited as a sexual dimorphism in lower limb biomechanics exists during dynamic landings (Brown et al., 2009). All potential participants self-reported the ability to safely carry loads heavier than 40 kg. Potential participants who reported: current pain or recent injury to the back or lower extremity (previous six months), history of back or lower extremity injury or surgery, and/or any known neurological disorder were excluded from testing. Prior to testing, research approval was obtained from the local institutional review board and each participant gave their written consent. After signing the consent, all participants had their age, height and weight recorded (20.9 ± 3.1 yrs, 1.8 ± 0.1 m and 75.6 ± 11.6 kg).

2.2. Load configurations

Participants performed a drop landing task wearing three different, body borne load configurations (light, medium, and heavy) (Fig. 1). The testing order of the body borne loads were randomly ordered and assigned to each participant from a 3 × 3 Latin Square prior to beginning the study. For the light load (~6 kg), participants carried a mock weapon and wore a helmet. For the medium load (~20 kg), participants wore body armor with a fabric ammo panel attached on the anterior abdomen in addition to the items borne for the light load. For the heavy load (~40 kg), participants wore a standard issue military backpack in addition to the items borne for the medium load.

2.3. Land protocol

For the drop landing task, participants stepped off a 30 cm box, landed on both feet, each on a separate force platform, and then quickly cut at 45° angle off their dominant limb and ran 3 m towards their non-dominant side. The dominant limb was defined as the leg each participant reported they could kick a ball the farthest. During each drop landing, three-dimensional (3D) joint (hip, knee and ankle) kinematic and kinetic data were recorded. Specifically, twelve motion capture (240 Hz) cameras (Oqus, Qualisys AB, Gothenburg, Sweden) captured motion data, while two force platforms (AMTI Optima, Advanced Mechanical Technology Inc., Watertown, MA) captured synchronous ground reaction force (GRF) data (1200 Hz). A drop landing was considered successful if each foot contacted only the assigned force platform, each foot landed synchronously, and the cut was within ± 5° of the target angle. Participants performed the drop landings until three successful trials were obtained.

2.4. Biomechanical collection and analysis

During the drop landings, joint kinematics were quantified from the trajectories of thirty-six (14 mm diameter) reflective skin markers (Appendix A). Initially, the participant stood stationary in a neutral (stationary) position while a high-speed recording was taken. This stationary recording was used to define a seven segment (bilateral foot, shank and thigh, and pelvis) kinematic model using Visual 3D v4.00 (C-Motion, Rockville, MD). The knee and ankle joint centers were calculated with Visual 3D, as the midpoints between the medial and lateral femoral epicondyles and between the medial and lateral malleoli, respectively. While the functional hip joint center was calculated with Visual 3D from a method adapted from Schwartz and Rozumalski (Schwartz and Rozumalski, 2005). For each landing trial, synchronous GRF data and marker trajectories were low pass filtered with a fourth-order