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Body borne loads impact walk-to-run and running biomechanics

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ABSTRACT

The purpose of this study was to perform a biomechanics-based assessment of body borne load during the walk-to-run transition and steady-state running because historical research has limited load carriage assessment to prolonged walking. Fifteen male military personnel had trunk and lower limb biomechanics examined during these locomotor tasks with three different load configurations (light, ~6 kg, medium, ~20 kg, and heavy, ~40 kg). Subject-based means of the dependent variables were submitted to repeated measures ANOVA to test the effects of load configuration. During the walk-to-run transition, the hip decreased ($P = 0.001$) and knee increased ($P = 0.004$) their contribution to joint power with the addition of load. Additionally, greater peak trunk ($P = 0.001$), hip ($P = 0.001$), and knee flexion ($P < 0.001$) moments and trunk flexion ($P < 0.001$) angle, and reduced hip ($P = 0.001$) and knee flexion ($P = 0.001$) posture were evident during the loaded walk-to-run transition. Body borne load had no significant effect ($P > 0.05$) on distribution of lower limb joint power during steady-state running, but increased peak trunk ($P < 0.001$), hip ($P = 0.001$), and knee ($P = 0.001$) flexion moments, and trunk flexion ($P < 0.001$) posture were evident. During the walk-to-run transition the load carrier may move joint power production distally down the kinetic chain and adopt biomechanical profiles to maintain performance of the task. The load carrier, however, may not adopt lower limb kinematic adaptations necessary to shift joint power distribution during steady-state running, despite exhibiting potentially detrimental larger lower limb joint loads. As such, further study appears needed to determine how load carriage impairs maximal locomotor performance.

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1. Introduction

Locomotion with body borne loads has a deleterious effect on the load carrier's capacity to run, jump, and maneuver [1]. This reduced physical capacity may be further exacerbated with greater load mass [2] and attributed to significant trunk and lower extremity biomechanical adaptations [3]. Specifically, during prolonged walking, greater sagittal plane trunk, hip, and knee joint motions [4–6] and moments [7] occur while supporting body borne loads. Yet during dynamic locomotor activities, such as movements that require a quick increase of speed, mechanical adaptations to body borne load may be greater than exhibited during walking, further impairing performance. To date, biomechanics-based load carriage research has limited its assessment to prolonged steady state walking [3,4], despite the fact that soldier-relevant body borne loads, which often exceed 45 kg [8], may significantly reduce the physical capacity to successfully perform dynamic locomotor activities.

To successfully perform a dynamic locomotor activity, muscles must generate energy to accelerate the center of mass. It may be, however, that accelerating the center of mass with body borne load results in large biomechanical adaptations of the lower limb. Previous experimental evidence suggests a unique set of kinematic [9] and kinetic [10] criteria define the transitional period of accelerating from a walk to a run. Segers et al. [10] concluded that the walk-to-run transition is realized in one step. During this transitional step, the stance leg exhibited greater flexion posture [9] and required three times the mechanical energy [11] to propel the body into the flight phase that demarcates running. When impaired with load, this transition may require greater power and

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larger attenuation of forces to initiate running, further inhibiting performance. With body borne loads, the lower limb musculature may take substantially longer to stabilize the external load and increase the time required to generate the mechanical energy needed to initiate running. Currently, however, it is not understood how body borne load may impact the joint kinematics, kinetics, and power distribution during a walk-to-run transition.

When running the body alternates between periods of energy generation and absorption. With steady-state locomotion, i.e. constant speed of running, muscles do not perform net mechanical work, as neither potential nor kinetic energy change from step to step. Experimental evidence suggests distribution of joint power, the rate at which mechanical energy is added or removed from the body via either concentric or eccentric muscular contractions, does not significantly shift during steady-state running [12]. Joint power may be redistributed from proximal to distal or distal to proximal among the lower limb joints when kinematic adaptations, such as increased flexion posture, change the mechanical advantage of the lower limb musculature [13,14]. As such, transporting body borne loads, where the load carrier demonstrates greater lower limb flexion posture, may substantially shift joint power production, but to date the effect of load carriage on joint power distribution during steady-state running is unknown.

The purpose of this study was to perform a biomechanics-based assessment of body borne load during the walk-to-run transition and steady-state running. We hypothesized that trunk, hip, and knee flexion angle and moments would increase, and joint power production would shift proximally up the kinetic chain as load mass increases during a walk-to-run transition and steady-state running.

2. Methods

Fifteen male (age: 20.9 ± 3.1 years, height: 1.8 ± 0.1 m and weight: 75.6 ± 11.6 kg) military personnel volunteered for this study. Participants were between the ages of 18–40 years and had the ability to safely carry loads up to ~43 kg. Participants who reported: (1) a history of previous back or lower extremity injury or surgery, (2) any recent pain or injury to the back or lower extremity (previous 6 months) and/or (3) any known neurological disorder were excluded from participation. Prior to testing, research approval was obtained from the local institutional review board and all participants gave written consent.

All participants completed three test sessions. During each session, participants performed the study procedures with a different load configuration (light, medium or heavy) (Fig. 1). For the light load (~6 kg), participants wore a helmet and carried a mock weapon. The medium load (~20 kg) consisted of the light load plus body armor with a fabric ammo panel attached on the anterior of the participant. The heavy load (~40 kg) added a standard issue military backpack to the medium load. To randomize and balance the testing order, each participant was randomly assigned a sequence of load configurations prior to beginning the study from a 3 × 3 Latin Square scheme.

Participants had synchronous three-dimensional (3D) joint (trunk, hip, knee and ankle) biomechanical data recorded during a series of dynamic movements. Two force platforms (AMTI Optima, Advanced Mechanical Technology Inc., Watertown, MA) synchronously captured ground reaction force (GRF) data (1200 Hz), while twelve high-speed (240 fps) cameras (Oqus, Qualisys AB, Gothenburg, Sweden) captured motion data during the stance phase of all dynamic movements. For each movement, participants accelerated (walk-to-run) or maintained (run) the velocity of movement, while two sets of infrared photocell timing lights (Brower Timing, Draper, UT, USA), captured their velocity immediately prior to contacting the force platforms. For the walk-to-run task, participants walked at 1.3 m/s (±5%) before transitioning to a 3.5 m/s run while contacting the force platform. The run task required participants run 3.5 m/s (±5%) across the force platform. For all tasks, participants ran a total of 10–15 m by starting between 5 and 8 m from the edge of force platforms and running out of the motion capture volume, approximately another 5–8 m, after contacting the force platform. A trial was considered successful if the dominant limb contacted only the force platform. Participants repeated each task until three successful trials were obtained.

During all movements, joint rotations were quantified from 3D coordinates of thirty-six (14 mm diameter) reflective skin markers.

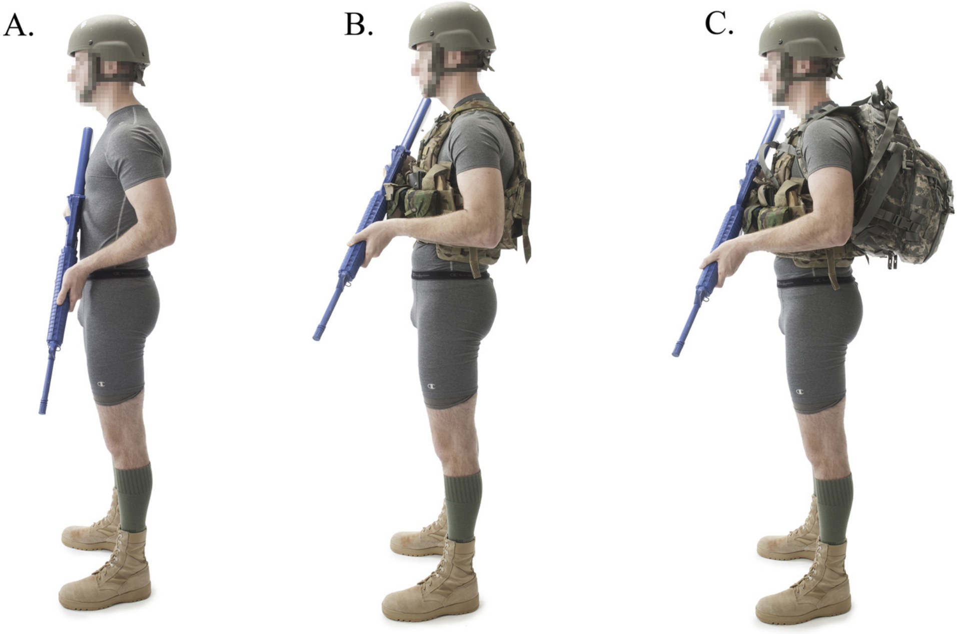

Fig. 1. Load carriage equipment for the three configurations. For the light load (~6 kg), participants wore tight spandex top and shorts, combat boots, helmet and carried a mock weapon. For the medium load (~20 kg), participants added body armor and ammo panel to the light load. For the heavy load (~40 kg), participants added a rucksack to the medium load. Prior to testing, participants were properly sized for load carriage equipment to ensure fit and confirm components were not restricting movement or contacting the lower extremity during testing.