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Original Articles

The role of military footwear and workload on ground reaction forces during a simulated lateral ankle sprain mechanism

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ABSTRACT

Background: Ankle sprains are a common orthopedic injury in military populations, which may be attributed to occupational demands and footwear. Minimalist military boots have become popular, but their influence on ground reaction force (GRF) attenuation capabilities during an ankle inversion perturbation are unknown. Therefore, the purpose of this study was to examine potential differences in GRFs during an ankle inversion perturbation in a standard issue (STN) and minimalist military boot (MIN) before and after a simulated military workload.

Methods: Twenty-one healthy adult males completed an ankle inversion perturbation protocol in each footwear condition before and after an incremental treadmill exercise protocol to volitional exhaustion while wearing a 16 kg rucksack. The ankle inversion perturbation protocol consisted of stepping down from a 27 cm box onto a force platform with a fulcrum (FUL), which created 25° of inversion upon landing, or flat (FLT) outer sole attached to the plantar aspect of the participants' footwear in random order. Peak vertical, anterior/posterior, and medial/lateral components of the GRF during FUL and FLT conditions were assessed, normalized to multiples of body weight in each footwear. Dependent variables were then analyzed using separate 2 (footwear) × 2 (time) repeated measures ANOVA ($p < 0.05$).

Results: The MIN footwear demonstrated significantly greater vertical GRF and significantly less medial GRF during the FUL condition.

Conclusions: These results indicate that various mechanical and design characteristics of military footwear may influence GRF attenuation capabilities and ankle joint loading when the foot/ankle complex is forced into inversion.

1. Introduction

Musculoskeletal injuries are a leading health concern for members of the United States military [1]. Lateral ankle sprains (LAS) are the most commonly reported physical training and combat related musculoskeletal injury sustained by military personnel which severely limits soldier mobility, combat readiness and increases the number of days limited on duty [2,3]. The lateral, or ankle supination sprain occurs when the subtalar joint is unexpectedly forced into excessive inversion, or a combination of subtalar inversion, internal rotation and talocrural plantar flexion, resulting in damage to the lateral ankle ligament complex [4,5].

During ground contact, effective attenuation of the ground reaction forces (GRF) requires talocrual plantarflexion and in many cases subtalar inversion [6,7], which may result in unexpected rearfoot supination leading to an ankle injury. As such, unexpected ankle joint perturbations require primary evertor and invertor muscles of the foot/ankle complex to stabilize joint movement in the frontal plane. The magnitude of the vertical GRF during ground contact, especially when the foot/ankle complex is forced into inversion, has implications for LAS propensity. Specifically, a subtalar joint axis of rotation that is positioned more lateral during ground contact, in relation to the vertical GRF vector, has the potential to generate a greater supination moment of the foot/ankle complex that could result in lateral ligament damage [5,8]. Military personnel frequently encounter environmental hazards such as irregular and uneven terrain during long marches,

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training and/or actual combat scenarios [9–11]. Hence, landing on irregular or uneven terrain has the potential to position the vertical GRF more medial on the plantar aspect of the foot. This may generate a supination moment that could potentially force the foot/ankle complex into excessive inversion resulting in damage to the lateral ligament complex.

Standard military boots are provided to service members that they must wear during active duty that protect the distal shank and foot [12]. Recently, an increasing trend in minimalist footwear design characteristics have emerged into various styles of athletic and occupational footwear. Minimalist footwear features: (i) reduced mass, (ii) more flexible boot shaft, (iii) thin-hard midsole, and (iv) no heel to toe drop [13]. Current military footwear incorporates mechanical and design characteristics such as soft, thick midsoles and a stiff boot shaft. Previous research has shown that these characteristics influence subtalar joint adaptability, range of motion (ROM), and GRF attenuation capabilities [14–16]. Furthermore, these design characteristics have been attributed to reductions in postural stability, somatosensory and proprioceptive feedback from cutaneous receptors of the foot/ankle, and increased energy expenditure [17,18]. Although evidence regarding ankle stability in military footwear in acute fatiguing conditions is limited, decrements in postural stability have been reported in different styles of occupational footwear following an occupational style workload [19–21]. Military personnel are subject to intense occupational workloads while wearing heavy tactical footwear [9,18], which can induce a faster rate of acute fatigue that negatively impacts somatosensory and proprioceptive feedback that is crucial for ankle stability. Therefore, examining the potential effect of footwear mechanical and design properties in fatiguing conditions may provide clinical relevance to the current ankle sprain injury paradigm in military populations and provide suggestions for future footwear modifications that may be advantageous for improving ankle stability.

Technological advancements in footwear research and manufacturing have contributed to essential modifications intended to improve human performance, reduce musculoskeletal injury potential, and meet occupational safety standards [13,22,23]. The nature of military occupational workloads and the high rate of ankle sprain injuries may be attributed to the standard issue footwear that is provided to military personnel. However, the potential impact of a minimalist style military boot on GRF attenuation capabilities during an inversion perturbation under acute fatiguing conditions has not been examined. Therefore, the purpose of this study was to examine potential differences in GRFs during an inversion perturbation in two types of military footwear before and after a simulated military workload wearing a 16 kg rucksack. Previous literature indicates GRF attenuation capabilities have been linked to midsole properties [16,22], while decrements in postural stability have been observed in occupational footwear following an occupational style workload [19,20]. Therefore, the authors hypothesized that the minimalist style military boot would have reduced GRF attenuation capabilities during an inversion perturbation compared to a standard issue military boot, and that GRFs would increase following the simulated military workload in both types of footwear.

2. Materials and methods

2.1. Participants

Twenty-one healthy adult males (age: 22.0 ± 3.0 years; height: 176.9 ± 6.5 cm; mass 79.7 ± 8.7 kg) from the authors' university that had no history of LAS or any other musculoskeletal injuries and participated in ≥150 min/week of aerobic and ≥2 days/week of resistance training for at least three months completed the study procedures. Sample size estimation using G-Power software (Düsseldorf, Germany) determined 20 participants would be needed to achieve a power of 0.80 using an effect size of 0.50 with alpha set at 0.05. Prior to the initiation of data collection, each participant was required to complete a self-reported physical activity recall, sign a physical activity readiness questionnaire and informed consent document that outlined the risks, requirements, and procedures of the study. Participants' height and mass and were obtained using a stadiometer (Webb City, MO, USA) and a physicians' scale (Tanita Corporation, Tokyo, Japan), respectively. The study procedures were approved by the Institutional Review Board at the authors' university prior to initiation of data collection.

2.2. Experimental protocol

This study utilized a within subjects repeated measures design with a crossover counterbalanced footwear assignment. Participants first completed a familiarization trial where testing procedures were explained and participants' shoe size were recorded. Following completion of the familiarization trial, participants returned to the laboratory less than a week later and two testing sessions separated by at least 72 h in each footwear condition were completed. The military footwear used in this study was a standard tactical boot (STN: Belleville 310T hot weather standard tactical boot, Belleville, IL, USA) and a minimalist tactical boot (MIN: Belleville TR101 MiniMil ultra-light minimalist tactical boot, Belleville, IL, USA) (Table 1). An inversion perturbation protocol using the outer sole fulcrum method, which has previously been used in laboratory research to safely replicate the LAS mechanism [24–27], was assessed before and after a simulated military workload. The fulcrum was placed along the medial boarder of the outer sole to ensure that the subtalar joint axis of rotation was located laterally in relation to the vertical GRF vector during ground contact. This method was chosen and utilized in this study because it creates a dynamic inversion perturbation of 25° upon landing (Fig. 1). Participants stood in a unilateral stance with the contralateral hip extended and knee flexed so that the testing foot was placed behind them, while a researcher stood behind them to attach a flat (FLT) or fulcrum (FUL) outer sole to the bottom of the participants' footwear in a completely randomized fashion. This was done to prevent participants from having any knowledge of the outer sole that was attached and to mitigate any anticipatory landing mechanics that could alter the results. In addition, the flat (134 g) and fulcrum (178 g) were constructed to be consistent with the outer soles used by Knight and Weimar [26] and to be of similar mass to prevent participants from knowing which outer sole was attached due to a large difference in mass. After the outer sole (FUL or FLT) was attached, participants were then instructed to step down from a 27 cm box onto a portable AMTI (AccuGait, Watertown, MA, USA) force platform sampling at 500 Hz with a vertical acquisition trigger of 10 N (Fig. 1). A total of 5 successful trials with the FUL and FLT outer sole (10 total trials) were completed and the order of the trials was randomized for each participant. After completion of the inversion perturbation protocol, participants completed a simulated military workload.

Table 1
Descriptive characteristics of the standard (STN) and minimalist tactical boots (MIN).

Footwear design characteristics	Standard tactical boot (STN)	Minimalist tactical boot (MIN)
Weight (lbs.)	1.76 ± 0.08	1.10 ± 0.05
Sole surface area (cm^2)	288.6 ± 24.1	235.4 ± 8.2
Sole tread depth (mm)	3–4	3–4
Midsole stiffness	Shore A 66	Shore A 83
Shaft height (cm)	20	20
Shaft type	Stiff–laced	Flexible–laced
Heel-toe drop (mm)	18	2
Shoe size (men's)	10.3 ± 0.7	10.6 ± 0.7