



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

The effects of British Army footwear on ground reaction force and temporal parameters of British Army foot-drill

Citation for published version:

Rawcliffe, A, Graham, SM, Simpson, RJ, Moir, G, Martindale, R, Psycharakis, S & Connaboy, C 2020, 'The effects of British Army footwear on ground reaction force and temporal parameters of British Army foot-drill', *Journal of Strength and Conditioning Research*, vol. 34, no. 3, pp. 754-762.
<https://doi.org/10.1519/JSC.0000000000002139>

Digital Object Identifier (DOI):

[10.1519/JSC.0000000000002139](https://doi.org/10.1519/JSC.0000000000002139)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Journal of Strength and Conditioning Research

Publisher Rights Statement:

This is the Accepted Manuscript of Rawcliffe, A. J., Graham, S. M., Simpson, R. J., Moir, G. L., Martindale, R. J., Psycharakis, S. G., & Connaboy, C. (2017). The Effects of British Army Footwear on Ground Reaction Force and Temporal Parameters of British Army Foot-Drill. *Journal of Strength and Conditioning Research*, 1.
doi:10.1519/jsc.0000000000002139

The final published version can be found at http://journals.lww.com/nsca-jscr/Abstract/publishahead/The_Effects_of_British_Army_Footwear_on_Ground.95811.aspx

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Cover Letter:

This manuscript contains original material that has not previously been published and is not currently under consideration elsewhere, nor will be submitted elsewhere until a final decision has been made by the journal.

Corresponding authors contact information:

Name: Alex J Rawcliffe

Work Address: Edinburgh Napier University

Sighthill Campus

Edinburgh

EH11 4BN

Email: a.rawcliffe@napier.ac.uk

Phone number: 0131-455-2350

Title: The Effects of British Army Footwear on Ground Reaction Force and Temporal Parameters of British Army Foot-Drill.

Running head: Effects of Military Footwear on Foot-Drill

Authors: Alex J Rawcliffe¹, Scott M Graham¹, Richard J Simpson², Gavin L Moir³, Russell JJ Martindale¹, Stelios G Psycharakis⁴ and Chris Connaboy⁵

Institutional affiliations:

¹School of Life, Sport & Social Sciences, Edinburgh Napier University, UK

²Department of Health and Human Performance, University of Houston, USA

³Exercises Science Department, East Stroudsburg University, USA

⁴Institute of Sport, Physical Education and Health Sciences, University of Edinburgh, UK

⁵Neuromuscular Research Laboratory, University of Pittsburgh, USA

Corresponding author: Alex J Rawcliffe

Abstract

High rates of occupational training-related lower-limb musculoskeletal [MSK] overuse injuries are reported for British Army recruits during basic training. Foot-drill is a repetitive impact loading occupational activity and involves striking the ground violently with an extended-knee [straight-leg] landing. Foot-drill produces vertical ground reaction forces [vGRF] equal to and/or greater than those reported for high-level plyometric exercises/activities. Shock absorbing footwear aid in the attenuation of the magnitude of vGRF, resulting in a reduced risk of lower-limb MSK overuse injury when running. The potential shock absorbing characteristics of standard issue British Army footwear on the magnitude of vGRF and temporal parameters of foot-drill are scant. Therefore, this study sought to determine the magnitude of, and examine changes in vGRF and temporal parameters of foot-drill across three types of British Army footwear. Sampled at 1000hz, the mean of eight-trials from fifteen recreationally active males were collected from four foot-drills; stand-at-ease [SaE], stand-at-attention [SaA], quick-march [QM] and halt. Analysis of a normal walk was included to act as a comparison with quick-march. Significant main effects [$P < 0.05$] were observed between footwear and foot-drill. The training shoe demonstrated significantly greater shock absorbing capabilities when compared with the combat boot and ammunition boot. Foot-drill produced peak vGRF and peak vertical rate of force development in excess of 5bw, and 350bw/sec, respectively. Time to peak vGRF ranged from 0.016- 0.036ms across foot-drills, indicating that passive vGRF may not be under

Introduction

British Army personnel are required to maintain a state of physical readiness enabling them to perform effectively in any training and/or operational environment. Due to the rigorous physical demands of warfighting and physical training, basic military training [BMT] is a critical feature in the physical development of the entry-level recruit. However, high rates of occupational training-related lower-limb musculoskeletal [MSK] overuse injuries are reported for recruit populations during BMT, significantly impacting on their tactical and operational readiness²². The etiology of occupational training-related injuries sustained during BMT are multi-factorial and diverse. Therefore, efforts to minimise the injury incidence during recruit physical training is of primary focus for military organisations worldwide²⁵.

British Army foot-drill, most notably, stand-at-attention [SaA], stand-at-ease [SaE], halt, and quick-march [QM], is a fundamental military occupational activity that is learned by recruits during the initial weeks of BMT and practiced throughout their military career. Foot-drills are characterised by their own unique key performance markers³. QM involves marching at two paces per second whilst impacting the ground with an exaggerated heel strike. SaA, SaE (left-leg) and Halt (right-leg) require soldiers to raise the active limb to 90° hip flexion and forcefully stamp the heel onto the ground with an extended-knee (straight-leg) landing. Foot-drill is performed in standard issue military footwear, namely, the combat boot [CB], and ammunition boot [AB]. The CB is issued to entry-level recruits on induction to BMT, and worn with uniforms on a daily basis, and by military units on parade in full dress uniform⁷. The AB [or similar] is commonly worn by British military personnel in dress uniform or during ceremonial and/or drill duties¹⁷ [figure 1].

Measurement of GRF and temporal parameters such as vertical ground reaction force [vGRF], vertical rate of force development [vertical RFD], and time to peak vertical force [TTP] have been utilised as non-invasive measures of lower-limb bone loading as a means of quantifying the potential development of MSK overuse injuries, most notably, bone microdamage and subsequent stress

fracture of the foot and/or shank^{4,27}. Furthermore, these specific vGRF and temporal parameters have been utilised to indirectly assess the shock absorbing functionality of specific footwear, during a variety of lower-limb tasks^{12, 13, 27}. For example, previous footwear research has demonstrated that the CB, when compared with other military and commercially available footwear, produces significantly greater impact loading forces when running and marching at velocities of $4\text{m}\cdot\text{s}^{-1}$ and $1.5\text{m}\cdot\text{s}^{-1}$, respectively^{12, 27}. In addition, the CB has also been shown to significantly increase the risk of metatarsal stress fracture when running at $3.6\text{m}\cdot\text{s}^{-1}$ ¹⁹.

The magnitude of specific vGRF parameters representative of foot-drill, irrespective of the type of footwear worn, may be a contributing risk factor in the development of lower-limb MSK overuse injuries within recruit populations^{4,24}. To date, only three studies have investigated the impact loading forces of foot-drill whilst wearing training shoes^{6,24} and defender combat boots⁴; reporting peak vGRF [range = 1.3 – 5.1 bodyweights] [BW] and peak vertical RFD [range = 67.6 – 536 bodyweights/second] [BW/s] values similar to, and in some cases greater than those observed for high level plyometric exercises^{2,29}. The primary objective of these studies was to quantify vGRF parameters of foot-drill, and did not directly consider the potential influential factors associated with standard issue footwear on impact loading forces of foot-drill.

Factors that mitigate the magnitude and rate of force transmitted to the MSK structures of the lower-limbs can be achieved via the use of footwear with shock absorbing capabilities¹⁴, thereby potentially reducing the risk of developing such MSK injuries as lower-limb stress fractures. Recently, military footwear has undergone considerable scrutiny regarding its functionality and capacity to provide military personnel with the necessary shock absorbing properties required to withstand the demands of military training-related activities. For example, Nunns¹⁹ and Sinclair and Taylor²⁷ demonstrated that the CB increased the magnitude of several biomechanical risk factors associated with third metatarsal stress fractures during marching, and was inferior in minimising the instantaneous and average loading rates of running when compared with training shoes. Previous footwear research^{13,33}

has demonstrated that the CB produced significantly greater peak decelerations, shorter times to deceleration, higher peak-plantar pressures, and greater vGRF forces at the heel and forefoot when compared with hiking boots and training shoes. From these studies, it can be suggested that the CB may not achieve the necessary shock absorbing capacity required to effectively attenuate the cyclic high impact loading forces during running, marching or drop landings. Therefore, in agreement with previous research^{19, 12, 33} the CB and its use during cyclic high impact loading activities, may potentially be a contributing mechanism responsible, in part, for the high rates of lower-limb MSK overuse injuries sustained by recruits during BMT. Nevertheless, it remains unclear as to how the vGRF and temporal parameters of foot-drill are influenced by the CB and other types of British Army footwear within a recruit population. Limited empirical research exists regarding the magnitude of loading during foot-drill within a recruit population, with no research investigating the influence of current standard issue footwear on specific vGRF and temporal parameters of foot-drill.

Knowledge of the biomechanical loading forces of these regimented movements is an essential component of understanding the dynamics of foot-drill as a potential training-related lower-limb MSK overuse injury risk factor. Furthermore, these data can provide a greater understanding of whether the use of a shock absorbing footwear is effective in the attenuation of the impact loading forces of foot-drill experienced by a British Army recruit population. Therefore, the aim of the present study was to compare the magnitude of the vGRF and temporal parameters of each foot-drill, namely, peak vGRF, peak vertical RFD, and TTP across three different types of standard issue British Army footwear, namely the CB, AB and Hi-Tech Silver Shadow training shoe [TR]. This study tests the hypothesis that foot-drill, when compared with the loading patterns of a normal gait, would produce greater peak vGRF, peak vertical RFD, and shorter TTP values; and that the TR would significantly attenuate peak vGRF, peak vertical RFD, and produce longer TTP values when compared with the CB and AB for all foot-drills.

Methods

Fifteen recreationally active healthy males [mean \pm SD; age 24.4 ± 2.1 years; height 175 ± 8.3 cm; weight 86 ± 5.7 kg] with no pathological lower-limb, hip or spinal conditions volunteered to participate in the present study. All participants at the time of testing were taking part in moderate physical activity [gym training] and/or sport [soccer, rugby, badminton] a minimum of two-to-three times per week for approximately 1-2 hours over the previous three years. Forty-eight hours prior to testing participants refrained from high intensity activity as to eliminate potential fatigue effects on performance data. Ethical approval for the present study was gained from the local ethics committee and written informed consent was obtained from each participant prior to data collection. Study participants were defined as “untrained” as they had no prior experience of British Army foot-drill preceding data collection. Nevertheless, the study participants obtained similar anthropometric characteristics and training histories when compared with male entry-level recruit populations²².

A within-participant repeated-measures study design was employed to assess the vGRF dependent variables of five British Army foot-drills involving; stand-at-attention [SaA], stand-at-ease [SaE], quick-march [QM], halt, and a normal walking gait. Eight trials of a normal walk were collected to act as a comparison with the vGRF and temporal data of QM based on similarities in biomechanical movement patterns. The vGRF and temporal parameters of each foot-drill were assessed across three different types of standard issue British Army footwear. The allocation of footwear was counterbalanced for each day of testing. A Kistler force plate [Kistler Instruments AG, 9281CA, Switzerland] flush with the lab floor [Force plate dimensions: 600mm x 400mm x 100mm] situated in a 10-m walkway was used to measure and record peak vGRF, peak vertical RFD, and TTP. Study participants attended the lab on three non-consecutive days with 24-hours separating each test day. Each testing session was conducted at the same time of day and performed under the instruction and guidance of the same researcher.

Each participant performed a standardised 10-min warm up consisting of dynamic lower-limb bodyweight exercises, namely, variations of the lunge and bilateral squat. Preceding the collection of foot-drill vGRF and temporal data, a single familiarisation session was conducted on the first day of testing, whereby each participant performed ten trials of each foot-drill²⁴. Post familiarisation and a 15min recovery period, a total of eight trials per foot-drill were collected, as it has been demonstrated that a minimum of eight-trials is required to produce accurate and stable levels of foot-drill vGRF data [$CV_{te}\% < 10\%$, $ICC > 0.75$]²⁴. The force plate was interfaced with BioWare 3.2.5 software and set at a sampling frequency [fs] of 1000Hz, with each foot-drill recorded for a maximum of 3-sec. The foot-drill vGRF and temporal data were collected using an eight channel 16-bit analog to digital converter [Qualisys, 8128, Sweden]. A 90-sec recovery period between each trial and a 15-min recovery between foot-drills was employed. All footwear used for analysis in the present study was unworn prior to data collection, eliminating the influence of retrospective wear on foot-drill data. Trials were discarded and repeated if targeting⁵ and/or adjustments in key performance markers of foot-drill were observed.

Figure 1 – British Army Standard Issue Footwear



Figure 1 – Depicts the three different types of standard issue British Army Footwear used in the present study. From left to right - Combat boot [CB], Ammo Boot [AB], and Hi-Tech Silver Shadow™ training shoe [TR].

A comprehensive description of each foot-drill analysed within the present study can be found in the British Army Drill Instructor Manual³. The foot that struck the force plate during each of the foot-drills was referred to as the active limb with the opposite limb referred to as the support limb [figure 2]. Study participants were instructed to walk at their preferred walking speed. Speed [m/s] was measured via timing gates [Fusion sport, SmartSpeed, Australia] situated at 0-m, 5-m and 10-m along

the 10-m walkway, and monitored across each test session, with a maximum deviation of +/- 5% allowed from each participant's predetermined walking velocity²⁷.

Figure 2. Representation of a typical British Army Stand-at-Attention foot-drill wearing the CB

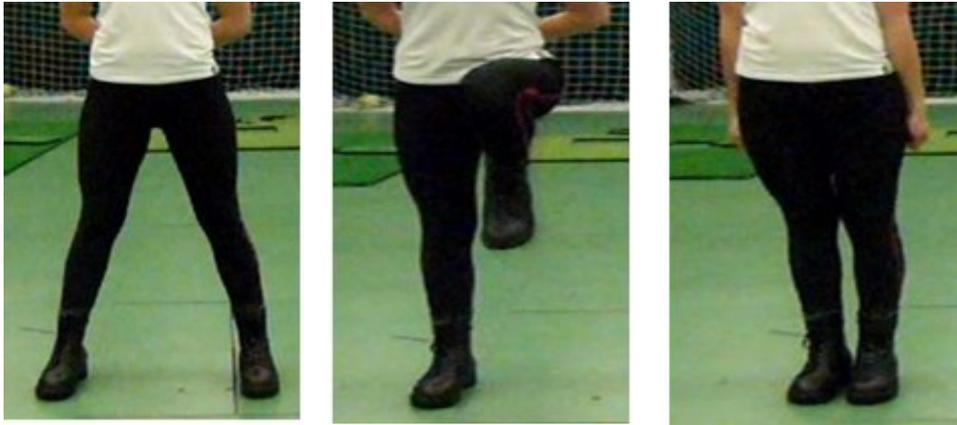


Figure 2. Illustrates a typical SaA British Army foot-drill whilst wearing the CB. From left to right, the SaA is performed from the SaE position. On command, the participant flexes at the hip to 90° followed by an exaggerated stamping of the foot onto the surface of the force plate, landing with the knee in an extended position.

The foot-drill vGRF and temporal data were exported via BioWare 3.2.5 system. Based on previous power spectrum analysis, ensuring that 95% of the signal content was retained, data were filtered with a low pass 4th order zero-lag [single bi-directional] Butterworth filter with a cut off frequency ranging between 50hz (walk, QM) and 150Hz (SaA, SaE, Halt). As a means of comparing between participants the vGRF and RFD foot-drill data were normalised to BW, computed as;

$$BW_{Norm} = \frac{Fz_{peak}}{BW} \quad [1]$$

where, BW_{Norm} is the normalized vGRF expressed in BW, Fz_{peak} is the peak vGRF measured in Newtons [N], and BW is the participant's bodyweight determined via the force plate and expressed in N. The vertical RFD variable was computed as;

$$RFD = \frac{\Delta F}{\Delta T} \quad [2]$$

where, RFD is the vertical rate of force development measured in N per second [N/s], ΔF represents the change in force measured in N and, ΔT represents the change in time measured in sec. $vRFD$ was normalised relative to the participant's BW computed as;

$$NormRFD = \frac{RFD}{BW} \quad [3]$$

where, $NormRFD$ is the RFD normalised to the participant's bodyweight, measured in N. $Time\ to\ Fzpeak$ is defined as the time to reach $Fzpeak$ expressed in milliseconds [ms] computed as;

$$Time\ to\ Fzpeak = t_{max} - t_{min} \quad [4]$$

where, t_{min} represents the time point of the initial onset of vGRF and t_{max} represents the time point of $Fzpeak$, measured in sec. The initial onset of vGRF was defined as when the vGRF component exceeded a threshold of 20N.

Prior to statistically analysing the vGRF dependent variables of foot-drill and walk data between footwear; peak vGRF, peak vertical RFD, and TTP were examined for heteroscedascity⁹. The vGRF and vertical RFD data illustrated a significant violation in the assumption of normality. Therefore, these data were log transformed in SPSS using natural logarithm of the observed value¹. The time to peak force [TTP] data illustrated no significant violation from a normal distribution. Therefore, the raw TTP data were utilised in the analysis. A series of one-way repeated-measures analysis of variance [RM ANOVA] with Bonferroni adjusted multiple comparisons were conducted for each of the vGRF dependent variables [vGRF, vertical RFD, and TTP] for each of the foot-drills and walk across each footwear. A paired samples t-test was conducted to quantify potential significant differences in mean peak vGRF and vertical RFD between the QM and walk foot-drill across footwear. Alpha was set at $p < .05$ and data were statistically analysed via IBM SPSS™ 20.

Results

The mean walking speed for all participants was $1.6 \pm 0.6 \text{ m/s}$. Although a metronome was used to standardise QM pacing across participants, the mean speed for QM was $2.02 \pm 0.01 \text{ m/s}$. Significant differences in force-time characteristics between the QM and walk foot-drill were determined. As illustrated in figure 6, the QM foot-drill demonstrates a distinct impact peak in comparison to the walk, with QM showing a steeper initial slope from initial contact to peak vGRF; characterising the magnitude of the vertical RFD of the initial portion of the vGRF component.

Figure 3. A representative force-time profile of the QM and walk across all footwear types

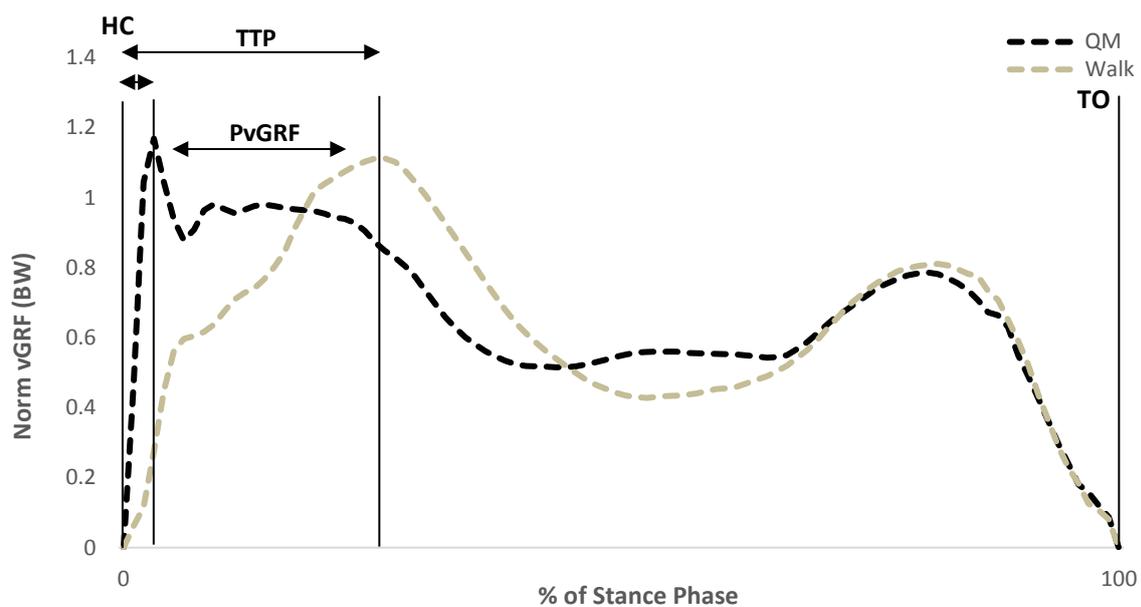


Figure 3. An exemplar of a typical QM and Walk (right foot) gait cycle of a single participant whilst wearing the CB. These data were time normalised in Visual 3D to 100 data points representing 0% to 100% of the stance phase from heel contact to toe off. HC = Heel contact for both QM and Walk, TO = toe off for both QM and Walk, TTP = time to peak vertical force, PvGRF = peak vertical ground reaction force.

Statistically significant main effects were found for peak vGRF in SaA, SaE, and Halt foot-drill. Pairwise comparisons indicated significant differences between footwear conditions, with the TR exhibiting significantly lower magnitudes of vGRF in SaA [$3.9 \pm 0.3 \text{bw}$], SaE [$3.8 \pm 0.3 \text{bw}$], and Halt [$4.2 \pm 0.3 \text{bw}$] when compared to the CB and AB [$p < .05$] [figure 4]. No significant differences were observed for walk [$F = 0.028$, $P = .973$, $Np^2 = .003$] or QM [$F = 2.518$, $P = 0.106$, $Np^2 = 0.201$].

Figure 4. The vGRF as a function of footwear across British Army foot-drill.

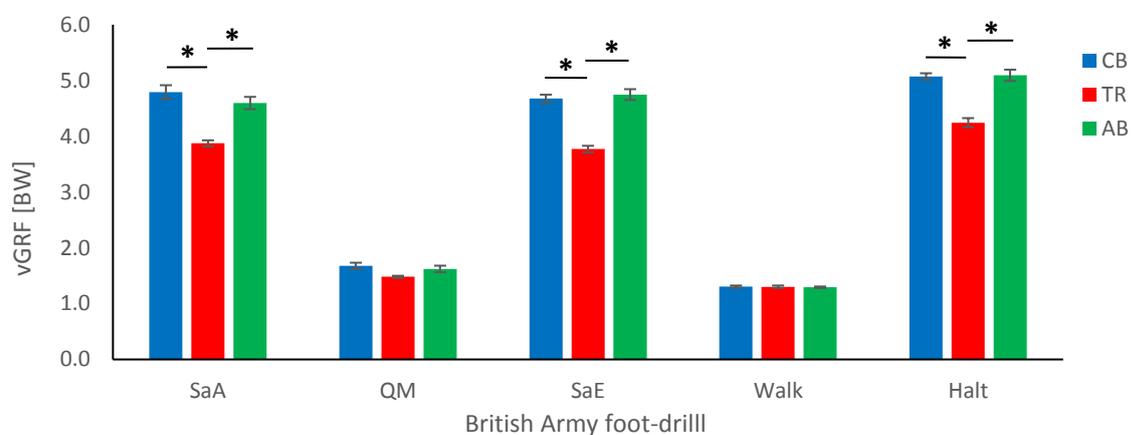


Figure 4. The mean peak vGRF of each foot-drill across each footwear, showing significant differences [$p < 0.05$] between footwear across foot-drill with vGRF data normalised to bodyweight [BW]. * = illustrates a significant difference. Values are means; bars are SD.

Statistically significant main effects were observed for the peak vertical RFD in SaA, SaE, QM, and Halt foot-drill [$p < .05$]. Pairwise comparisons indicated significant differences between footwear conditions with the TR exhibiting significantly lower magnitudes of vertical RFD in SaA [$226 \pm 24 \text{bw/s}$], QM [$36 \pm 8.9 \text{bw/s}$], SaE [$217 \pm 19.4 \text{bw/s}$] and Halt [$249 \pm 18.6 \text{bw/s}$] when compared to CB and AB [$p < .05$] [figure 5]. No significant differences were observed for walk [$F = 2.673$, $P = .094$, $Np^2 = .211$] between footwear conditions.

Figure 5. The mean peak vertical RFD as a function of footwear across British Army foot-drill

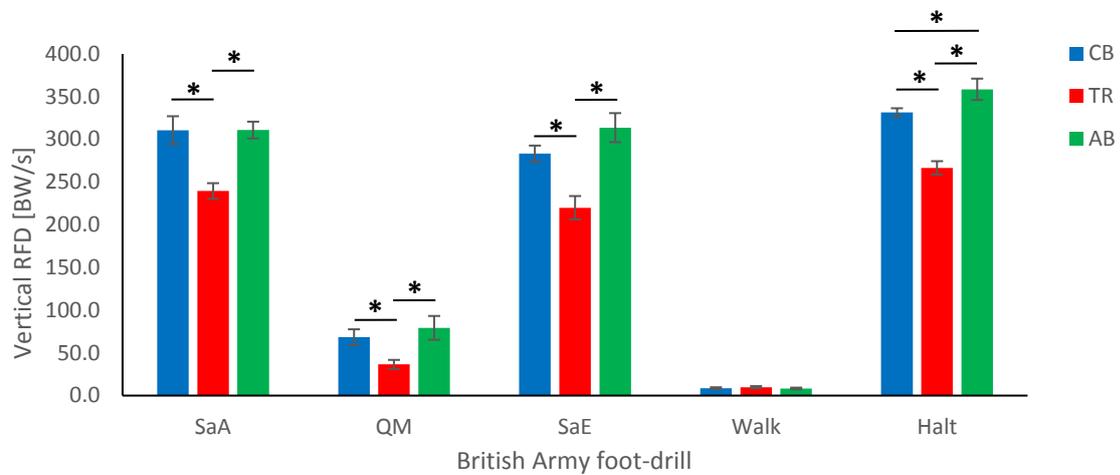


Figure 5. The mean peak vertical RFD of each foot-drill across the three types of footwear, showing significant differences [$p < 0.05$] between footwear across foot-drill with vertical RFD data normalised to bodyweight/second [BW/s]. * = illustrates a significant difference. Values are means; bars are SD.

Statistically significant differences were observed in the mean peak vGRF and vertical RFD values between the QM and walk foot-drill across footwear conditions [$p < .001$], with QM exhibiting significantly greater mean vGRF [$1.6 \pm 0.2 \text{ bw}$] and vertical RFD [$62.2 \pm 22.8 \text{ bw/s}$] across footwear conditions [figure 6].

Figure 6. The vGRF and vertical RFD as a function of footwear across the QM and Walk foot-drill

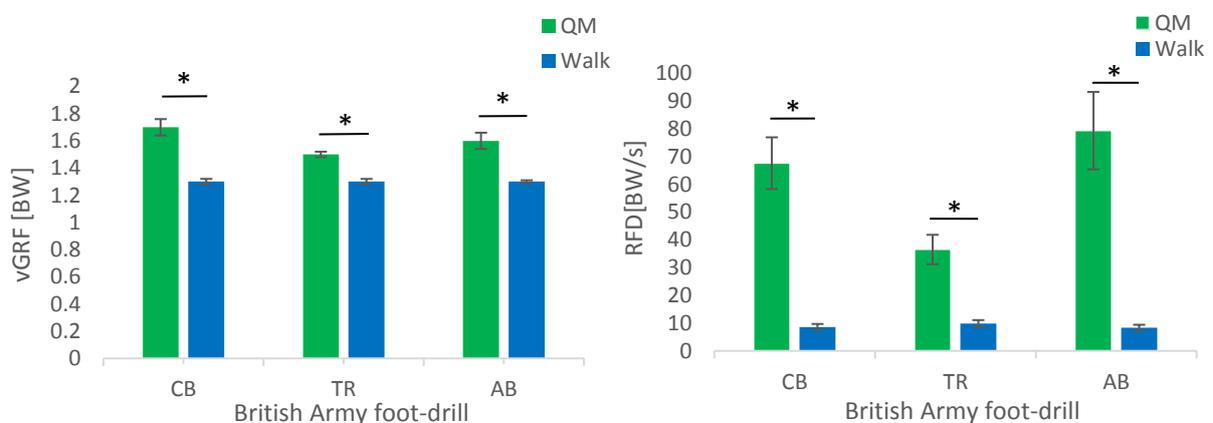


Figure 6. Significant differences [$p < 0.05$] between the QM and Walk foot-drill across footwear, with vGRF normalised to [BW], and vertical RFD data normalised to BW/s. * = illustrates a significant difference. Values are means; bars are SD.

Statistically significant main effects were observed for TTP across footwear in SaA, SaE, QM, and Halt. Pairwise comparisons indicated significant differences between footwear conditions with the TR demonstrating significantly greater TTP in SaA [$17 \pm .01$ ms], SaE [$18 \pm .01$ ms] and Halt [$16 \pm .01$ ms] when compared to the AB, with significantly greater TTP values observed for TR in QM [$71 \pm .02$ ms] when compared to the CB and AB [$p < .05$] [table 1]. No significant differences were observed in walk across footwear conditions [$F = 1.991$, $P = .166$, $Np^2 = .181$].

Table 1. The TTP as a function of footwear across each British Army Foot-drill.

Foot-drill	British Army Footwear			Δ [%]		
	CB	TR	AB	CB vs AB	TR vs AB	CB vs TR
SaA	0.016 [0.002]	0.017 [0.003]	0.015* [0.001]	6.3%	11.8%	5.9%
SaE	0.017 [0.001]	0.018 [0.002]	0.015* [0.002]	11.8%	16.7%	5.6%
Halt	0.017 [0.012]	0.016 [0.002]	0.014* [0.002]	17.6%	12.5%	5.9%
QM	0.036* [0.032]	0.071 [0.037]	0.026* [0.077]	27.8%	63.4%	49.3%
Walk	0.229 [0.167]	0.196 [0.169]	0.275 [0.190]	16.7%	28.7%	14.4%
Mean [SD]	-	-	-	16% [8]	27% [22]	16% [0.19]

Table 1. The mean [SD] time to peak vGRF [TTP] [sec] of each foot-drill across footwear, showing percentage differences [Δ] between footwear and foot-drill, with TTP expressed in seconds [sec]. * = indicates the specific foot-drill and footwear type that exhibited significantly shorter TTP values. CB=Combat boot, TR=Training shoe, AB=Ammunition boot. Δ [%] = indicates percentage difference. Alpha $p < 0.05$.

Discussion

Knowledge of the kinetics of British Army foot-drill is an essential component for a better understanding the dynamics of foot-drill as a potential occupational training-related lower-limb MSK injury risk factor. The present study sought to determine and compare the magnitude of the vGRF and temporal parameters of British Army foot-drill across three different types of standard issue British Army footwear. These results confirm the hypothesis, indicating that when performing British Army foot-drill in footwear with greater shock absorbing capabilities, namely the TR, significant reductions in peak vGRF and peak vertical RFD are achieved when compared to CB and AB. Given the structural and mechanical properties of the AB outsole, it was anticipated that the AB would provide less shock absorbency resulting in greater peak vGRF and vertical RFD when compared with the CB. However, similar magnitudes of peak vGRF and vertical RFD to that of the CB were observed. These results mirror those of others⁹, whereby little to no significant differences in the magnitude of impact forces between hard and moderately hard midsole footwear were observed. Apart from QM, the AB demonstrated significantly shorter TTP values when compared to CB and TR. However, regardless of footwear, all foot-drills demonstrated TTP values ≤ 50 ms, which may have implications for reduced neuromuscular control at ground contact¹¹, as recruits are taught to actively minimize the magnitude of knee and hip flexion at ground contact, thus reducing the ability of the quadriceps and hamstring co-contraction forces to absorb and attenuate the high impact loading forces of British Army foot-drill.

The CB and AB exhibited mean peak vGRF and vertical RFD in excess of 5.1BW and 358.6BW/s for SaA, SaE, and Halt. Two participants wearing the CB and AB demonstrated peak vGRF and peak vertical RFD in excess of 6.6BW and 514BW/s for SaA, SaE, and Halt. The magnitude of impact loading forces of foot-drill are similar to those reported by Carden⁴, whereby untrained [recruits] exhibited mean peak vGRF and vertical RFD in excess of 4.6BW and 536BW/s whilst wearing the Defender Combat Boot [DCB], respectively. The DCB has been standard issue within the British Army since 2012; specifically designed to minimise the risk of lower-limb MSK injury in the dismounted soldier via the integration of an inbuilt shock absorbing mid-layer¹⁶. However, based on the vGRF and temporal parameters of

foot-drill, the direct comparison from the present study, and an indirect comparison of the data from Carden⁴ would suggest that the DCB may not provide greater shock absorbing capabilities when compared with the CB. However, like the CB, the DCB was not solely designed to reduce the impact loading forces of foot-drill, rather to accommodate dismounted troops during high-level activity roles in temperate climates. Thus, based on the results of the present study and those of others^{4,27}, it is recommended that recruits wear a form of shock absorbing footwear similar to that of the TR, to reduce the cyclic high impact loading forces of foot-drill, that may contribute to an increased risk of lower-limb MSK injury.

In comparison to CB and AB, the TR demonstrated significantly smaller magnitudes of peak vGRF and vertical RFD across the majority of foot-drills. These results are comparable to others²⁷, whereby training shoes [running and cross trainer] demonstrated superior shock absorbing capabilities when compared with military boots. However, the TR demonstrated peak vGRF and peak vertical RFD in excess of 4bw and 260.7bw/s, respectively, with two participants producing values in excess of 5.8bw and 420bw/s for Halt. Although the TR displayed significant reductions in impact force, the mean peak vGRF of SaA, SaE, and Halt whilst wearing the TR are similar to those reported for 30cm, 60cm, and 90cm drop landings in adolescent Division 1 collegiate gymnasts²⁶. In addition, the peak vertical RFD observed for the TR during foot-drill far exceed those exhibited during running speeds of 6.7m/s whilst wearing a hard-soled spike running shoe¹⁴. Despite the significant reductions in peak vGRF and vertical RFD of foot-drill associated with the TR, the magnitude of these GRF components similar to those reported in previous empirical studies^{14,26}, may be a contributing lower-limb MSK injury risk factor. Nevertheless, based on the present study's results, further research is warranted to determine if the shock absorbing capabilities of the TR in comparison to the CB and AB are associated with the lower levels of MSK injury risk.

The unique landing techniques of foot-drill combined with the lack of shock absorbing capabilities of standard issue footwear, namely the CB and AB, typically present high vertical RFD. The magnitude of

peak vertical RFD of SaA, SaE, and Halt [range: 286.3 - 514BW/s] are higher than those reported for countermovement jumps and box step offs [mean range: 185.9 – 303.7BW/s]¹, and for those reported for 61cm drop landings [472BW/s]². The large disparity in the magnitude of vertical RFD between foot-drill and other high impact activities is that individuals will attempt to actively mitigate the impact loading forces by increasing the duration of loading via greater hip and knee flexion and ankle plantarflexion, whereas during foot-drill they will not, as recruits are instructed to land with the heel in an extended-knee landing⁴. All biological MSK structures are viscoelastic in nature, whose material properties are rate dependent¹¹. Therefore, when considering the relative safety of high impact loading activities, it is important to determine the vertical RFD as it is generally accepted that greater magnitudes of vertical RFD are more associated with risk of injury; as MSK structures are generally stiffer under high velocity movements¹¹. Although the experimental evidence to support these claims is scant, it is likely that the high mean vertical RFD of foot-drill [\bar{x} range: 8.3 – 358BW/s] could place recruits at greater risk of lower-limb MSK overuse injury⁸.

Results of the present study are similar to those reported previously^{4, 7, 24} demonstrating similarities in the magnitudes of the impact loading forces of QM within trained and untrained men and women. The QM foot-drill, regardless of the type of footwear worn, exhibited significantly greater magnitudes of peak vGRF [$\bar{x}\Delta$: 18.4%], peak vertical RFD [$\bar{x}\Delta$: 85.4%], and shorter TTP [$\bar{x}\Delta$: 80.7%] when compared to walk. These significant differences observed between QM and walk may be associated with the greater mean speeds observed in QM [0.39m/s, $\bar{x}\Delta$: 19.2%] when compared to walk. Further observations indicated that QM demonstrated a distinct impact peak across all footwear types when compared to the walk, with a steeper initial slope from initial contact to peak vGRF [figure 2].

The greater forces and shorter TTP of QM have been linked to the effective mass of the stamping [active] limb travelling at a higher velocity prior to ground contact⁴. It was reported that untrained [recruits] men produced mean peak tibial impact accelerations of $38 \pm 16\text{m/s}^{-2}$ when marching⁴, suggesting that the exaggerated heel strike of QM is likely a factor associated with an increased risk

of calcaneus stress fractures, plantar fasciitis, Achilles tendinopathy, and muscle strains of the soleus and gastrocnemius. Despite these data being extracted during the impact phase, whereby footwear and specific neuromuscular mechanisms are likely to have influenced the magnitude of accelerations, these data provide an indirect approximation of the peak tibial impact accelerations of British Army foot-drill in an untrained military sample.

In accordance with previous research²⁶, an inverse relationship generally exists between the magnitude of peak vGRF and TTP. During cyclic high impact loading activities, the MSK system is exposed to forces that contain passive components; forces that peak within the initial 10ms, and active components; forces that peak over a longer period and represent the role of the muscles in force attenuation¹⁵. The mean TTP relative to Halt, SaA, and SaE ranged between 18–14ms, which is considerably lower than the threshold range [50-70ms] for muscle to actively respond to the landing/contact stimulus⁸. Consistent with previous research⁸, it is reasonable to suggest that the peak vGRF of SaA, SaE and Halt are passive forces, and when achieved, may not be under neuromuscular control, potentially causing the corresponding high deflection in the vertical direction to exceed the threshold stress (maximum tolerable stress)¹⁵. This potentially increases the risk of bone-on-bone contact and subsequent depression of the tibial and femoral cartilage and meniscus¹⁵.

Unlike traditional athletic landing techniques, whereby athletes are encouraged to land with greater degrees of knee and ankle flexion as a means of attenuating and dispersing the impact loading forces at ground contact, foot-drill necessitates an extended-knee landing. Both male and female recruits are taught to forcefully impact the ground with minimal to no hip, knee and/or ankle joint flexion [figure 2]. The stiffer landing patterns/strategies of foot-drill may predispose recruits to bone strains within [400-1500 $\mu\epsilon$] and above [10,000 $\mu\epsilon$] the single-load failure threshold, typically resulting in bone micro-damage and subsequent stress fracture³⁰.

Understanding the function and utility of different military footwear and their implications with respect to injury risk potential [and its mitigation] in recruits during BMT, is essential for maintaining

effective operational and tactical performance. Based on these results and those of other empirical research^{4,6}, it could be suggested that the movement/landing patterns of specific British Army foot-drill manoeuvres be modified and/or strategically managed in accordance with other maximal and submaximal loading activities, reducing the potential risk of lower-limb MSK injury associated with the high impact loading forces experienced by British Army personnel. However, British Army foot-drill is the primary method of instilling discipline into entry-level recruit populations and has been taught and practiced for centuries, and thus, unlikely to change. Therefore, a strategically more robust shock absorbing outsole design worn during foot-drill training may contribute to a marginal reduction in the relative magnitude and accumulative impact loading forces of foot-drill. Nevertheless, future research into the efficacy of specific shock absorbing footwear and its potential for lower-limb MSK injury risk mitigation is required, as reducing the cyclic high impact loading forces of foot-drill may contribute to a potential reduction in the high incidence rates of lower-limb MSK overuse injuries and medical discharges of British Army recruit populations.

Practical Implications

The foot-drill movement performed with the TR resulted in a total reduction in the magnitude of peak vGRF and peak vertical RFD of 17.9% and 16.8% when compared to the CB, and 25.5% and 32.3% when compared to the AB, respectively. These data provide commanders and PTIs with important information concerning the shock absorption interactions of specific standard issue footwear during foot-drill and the potential for impact-related lower-limb MSK overuse injury. Furthermore, commanders and PTIs are able to make better-informed decisions on the specific type of footwear most effective at marginally reducing the accumulative high impact loading forces of foot-drill during the initial phases of BMT.

References

1. Afifi M. Hinrichs R.N. A Movement Comparison between Landing from a Countermovement Jump and Landing from Stepping off a Box. *J App Biomech*, 28: 1-9, 2012.
2. Bauer JJ. Fuchs RK. Smith GA. Snow C.M. Quantifying Force Magnitude and Loading Rate from Drop Landings that Induce Osteogenesis. *J App Biomech*, 17: 142-152, 2001.
3. British Army Drill Instructor Manual [BADIM]. 2009. *ATM-Media*, [CD-ROM].
4. Carden PPJ. Iazard R. Greeves JP. Lake JP. Myers SD. Force and Acceleration Characteristics of Military Foo Drill: Implications for Injury Risk in Recruits. *BMJ Open Sport and Exercise Medicine*, 1-7, 2015.
5. Challis, JH. The Variability in Running Gait cause by Force Plate Targeting. *J App Biomech*, 17: 77-83, 2001.
6. Connaboy C. Lyall N. Simpson R. Murray-Graham S. Florida-James G Coleman S. Soldiers as Tactical Athletes: Incorporating Military Drill within a Periodised Training Programme. In: *Proceedings of the 2nd International Congress on Soldiers' Physical Performance*. Jyvaskyla, Finland, 142, 2011.
7. Decker MJ. Torry MR. Wyland DJ. Sterett WI. Steadman JR. Gender Difference in Lower Extremity Kinematics, Kinetics and Energy Absorption during Landing. *Science Direct*, 18: 662-669, 2003.
8. Donoghue OA. Shimojo H. Takagi H. Impact Forces of Plyometric Exercises Performed on Land and in Water. *Sports Physical Therapy*, 3 (3): 303-309, 2011.
9. Field A. *Discovering Statistics using IBM SPSS Statistics*. 4th Edition. Sage Publications Ltd, pg 543-546, 2012.
10. Foti T.A. Hamill J. Shoe Cushioning Effects on Vertical Ground Reaction Force during Running. *XIVth Congress of the International Society of Biomechanics*, 1: 418-419, 1993.

11. Fowler NE. Lees A. A Comparison of the Kinetic and Kinematic Characteristics of Plyometric Drop-Jump and Pendulum Exercise. *J App Biomech*, 14: 260-275, 1998.
12. Hamill J. Bensek CK. Biomechanical Analysis of Military Boots: Phase III Recommendations for the Design of Future Military Boots. *U.S. Army Soldier Systems Command Natick Research, Development and Engineering Centre*, 1-36, 1996.
13. Harman E. Frykman P. Pandorf C. Lafiandra M. Smith Ty. Mello R. Patton J. Bensek C Obusek J. A Comparison of 2 Current-Issue Army Boots, 5 Prototype Military Boots, and 5 Commercial Hiking Boots: Performance, Efficiency, Biomechanics, Comfort and Injury. *U.S Army Research Institute of Environmental Medicine Natick Soldier Centre*, 1-104, 1999.
14. Logan S. Hunter I. Hopkins JTy. Feland B. Parcell AC. Ground Reaction Force Differences between Running Shoes, Racing Flats, and Distance Spikes in Runners. *J Sp Sci Med*, 9: 147-153, 2010.
15. Makinejad MD. Osman NAA. Abas WABW. Bayat M. Preliminary Analysis of Knee Stress in Full Extension Landing. *Clinical Science*, 68 (9): 1180-1188, 2013.
16. Milner CE. Ferber R. Pollard CD. Hamill J. Davis IS. Biomechanical Factors Associated with Tibial Stress Fracture in Female Runners. *Med. Sci. Sports. Exerc*, 38 (2): 323-328, 2006.
17. Ministry of Defence [MOD]. *Announcement: Deal signed for new combat boots*. Gov.uk. July 2012.
18. Milgrom C. Finestone A. Shlamkovitch N. Rand N. Lev B. Simkin A. Wiener M. [1994]. Youth is a Risk Factor for Stress Fracture. *J Bone Joint Surg*, 76-B [1]: 20-22, 1994.
19. Nunns M. Stiles V. Dixon S. The Effects of Standard Issue Royal Marine Recruit Footwear on Risk Factors associated with Third Metatarsal Stress Fractures. *Footwear Science*, 4 (1): 59-70, 2012.
20. Pohl MB. Mullineaux DR. Milner CE. Hamill J. Davis IS. Biomechanical Predictors of Retrospective Tibial Stress Fractures in Runners. *J biomech*, 41: 1160-1165, 2008.

21. Puddle D. Maulder P S. Ground Reaction Forces and Loading Rates associated with Parkour and Traditional Drop Landing Techniques. *J of Sports Sci Med*, 12: 122-129, 2013.
22. Popovich RM. Gardner JW. Potter R. Knapik JJ. Jones BH. Effects of Rest from Running on Overuse Injuries in Army Basic Training. *Am J of Prev Med*, 18: 147-155, 2000.
23. Ramey MR. Williams KR. Ground Reaction Forces in the Triple Jump. *Int J Sport Biomech*, 1: 233-239, 1985.
24. Rawcliffe AJ. Simpson RJ. Graham SG. Psycharakis SG. Moir GL. Connaboy C. Reliability of the Kinetics of British Army Foot-Drill in Untrained Personnel. *J Strength Cond Res*, 31 (2): 435-444, 2016.
25. Rosendale L. Langberg H. Skov-Jensen A. Kjaer M. [2003]. Incidence of Injury and Physical Performance Adaptations during Military Training. *Clin J Sports Med*, 2003; 13, 157-163. 2003.
26. Seegmiller J.G. McCaw S.T. Ground Reaction Forces among Gymnasts and Recreational Athletes in Drop Landings. *J Athl Train*, 38 [4]: 311-314, 2003.
27. Sinclair J. Taylor PJ. Influence of New Military Athletic Footwear on the Kinetics and Kinematics of Running in relation to Army Boots. *J Strength Cond Res*, 28 (10): 2900-2908, 2014.
28. United Kingdom Defence Statistics [UKDS]. Ministry of Defence: published June 2012.
29. Wallace BJ. Kernozek TW. White JM. Kline DE. Wright GA. Peng HT. Huang CF. Quantification of Vertical Ground Reaction Forces of Popular Bilateral Plyometric Exercises. *J Strength Cond Res*, 24 (1): 207-212, 2010.
30. Warden SJ. Burr DB. Brukner PD. Stress Fracture: Pathophysiology, Epidemiology, and Risk Factors. *Curr Osteoporos Rep*, 4: 103-109, 2006.
31. Whitting JW. Steele JR. Jaffrey MA. Munro BJ. Parachute Landing Fall Characteristics at Three Realistic Vertical Descent Velocities. *Aviat Space Environ Med*, 78: 1135-1142, 2007.

32. Williams AG. Effects of Basic Training in the British Army on Regular and Reserve Army Personnel.

J Strength Cond Res, 19 (2): 254-259, 2005.

33. Williams MK. Brodine SK. Shaffer RA. Hagy J. Kaufman K. Biomechanical Properties of Infantry

Combat Boot Development. Navel Health and Research Centre, Report No. 97-26: 1997.