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 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 neuromuscular control. The marginal reductions in the magnitude of vGRF and temporal parameters in foot-drill associated with the training shoe may act to reduce the accumulative impact shock experienced by recruits, subsequently minimising the severity and rates of lower-limb MSK overuse injuries and recruit medical discharges during basic training.

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 readiness[22]. 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 worldwide[25].

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 markers[3]. 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 uniform[7]. The AB [or similar] is commonly worn by British military personnel in dress uniform or during ceremonial and/or drill duties[17] [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 4m-s^1 and 1.5m-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 3.6m-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 boots[4]; reporting peak vGRF [range = 1.3 – 5.1 bodyweights] [BWs] and peak vertical RFD [range = 67.6 – 536 bodyweights/second] [BWs/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 capabilities[14], 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, Nunns[19] and Sinclair and Taylor[27] 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 ± SD; age 24.4 ± 2.1years; height 175 ± 8.3cm; weight 86 ± 5.7kg] 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 populations[22].

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-drill[24]. 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 targeting[5] 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 Manual[3]. 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 velocity[27].

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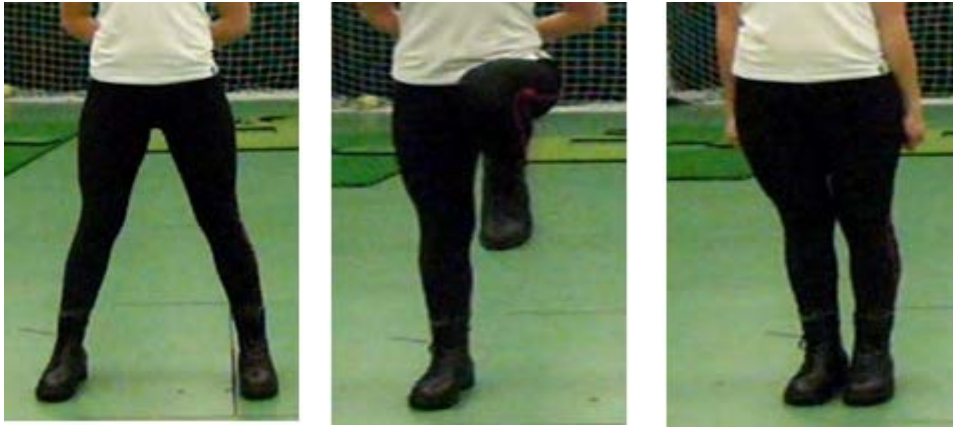

Figure 2. Illustrates a typical SaA British Army foot-drill whilst wearing the CB. From left to right, the SaA is performed from the SaE position. On command, the participant flexes at the hip to 90° followed by an exaggerated stamping of the foot onto the surface of the force plate, landing with the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

$$BW_{Norm} = \frac{\text{Fz}_{peak}}{BW} \qquad [1]$$

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;

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

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;

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

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

$$Time\ to\ Fz_{peak} = t_{max} - t_{min}$$ [4]

where, t*min* represents the time point of the initial onset of vGRF and t*max* represents the time point of Fz*peak,* 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 heteroscedascity[9]. 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 value[1]. 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 0.05 and data were statistically analysed via IBM SPSS™ 20.

Results

The mean walking speed for all participants was 1.6±0.6m/s. Although a metronome was used to standardise QM pacing across participants, the mean speed for QM was 2.02±0.01m/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.

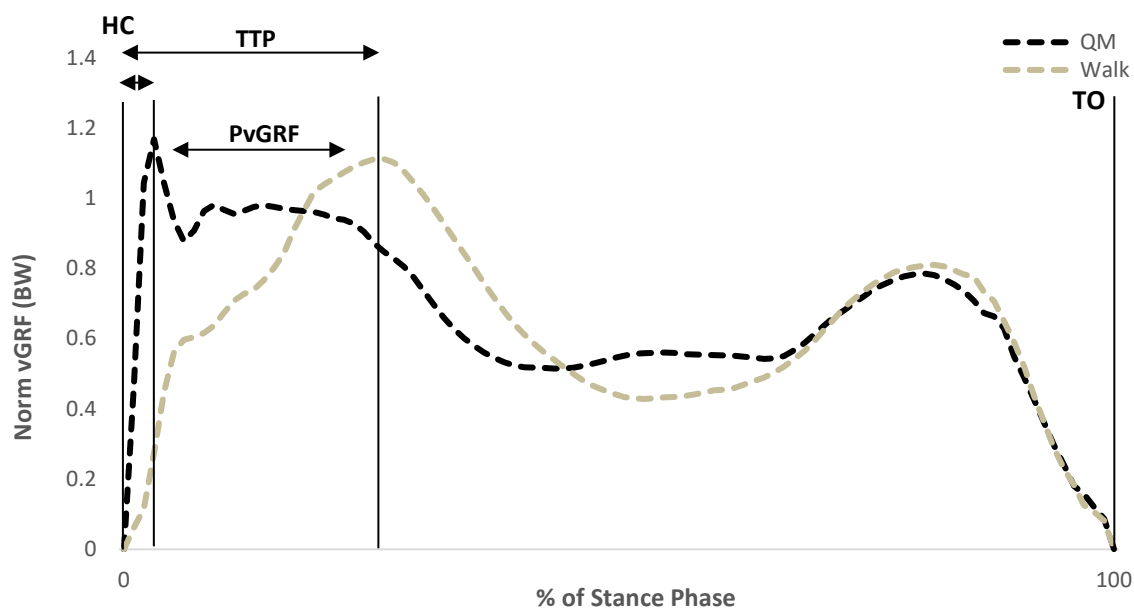**Figure 3.** A representative force-time profile of the QM and walk across all footwear types

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±0.3bw], SaE [3.8±0.3bw], and Halt [4.2±0.3bw] 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±24bw/s], QM [36±8.9bw/s], SaE [217±19.4bw/s] and Halt [249±18.6bw/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
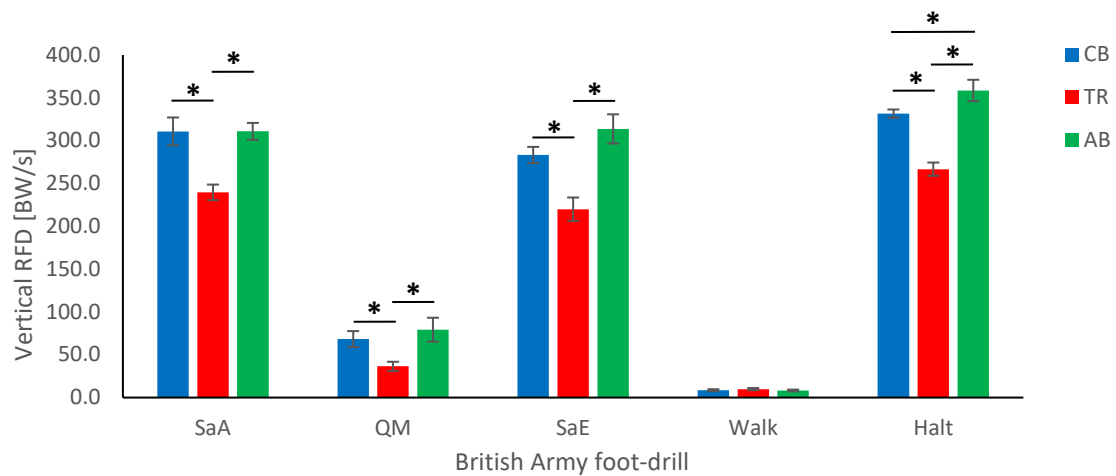

Figure 5. The mean peak vertical RFD of each foot-drill across the three types of footwear, showing significant differences [*p*<0.05] between footwear across foot-drill with vertical RFD data normalised to bodyweight/second [BW/s]. * = illustrates a significant difference. Values are means; bars are 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±0.2bw] and vertical RFD [62.2±22.8bw/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
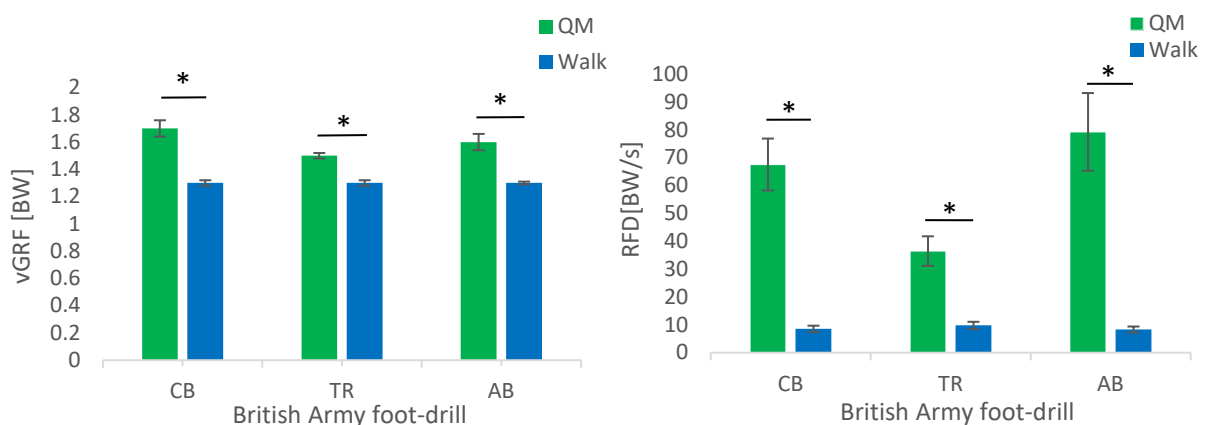

Figure 6. Significant differences [*p*<0.05] between the QM and Walk foot-drill across footwear, with vGRF normalised to [BW], and vertical RFD data normalised to BW/s. * = illustrates a significant difference. Values are means; bars are SD.

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±.01ms], SaE [18±.01ms] and Halt [16±.01ms] when compared to the AB, with significantly greater TTP values observed for TR in QM [71±.02ms] 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 biomechanical loading forces of British Army foot-drill is an essential component of 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 others[9], 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 ≤50ms. It is suggested that the capacity of any active force [under neuromuscular control] generated by the lower-limb neuromuscular system at ground contact may have been reduced by the exaggerated heel strike of QM, and the extended straight-leg landing of SaA, SaE, and Halt. Nevertheless, shorter TTP values were expected for foot-drill when compared to other landing activities, namely, drop jumps[11], as recruits are taught to actively reduce 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 Carden[4], 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-layer[16]. 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 Carden[4] 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, as 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 others[27], 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 gymnasts[26]. 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 shoe[14]. 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, it can be suggested that lower levels of MSK injury risk are associated with the shock absorbing capabilities of the TR in comparison to the CB and AB.

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 considerably higher than those reported for countermovement jumps and box step offs [mean range: 185.9 – 303.7BW/s][1], and moderately higher than 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 landing[4]. All biological MSK structures are viscoelastic in nature, whose material properties are rate dependent[11]. 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 movements[11]. 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 injury[8].

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 contact[4]. It was reported that untrained

[recruits] men produced mean peak tibial impact accelerations of 38 ± 16m/s^{-2} when marching[4]. 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 research[26], 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 attentuation[15]. 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 stimulus[8]. In accordance with previous research[8], 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], potentially increasing the risk of bone-on-bone contact and subsequent depression of the tibial and femoral cartilage and meniscus[15].

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, whereby 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 [400-1500με] and above [10,000με] the single-load failure threshold, typically resulting in bone micro-damage and subsequent stress fracture[30].

A strategically more robust shock absorbing outsole design worn during foot-drill training could potentially contribute to a marginal reduction in the relative magnitude and accumulative impact loading forces of foot-drill, subsequently contributing to a potential reduction in the high incidence rates of lower-limb MSK overuse injuries and medical discharges of British Army recruit populations. Understanding the functionality and utility of different military footwear and their implications with respect to injury potential [and its mitigation] in recruits during BMT, is essential for maintaining effective operational and tactical performance, and could provide important information regarding injury prevention and performance optimisation strategies for commanders. Furthermore, reducing the critical stress distributions and potential bone-on-bone contact of the knee and ankle joint during the exaggerated heel strike of QM, and the extended-knee landing of SaA, SaE, and Halt, we recommend that the movement/landing patterns of these regimented manoeuvres be modified and/or strategically managed by commanders and physical training instructors [PTIs] in accordance with other maximal and submaximal loading activities.

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.

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