# Reliability of the Kinetics of British Army Foot Drill in Untrained Personnel

Alex J. Rawcliffe,[1] Richard J. Simpson,[2] Scott M. Graham,[1] Stelios G. Psycharakis,[3] Gavin L. Moir,[4] and Chris Connaboy[5]

[1]School of Life, Sport & Social Sciences, Edinburgh Napier University, Edinburgh, United Kingdom; [2]Department of Health and Human Performance, University of Houston, Houston, Texas; [3]Institute of Sport, Physical Education and Health Sciences, University of Edinburgh, Edinburgh, United Kingdom; [4]Exercises Science Department, East Stroudsburg University, East Stroudsburg, Pennsylvania; and [5]Neuromuscular Research Laboratory, University of Pittsburgh, Pittsburgh, Pennsylvania

## Abstract

Rawcliffe, AJ, Simpson, RJ, Graham, SM, Psycharakis, SG, Moir, GL, and Connaboy, C. Reliability of the kinetics of British Army foot drill in untrained personnel. *J Strength Cond Res* 31(2): 435–444, 2017—The purpose of this study was to quantify the reliability of kinetic variables of British Army foot drill performance within untrained civilians and report the magnitude of vertical ground reaction force (vGRF) and vertical rate of force development (RFD) of foot drills. Fifteen recreational active males performed 3 testing sessions across a 1-week period, with each session separated by 24 hours. Within each testing session participants (mean ± *SD*; age 22.4 ± 1.7 years; height 177 ± 5.6 cm; weight 83 ± 8.7 kg) completed 10 trials of stand-at-attention (SaA), stand-at-ease (SaE), Halt, quick-march (QM) and a normal walking gait, with vGRF and vertical RFD measured on a force plate. Between-session and within-session reliability was calculated as systematic bias, coefficient of variation calculated from the typical error ($CV_{te}$%), and intraclass correlation coefficient (ICC). Significant ($p \leq 0.05$) between-session differences were found for the vGRF SaA and SaE, and vertical RFD SaA and SaE conditions. Significant ($p \leq 0.05$) within-session differences were found for the vGRF SaA and SaE conditions. A mean vGRF $CV_{te}$% ≤10% was observed across all foot drills. However, the mean vertical RFD $CV_{te}$% observed was ≥10% (excluding SaE) across all foot drills. The ICC analyses indicated that the vGRF Halt, QM, SaA, and Walk condition achieved moderate to large levels of test–retest reliability, with only SaE failing to achieve an ICC value ≥0.75. The vertical RFD QM, SaE, and Walk condition achieved moderate levels of test–retest reliability, with Halt and SaA failing to achieve an ICC value ≥0.75. It was determined that a single familiarization session and using the mean of 8 trials of vGRF are required to achieve acceptable levels of reliability.

**Key Words** military, training, systematic bias, within-subject variation, test–retest reliability

Address correspondence to Alex J. Rawcliffe, a.rawcliffe@napier.ac.uk.

31(2)/435–444

*Journal of Strength and Conditioning Research*


## Introduction

Lower-limb musculoskeletal (MSK) overuse injuries are defined as the single most significant medical impediment to the physical readiness of recruits within the British Armed Forces (24) and the most common cause of medical discharge from the British Army (MOD, 2015). Training status specific rate of medical discharges for untrained recruits (52.2 per 1,000 personnel) is significantly greater in comparison with trained personnel (11.8 per 1,000 personnel) (1). The high rates of medical discharge of untrained personnel reflect both the intensive physical nature of basic military training (BMT), and lack of exposure to the rigorous physical demands of high training loads specific to the BMT course (1). Efforts to reduce and/or minimize the incidence of lower-limb MSK overuse injuries and disorders are of primary focus for many military organizations worldwide.

British Army foot drill is a fundamental military occupational activity, routinely practiced by recruits during BMT, and used to enhance discipline, co-ordination, and body awareness (7). Organized foot drill sessions for recruits have been reported to range from 40 to 80 minute sessions per day up to a total of 13 hours per week (5). Each foot drill contains a number of key performance markers which define that particular foot drill. For example, quick march (QM) requires marching at 2 paces per second whilst repeatedly impacting the ground with an exaggerated heel strike. Other regimented movements performed while marching involve an exaggerated stamp of the dominant or nondominant foot (depending on foot drill performed) onto the surface of the ground. Foot drills such as stand-at-attention (SaA), stand-at-ease (SaE), and Halt, involve flexion at the hip to 90° followed by an exaggerated stamping of the foot onto the

**Table 1.** Regimented foot drill manoeuvres (BADIM, 2009).*

| Foot-drill | From QM | From SaE | From SaA | Active limb |
|---|---|---|---|---|
| QM | | | | R |
| Halt | X | | | R |
| SaA | | X | | L |
| SaE | | | X | L |
| Walk | | | | R |

*Illustrates the regimented foot drill manoeuvres completed from their respective foot drill, identified by X. The active limb refers to the left (L) or right (R) limb that is used in each foot drill.

ground, landing with the knee in an extended position. Selective British Army foot drill has previously been shown to produce high impact loading forces within soldiers who have been trained in foot drill (trained) (5) and recruits who have not (untrained) (5,9). To date, only 2 biomechanical studies have quantified the impact loading forces of selected foot drills within an untrained sample. Using the mean of 3 trials, Carden et al., (5) reported high vertical ground reaction forces (vGRF) for march, Halt, SaA and SaE; ranging from 1.3 to 4.4 BW, and high loading rates; ranging from 70 to 499 $BW\cdot s^{-1}$. Connaboy et al., (9) reported similar mean vGRF (3.06 ± 1.16 BW) and vertical rate of force development (RFD) (187.7 ± 94.2 $BW\cdot s^{-1}$) values for the same foot drills using the mean of 5 trials. Both studies illustrate impact loading forces similar to those experienced during high level plyometric exercises; a modality of training more commonly associated with highly trained athletic populations (4).

However, although Connaboy et al. (9) and Carden et al. (5) investigated the impact loading forces of foot drill, the number of trials used to accurately assess ground reaction force (GRF) variables of foot drill was selected arbitrarily, with no justification regarding the requirement for any familiarization sessions and/or trials before data collection, and no rationale for the mean number of trials used to represent the forces achieved. Using too few trials to assess biomechanical variables of foot drill may not reliably represent the individual's true performance. Consequently, the stability and reproducibility of mean values could be questioned as the magnitude and influence of variability within previous foot drill data was not calculated. The sources of error that contribute to the overall reliability of the measure primarily consist of biological, and technological–with a reliable test characterized by low within-subject (WS) variation and high test–retest correlation (16,18). Analyzing the magnitude of a systematic bias, within-subject variation, and test–retest correlation of foot drill will provide valuable information that will better inform future biomechanical studies of foot drill in terms of the necessary number of trials required to obtain accurate and stable measures of foot drill performance, and the requirement of any familiarization sessions and/or trials before analyzing the impact loading forces of foot drill within an untrained sample.

Therefore, the aims of the present study were threefold: (a) to determine the magnitude of any systematic bias among session(s) and between trial(s), (b) to establish the within-subject variation of key biomechanical variables, and (c) to analyze the test–retest reliability to indicate the number of sessions and/or trials required to maximize the possibility of identifying changes in the kinetics of British Army foot drill between different conditions and over time.

It was hypothesized that similar to other locomotor and landing tasks, several trials would be necessary to achieve high levels of performance stability during British Army foot drill, and that familiarization sessions and/or trials would be required before collecting stable foot drill biomechanical data. In addition, it was hypothesized that as random error decreased, test–retest correlation scores would increase when using the average of multiple trials.

## Methods

### Experimental Approach to the Problem

A within-participant repeated-measures study design was used to assess measures of reliability; establishing the requirement for familiarization sessions and/or trials to determine within-subject variation and test–retest reliability.

### Subjects

Fifteen recreational active healthy males (mean ± *SD*; age 22.4 ± 1.7 years; height 177 ± 5.6 cm; body mass 83 ± 8.7 kg) with no pathological lower-limb, hip, or spinal conditions volunteered to participate in the present study. Study participants were recreationally active, taking part in moderate physical activity and/or sport a minimum of 2–3 times per week over the previous 3 years (11). Ethical approval for the present study was granted from the local ethics committee. Written informed consent was obtained from each participant before data collection. Study participants were defined as "untrained" as they did not obtain any previous training of British Army foot drill before this study. Nevertheless, the study participants had similar anthropometric characteristics and training histories when compared with male entry-level recruits (21,28).

### Procedures

During each of the three 90 minute testing sessions, 10 acceptable trials (20) of 5 British Army foot drills, involving SaA, SaE, QM, Halt, and a normal walking gait were collected from each participant independently. Acceptable trials were those that conformed to the key performance markers

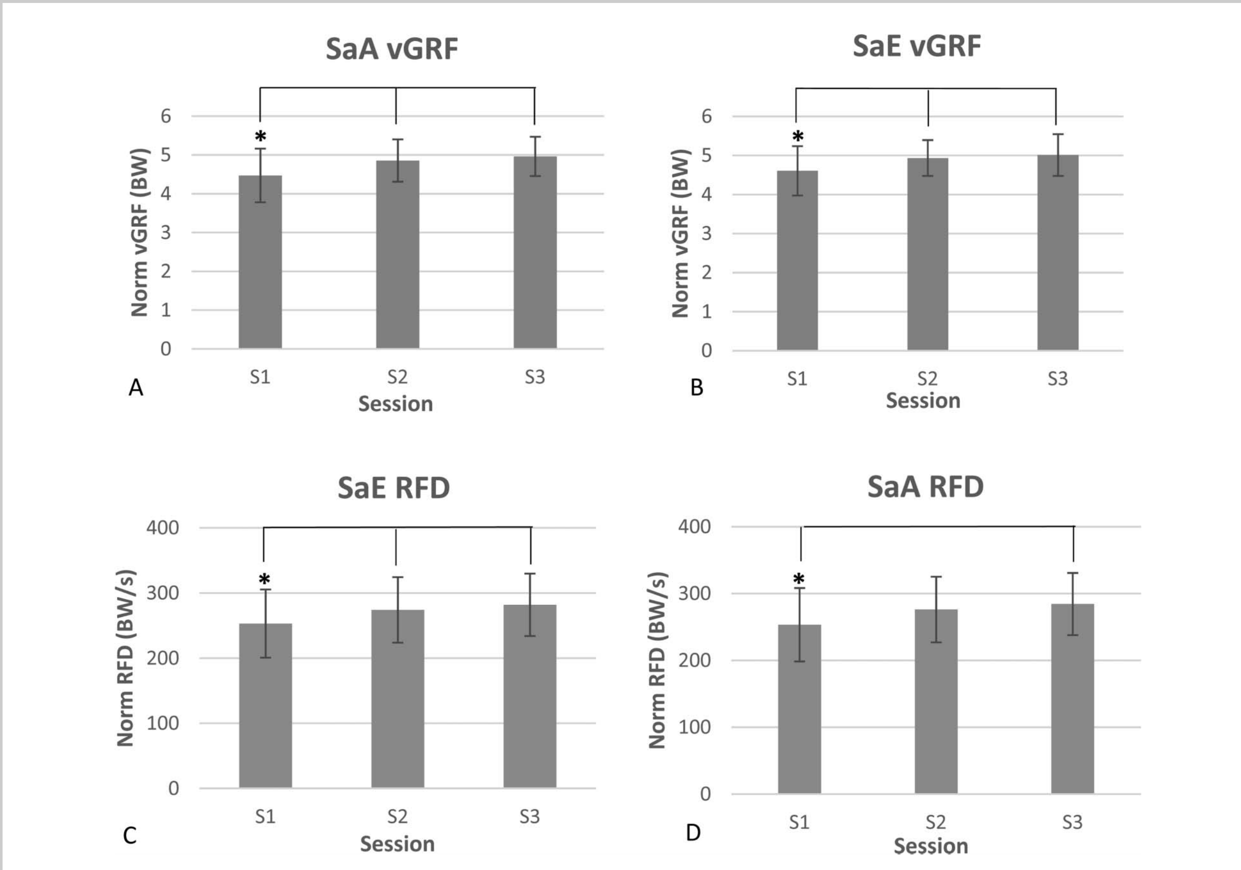


**Figure 1.** Reliability (systematic bias) of the vGRF and RFD SaA and SaE condition. Mean values for session (1–3) for vGRF SaA (A), vGRF SaE (B), RFD SaE (C), and RFD SaA (D). *Statistically significant difference ($p > 0.05$). Values are session means; bars are *SD*.

as described in the British Army Drill Instructors Manual (BADIM) (2). Furthermore, if obvious adjustments in foot-drill movements were identified, those trials were discarded and repeated. Ten trials of a normal walking gait were collected on each day of testing to act as a comparison with QM. Foot drill data were collected on 3 nonconsecutive days. All 3 test sessions were conducted at the same time of day and performed under the guidance of the same instructor. Participants were asked to avoid practicing foot drill throughout the testing period and to refrain from strenuous, high impact loading activity 24 hours before each test session.

Each participant was fitted with a size-specific pair of Hi-Tech Silver Shadow training shoes (TR) to reduce the influence of different shock absorbing properties of different footwear on force plate data (12). Each participant performed a standardized 10 minute warm up whilst wearing the TR, consisting of 5 minutes on a cycle ergometer (824-E; Monark Exercise AB, Vansbro, Sweden), cycling between 60 and 70 revolutions per minute under a 1.5 kg breaking force, followed by various dynamic lunging and squatting movements before each test session (27). Foot drill and Walk were performed on 2 embedded (side-by-side) Kistler force plates (9281CA; Kistler Instruments AG, Winterthur, Switzerland) –interfaced with BioWare 3.2.5 software to record and analyze the vGRF and vertical RFD of each foot drill and Walk. The force plate was set at a sampling frequency of 1,000 Hz with a 3 second capture period (25,31). Force data were collected using an 8 channel 16-bit analogue to digital converter (8128; Qualisys, Göteborg, Sweden). The vGRF values were normalized to bodyweight (BW) to enable direct comparison across participants.

Representative of an entry-level recruit, foot drill was a novel task for all participants before data collection. Furthermore, a combination of action observation and physical practice in accordance with the BADIM (2) was used as a means of demonstrating and teaching foot drill. Study participants were given a 3 second countdown before the execution of each foot drill. Specific to QM, participants were instructed to QM with an exaggerated heel strike across the 10-m walkway (2,5). During the execution of SaA, SaE, and Halt, study participants were instructed to flex their hip to 90° and land with an exaggerated stamp onto the surface of the force plate with

**TABLE 2.** vGRF and RFD foot drill WS variability results.*†

| Variable (units or ratio) | Trials ($n$) | | $TE_n$ | $TE_{LCL}$ | $TE_{UCL}$ | | %CV | $CV_{LCL}$ | $CV_{UCL}$ |
|---|---|---|---|---|---|---|---|---|---|
| Halt | 3 | ×/÷ | 1.08 | 1.06 | 1.11 | ×/÷ | 7.5 | 5.9 | 11.2 |
| | 4 | ×/÷ | 1.07 | 1.06 | 1.09 | ×/÷ | 7.0 | 5.6 | 9.5 |
| | 5 | ×/÷ | 1.07 | 1.05 | 1.09 | ×/÷ | 6.6 | 5.5 | 8.5 |
| | 6 | ×/÷ | 1.07 | 1.06 | 1.09 | ×/÷ | 6.9 | 5.8 | 8.6 |
| | 12 | ×/÷ | 1.07 | 1.06 | 1.08 | ×/÷ | 7.0 | 6.3 | 8.3 |
| | 18 | ×/÷ | 1.07 | 1.06 | 1.08 | ×/÷ | 6.8 | 6.2 | 7.8 |
| | 24 | ×/÷ | 1.07 | 1.06 | 1.07 | ×/÷ | 6.6 | 6.2 | 7.4 |
| Halt RFD | 3 | ×/÷ | 1.23 | 1.18 | 1.36 | ×/÷ | 23.5 | 18.0 | 35.9 |
| | 4 | ×/÷ | 1.02 | 1.16 | 1.27 | ×/÷ | 19.8 | 15.8 | 27.3 |
| | 5 | ×/÷ | 1.18 | 1.15 | 1.23 | ×/÷ | 18.0 | 14.7 | 23.5 |
| | 6 | ×/÷ | 1.17 | 1.14 | 1.21 | ×/÷ | 16.7 | 14.0 | 21.1 |
| | 12 | ×/÷ | 1.15 | 1.13 | 1.17 | ×/÷ | 14.7 | 13.0 | 17.1 |
| | 18 | ×/÷ | 1.16 | 1.15 | 1.18 | ×/÷ | 16.1 | 14.5 | 18.1 |
| | 24 | ×/÷ | 1.16 | 1.14 | 1.17 | ×/÷ | 15.5 | 14.2 | 17.2 |
| | 30 | ×/÷ | 1.14 | 1.13 | 1.16 | ×/÷ | 14.3 | 13.2 | 15.6 |
| QM vGRF | 3 | ×/÷ | 1.1 | 1.08 | 1.15 | ×/÷ | 10.0 | 7.8 | 15.0 |
| | 4 | ×/÷ | 1.11 | 1.08 | 1.14 | ×/÷ | 10.5 | 8.5 | 14.3 |
| | 5 | ×/÷ | 1.11 | 1.09 | 1.14 | ×/÷ | 10.6 | 8.7 | 13.7 |
| | 6 | ×/÷ | 1.1 | 1.08 | 1.12 | ×/÷ | 9.9 | 8.3 | 12.4 |
| | 12 | ×/÷ | 1.1 | 1.09 | 1.12 | ×/÷ | 10.1 | 8.9 | 11.7 |
| | 18 | ×/÷ | 1.09 | 1.08 | 1.1 | ×/÷ | 9.1 | 8.2 | 10.2 |
| | 24 | ×/÷ | 1.09 | 1.08 | 1.09 | ×/÷ | 8.6 | 7.9 | 9.5 |
| | 30 | ×/÷ | 1.08 | 1.08 | 1.09 | ×/÷ | 8.3 | 7.7 | 9.1 |
| QM RFD | 3 | ×/÷ | 1.55 | 1.41 | 1.9 | ×/÷ | 55.2 | 41.2 | 89.8 |
| | 4 | ×/÷ | 1.56 | 1.43 | 1.81 | ×/÷ | 55.6 | 43.3 | 80.7 |
| | 5 | ×/÷ | 1.6 | 1.48 | 1.82 | ×/÷ | 59.8 | 47.8 | 82.0 |
| | 6 | ×/÷ | 1.61 | 1.49 | 1.8 | ×/÷ | 60.7 | 49.4 | 79.9 |
| | 12 | ×/÷ | 1.49 | 1.43 | 1.58 | ×/÷ | 49.2 | 42.7 | 58.1 |
| | 18 | ×/÷ | 1.44 | 1.4 | 1.51 | ×/÷ | 44.3 | 39.5 | 50.5 |
| | 24 | ×/÷ | 1.41 | 1.37 | 1.46 | ×/÷ | 41.0 | 37.2 | 45.8 |
| | 30 | ×/÷ | 1.41 | 1.38 | 1.45 | ×/÷ | 41.1 | 37.7 | 45.4 |
| SaA vGRF | 3 | ×/÷ | 1.06 | 1.05 | 1.09 | ×/÷ | 6.3 | 4.9 | 9.4 |
| | 4 | ×/÷ | 1.06 | 1.05 | 1.08 | ×/÷ | 6.0 | 4.8 | 8.1 |
| | 5 | ×/÷ | 1.06 | 1.05 | 1.08 | ×/÷ | 6.4 | 5.3 | 8.2 |
| | 6 | ×/÷ | 1.06 | 1.05 | 1.08 | ×/÷ | 6.2 | 5.2 | 7.7 |
| | 12 | ×/÷ | 1.05 | 1.05 | 1.06 | ×/÷ | 5.5 | 4.8 | 6.3 |
| SaA RFD | 3 | ×/÷ | 1.26 | 1.20 | 1.40 | ×/÷ | 26.0 | 19.9 | 40.0 |
| | 4 | ×/÷ | 1.28 | 1.22 | 1.39 | ×/÷ | 28.2 | 22.4 | 39.4 |
| | 5 | ×/÷ | 1.24 | 1.20 | 1.32 | ×/÷ | 24.4 | 20.0 | 32.2 |
| | 6 | ×/÷ | 1.22 | 1.18 | 1.28 | ×/÷ | 22.1 | 18.4 | 28.0 |
| | 12 | ×/÷ | 1.16 | 1.14 | 1.18 | ×/÷ | 15.9 | 14.0 | 18.4 |
| | 18 | ×/÷ | 1.14 | 1.13 | 1.16 | ×/÷ | 14.3 | 12.9 | 16.1 |
| Walk vGRF | 3 | ×/÷ | 1.02 | 1.02 | 1.03 | ×/÷ | 1.9 | 1.5 | 2.9 |
| | 4 | ×/÷ | 1.02 | 1.02 | 1.03 | ×/÷ | 2.1 | 1.7 | 2.8 |
| | 5 | ×/÷ | 1.03 | 1.02 | 1.03 | ×/÷ | 2.5 | 2.1 | 3.3 |
| | 6 | ×/÷ | 1.03 | 1.02 | 1.03 | ×/÷ | 2.8 | 2.3 | 3.4 |
| | 12 | ×/÷ | 1.03 | 1.03 | 1.04 | ×/÷ | 3.1 | 2.4 | 3.3 |
| | 18 | ×/÷ | 1.03 | 1.03 | 1.03 | ×/÷ | 3.1 | 2.7 | 3.5 |
| | 24 | ×/÷ | 1.03 | 1.03 | 1.03 | ×/÷ | 3.1 | 2.7 | 3.4 |
| | 30 | ×/÷ | 1.03 | 1.03 | 1.03 | ×/÷ | 3.1 | 2.8 | 3.4 |
| Walk RFD | 3 | ×/÷ | 1.45 | 1.34 | 1.72 | ×/÷ | 45.2 | 34 | 72.2 |
| | 4 | ×/÷ | 1.5 | 1.39 | 1.71 | ×/÷ | 49.6 | 38.8 | 71.4 |
| | 5 | ×/÷ | 1.48 | 1.38 | 1.64 | ×/÷ | 47.6 | 38.3 | 64.4 |
| | 6 | ×/÷ | 1.49 | 1.4 | 1.64 | ×/÷ | 49.2 | 40.3 | 64.1 |
| | 12 | ×/÷ | 1.66 | 1.57 | 1.78 | ×/÷ | 65.7 | 56.6 | 78.3 |
| | 18 | ×/÷ | 1.59 | 1.53 | 1.68 | ×/÷ | 59.3 | 52.7 | 68.1 |
| | 24 | ×/÷ | 1.57 | 1.52 | 1.64 | ×/÷ | 57.4 | 51.8 | 64.5 |
| | 30 | ×/÷ | 1.55 | 1.51 | 1.61 | ×/÷ | 55.4 | 50.6 | 61.4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SaE vGRF | 3 | ×/÷ | 1.06 | 1.05 | 1.09 | ×/÷ | 5.9 | 4.6 | 8.7 |
| | 4 | ×/÷ | 1.05 | 1.04 | 1.07 | ×/÷ | 5.4 | 4.4 | 7.3 |
| | 5 | ×/÷ | 1.06 | 1.05 | 1.07 | ×/÷ | 5.8 | 4.8 | 7.5 |
| | 6 | ×/÷ | 1.06 | 1.05 | 1.08 | ×/÷ | 6.1 | 5.1 | 7.6 |
| | 12 | ×/÷ | 1.07 | 1.06 | 1.08 | ×/÷ | 6.6 | 5.9 | 7.6 |
| | 18 | ×/÷ | 1.06 | 1.06 | 1.07 | ×/÷ | 6.4 | 5.8 | 7.1 |
| SaE RFD | 3 | ± | 35.4 | 27.8 | 51.6 | ± | 13.0 | 10.18 | 21.9 |
| | 4 | ± | 31 | 25.2 | 41.5 | ± | 10.9 | 8.05 | 17.4 |
| | 5 | ± | 29 | 24.1 | 37 | ± | 10.4 | 7.76 | 16.7 |
| | 6 | ± | 28.7 | 24.3 | 35.5 | ± | 10.5 | 7.39 | 15.9 |
| | 12 | ± | 26.9 | 23.9 | 30.8 | ± | 9.8 | 7.03 | 15.1 |
| | 18 | ± | 25.7 | 23.4 | 28.7 | ± | 9.2 | 6.52 | 14.0 |

*TE = typical error for *n* cycles; LCL = lower confidence limit; UCL = upper confidence limit; random error is represented in absolute form (±); random error is represented in ratio form (×/÷).
†For the sake of brevity, a reduced number of trials were reported highlighting the initial changes in WS variation with the inclusion of additional single trials, and to highlight the extent of change in WS variation calculated from a greater number of trials. The vGRF and RFD foot drill data found to obtain a SB are not presented in Table 2, hence the variation in the total number of trials presented between foot drills.

the knee in an extended position. Study participants kept their head and eyes forward to minimize visual fixation (targeting) of the force plate during all foot-drill trials (6). During the initial testing session only, study participants were given 15 minutes to practice the 5 foot drills before data collection and become familiar with the TR.

A 90 second recovery period between each of the 10 trials and a 15 minute recovery between foot drills was used to reduce the risk of fatigue on foot drill performance (4). Ten trials were collected for each of the 5 foot drills during each of the 3 test sessions. A total of 30 trials were analyzed for each of the 5 foot drills. Accumulatively, 150 (acceptable) trials were collected and analyzed per participant. As a means of enhancing the internal validity of the present study whilst minimizing an order effect, foot drill was counterbalanced for each participant across all 3 testing sessions (15).

#### Key Performance Markers of British Army Foot Drill

A comprehensive description of each foot drill analyzed within the present study can be found in the BADIM (2). The foot which strikes the force plate during each of the foot drill is referred to as the active limb with the opposite limb referred to as the support limb (Table 1).

Ten trials of a normal walking gait were included in the analysis for each participant to compare with the biomechanical variables of QM. Walking, performed by each participant at their preferred walking speed, was measured in meters per second and was standardized for each individual participant via timing gates (SmartSpeed; Fusion Sport, Australia) located at 0-m, 5-m, and 10-m along the 10-m walkway. The velocity of walking was monitored across each test session and a maximum deviation of ±5% was allowed from each participant's walking velocity (33). Foot drill vGRF data were exported through BioWare 3.2.5 system and filtered through a low-pass fourth order zero-lag (single bi-directional) Butterworth filter, using a cutoff frequency of 50 Hz based on previous power spectrum analysis, ensuring that 95% of the signal content was retained (34).

The BW normalized vGRF was calculated as

$$BW_{Norm} = \frac{Fz_{peak}}{BW} \tag{1}$$

where, $BW_{Norm}$ is the normalized vGRF expressed in BW, $Fz_{peak}$ is the peak vertical ground reaction force measured in Newtons, and BW is the participant's bodyweight expressed in Newtons determined through the force plate. The kinetic variables of interest were defined and calculated as follows: $Fz_{peak}$–defined as the highest (Peak) vertical ground reaction force (measured in Netwons) of each foot drill.

Time to $Fz_{peak}$–defined as the time to reach $Fz_{peak}$ expressed in milliseconds.

$$\text{Time to } Fz_{peak} = t_{max} - t_{min} \tag{2}$$

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 20 N (27). The vertical RFD was calculated as

$$RFD = \frac{\Delta F}{\Delta T} \tag{3}$$

where, RFD is the rate of force development measured in Newtons per second, ΔF represents the change in force measured in Newtons and, ΔT represents the change in time measured in seconds (13).

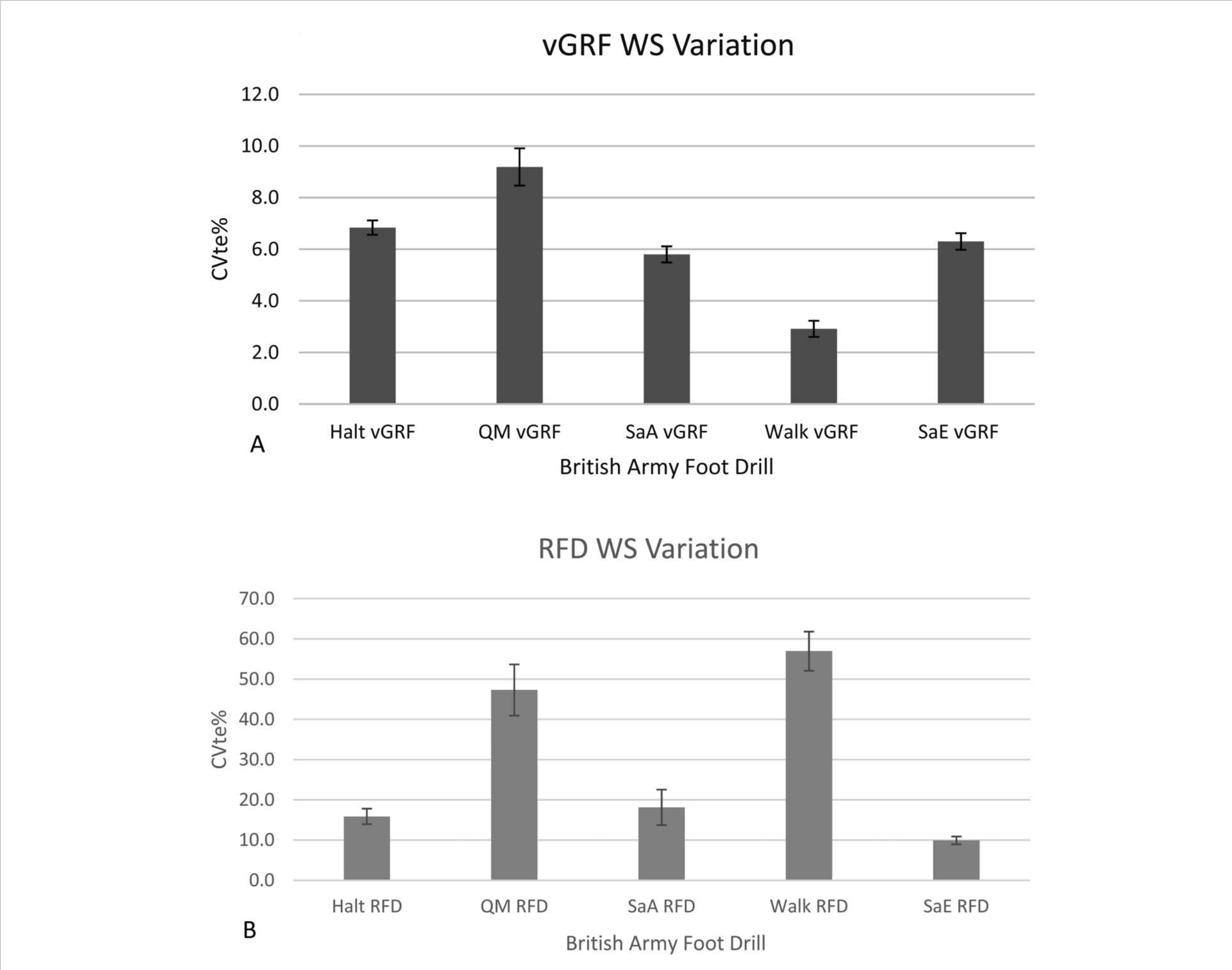


**Figure 2.** WS variation expressed as a CVte% of the vGRF and RFD across all foot drills. (A) vGRF WS variation, (B) RFD WS variation. Values are session means; bars are *SD*.

Vertical RFD was normalized relative to participant's BW calculated as

$$\text{Norm RFD} = \frac{\text{RFD}}{\text{BW}} \tag{4}$$

where, Norm RFD is the vertical RFD normalized to the participant's bodyweight, measured in Newtons.

### Statistical Analyses

Before calculating systematic bias, within-subject variation and test–retest correlation, each of the biomechanical variables was examined for heteroscedasticity (3). If heteroscedasticity was not present and showed no departures from a normal distribution, the raw data were used in the reliability calculations. However, if the data were found to be heteroscedastic, and shown to violate the assumption of normality, then data were log transformed in SPSS 20 using 100× natural logarithm of the observed value (3,16). To isolate the effects of the between-session and within-session systematic bias only the remaining 2 testing sessions and the initial 8 trials from each session were included in the subsequent reliability analyses (within-subject variation and test–retest correlations).

Systematic bias was determined using a repeated-measures analysis of variance (RM ANOVA) design. Multiple ($n = 5$) one-way RM ANOVAs with Bonferroni adjusted multiple comparisons were conducted for each of the predictor variables (vGRF and vertical RFD) for each of the foot drills. This analysis was used as a means to determine whether the magnitude of difference among the mean values for each session ($n = 3$) and trial ($n = 10$) was statistically significant. Alpha (α) value was set at 0.05. Where any statistically significant differences between-session and/or within-session occurred, those sessions and/or trials were removed from further calculations of reliability (within-subject variation and test–retest correlations). The within-subject variation was calculated for the remaining marching drill trials that did not contain any systematic bias.

**Table 3.** vGRF and RFD foot-drill ICC results.*

| Variable (unit or ratio) | ICC maximum (*n* cycles) | ICC | ICC (95% LCL) | ICC (95% UCL) | ICC 0.75 (*n* cycles) | ICC 0.80 (*n* cycles) | ICC 0.85 (*n* cycles) |
|---|---|---|---|---|---|---|---|
| Halt vGRF | 5 | 0.821 | 0.659 | 0.929 | 3 | 4 | – |
| Halt RFD | 15 | 0.673 | 0.503 | 0.843 | – | – | – |
| QM vGRF | 28 | 0.912 | 0.843 | 0.963 | 3 | 3 | 3 |
| QM RFD | 28 | 0.802 | 0.677 | 0.911 | 3 | 20 | – |
| SaA vGRF | 8 | 0.810 | 0.670 | 0.920 | 3 | 8 | – |
| SaA RFD | 16 | 0.621 | 0.446 | 0.810 | – | – | – |
| Walk vGRF | 3 | 0.924 | 0.818 | 0.972 | 3 | 3 | 3 |
| Walk RFD | 3 | 0.791 | 0.552 | 0.919 | 3 | – | – |
| SaE vGRF | 4 | 0.699 | 0.456 | 0.872 | – | – | – |
| SaE RFD | 19 | 0.764 | 0.622 | 0.892 | 10 | – | – |
| Mean (*SD*) | 12.9 (9.3) | | | | 4.0 (2.6) | 7.6 (7.2) | 3.0 (0.0) |

*Represents the maximum number of trials required to achieve poor, moderate, and strong levels of test–retest reliability; empty cells (–) indicate that the ICC values were never achieved. The minimum number of trials required to achieve ICC levels of 0.75, 0.80 and 0.85 were also calculated. Only the Walk and QM vGRF condition illustrated an ICC $<0.90$.

The within-subject variation was reported for the remaining trials as both the typical error and coefficient of variation of the typical error ($CV_{te}$). The within-subject variation was expressed as a percentage of the coefficient of variation of the typical error ($CV_{te}$%). The $CV_{te}$% was calculated using the methods proposed by Hopkins, (16) and was calculated as

$$CV_{te}\% = \left(\frac{TE_n}{M_n}\right) \times 100 \quad (5)$$

where $TE_n$ is the typical error of $n$ number of trials and $M_n$ is the mean value from the same $n$ repeated trials.

Test–retest reliability was calculated for all acceptable trials for each foot drill and evaluated using the intraclass correlation coefficient (ICC) (Model 3, 1) (3,17). The stability of the variation in each predictor variable was assessed using methods proposed by James et al. (20). Trials that contained a systematic bias were removed with the remaining trials used to calculate maximum ICC values. Initial ICC was calculated for all data to establish maximum ICC values and 95% confidence intervals (CI). An iterative process was then conducted by which ICC values were calculated for the initial 3 trials up to the maximum number of acceptable trials per foot drill (17). To assess the stability of each predictor variable, the minimum number of trials required to achieve maximum levels of ICC was calculated. Furthermore, to determine the minimum number of trials necessary to achieve a stable representation of the variation within each predictor variable, the numbers of trials required to achieve ICC values of 0.75, 0.80, and 0.85 were calculated.

## Results

### Systematic Bias

Statistically significant between-session differences were found for the vGRF and vertical RFD in the following foot drills: vGRF SaA condition ($F_{(2,28)} = 9.603$, $p = 0.001$, $Np^2 = 0.407$), vertical RFD SaA condition ($F_{(2,28)} = 7.152$, $p = 0.003$, $Np^2 = 0.338$), vGRF SaE condition ($F_{(2,28)} = 7.242$, $p = 0.003$, $Np^2 = 0.341$), and for the vertical RFD SaE condition ($F_{(2,28)} = 9.615$, $p = 0.001$, $Np^2 = 0.407$). Follow-up Bonferroni comparisons indicated a systematic bias between session 1 and the 2 remaining testing sessions for the vGRF SaA and SaE, and vertical RFD SaE conditions, with the vertical RFD SaA condition

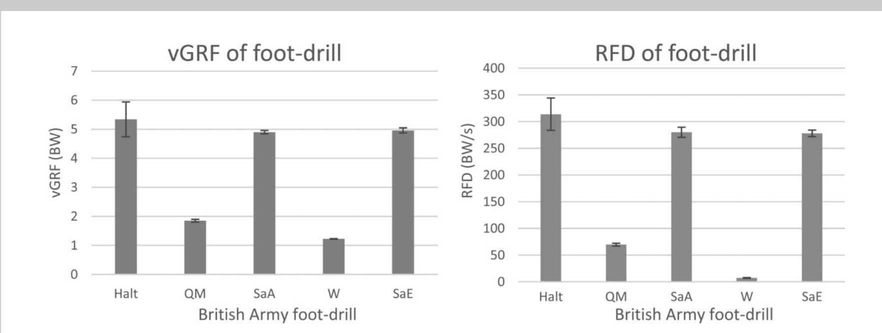


**Figure 3.** Ground reaction forces of foot drill. Normalized vGRF (BW) and RFD ($BW \cdot s^{-1}$) generated by all participants during all 5 foot drills. Values are means; bars are *SD*.

illustrating a systematic bias between sessions 1 and 3 only (Figure 1). No further statistically significant between-session systematic bias was observed for the remaining conditions.

Statistically significant within-session (between-trial) differences were found in the vGRF in the following foot drills: vGRF SaA condition ($F_{(9,126)} = 6.133$, $p < 0.01$, $Np^2 = 0.305$), vGRF SaE condition ($F_{(9,126)} = 4.408$, $p < 0.01$, $Np^2 = 0.239$), and vGRF Halt condition ($F_{(4.9,68.7)} = 2.406$, $p = 0.046$, $Np^2 = 0.147$). Bonferroni comparisons revealed a systematic bias in trial 10 for the aforementioned conditions. No further statistically significant within-session systematic bias was observed for the remaining conditions.

#### Within-Subject Variation

Table 2 illustrates the magnitude of the $CV_{te}$% found within repeated measurements of foot-drill data. Depending on the existence of heteroscedasticity, data were expressed in absolute form (preceded by ±) or ratio form (preceded by ×/÷) (3,16). Figure 2 indicates the magnitude of $CV_{te}$% relative to the vGRF variable, showing a mean $CV_{te}\% \leq 10\%$ across all foot drills (mean ± *SD* = Halt: 6.8 ± 0.3, QM: 9.2 ± 0.72, SaA: 5.8 ± 0.31, Walk: 2.9 ± 0.3, SaE: 6.3 ± 0.32) demonstrating low within-subject variability indicating good reliability. Note, however, that in Figure 2 the vertical RFD variable expressed a mean $CV_{te}\% \geq 10\%$ (excluding SaE) across foot drills (mean ± *SD* = Halt: 15.9 ± 1.93, QM: 47.3 ± 6.37, SaA: 18.1 ± 4.4, Walk: 56.9 ± 4.9, SaE: 9.9 ± 1.0) demonstrating poor levels of within-subject variability (16).

#### Test–Retest Reliability

Table 3 illustrates the level of performance stability achieved for all foot drills across the vGRF and vertical RFD variable. The maximum ICC values were recorded for the Walk vGRF condition (ICC = 0.92) with values ranging from 0.61 to 0.92. The number of trials required to achieve maximum ICC values ranged from 3 to 28 trials (mean ± *SD* = 12.9 ± 9.3 trials) across both predictor variables. With the exception of the vGRF SaE, vertical RFD SaA, and Halt conditions, all remaining foot drills achieved an ICC value ≥0.75 from 3 to 10 trials (mean ± *SD* = 4.0 ± 2.6). The vGRF variable illustrated greater levels of performance stability (mean ± *SD*, ICC = 0.835 ± 0.093) when compared with the vertical RFD variable (mean ± *SD*, ICC = 0.73 ± 0.79), suggesting that the vGRF variable could be defined as a more reliable measure with which changes in foot-drill performance could be accurately determined (Figure 3). The maximum number of trials required to achieve an ICC of 0.80 from the remaining 2 testing sessions and the initial 8 trials from each session ranged from 3 to 16 trials (mean ± *SD* = 6.8 ± 5.5). Only the QM and Walk vGRF conditions achieved an ICC ≥0.85 from a total of 3 trials (mean ± *SD* = 3.0 ± 0.0 trials).

## Discussion

The present study is the first to report reliability measures of the kinetic variables of British Army foot drill. The initial aim of the present study was to determine the existence and magnitude of between-session and within-session systematic bias. In addition, this study has quantified the impact loading forces and loading rates associated with British Army foot drill within an untrained male civilian population. The statistically significant ($p \leq 0.05$) between-session mean differences in vGRF and vertical RFD for SaA and SaE indicate that a single familiarization session is required before collecting reliable foot-drill force data suggesting that the key performance markers of selective foot drills (SaA and SaE) may require more time to learn when compared with other foot drills. The requirement of a single familiarization session can best be explained by the novelty and complexity of foot drill for untrained males. Initial analysis of the whole data set revealed within-session (between-trial) differences of the vGRF SaA and SaE conditions. However, after the removal of the first session data no between-trial differences remained, suggesting that the systematic bias apparent in the vGRF data during the first testing session was large enough to influence the remainder of the data.

The second aim was to ascertain the magnitude of the within-subject variation in each of the variables. The levels of $\%CV_{te}$ reported for the vGRF and vertical RFD variables within the present study (Figures 2A, B) are similar in magnitude to those reported by Floria et al., (14) which examined the reliability of repeated trials ($n = 3$) of the GRF of 2 different countermovement jumps ($\%CV_{te}$ range: vGRF = 12.3–13.3%, range RFD = 74.6–77.4%). In addition, Copic et al., (10) also revealed similar mean $\%CV_{te}$ values from repeated trials ($n = 3$) for GRF variables in vertical jump performance (mean $\%CV_{te}$: vGRF = 5.7%, RFD = 29.1%). As reported in previous reliability literature, (8,19) the $\%CV_{te}$ was found to reduce when the number of trials used to calculate the average score increased, with the greatest increases in reliability ($\%CV_{te}$) shown within the initial increase in the number of trials used to calculate the mean value.

Reductions in $\%CV_{te}$ (improved reliability) were apparent within the present study for the vGRF Halt, SaA, QM, and vertical RFD SaE condition, with the greatest increases in reliability shown within the initial changes in the number of trials used to calculate the mean value. For example, an average $\%CV_{te}$ reduction of 0.97% was observed when using 6 trials compared with 3 trials, a further 0.35% average reduction by using 7 trials compared with 4 trials, and an average reduction in $\%CV_{te}$ of 0.81% when using 8 trials compared with 5 trials. Beyond 8 trials, the use of additional trials of data to calculate the mean value across all foot drills resulted in diminishing returns; for every additional trial used in the calculation of the mean values, the smaller the reduction in the $\%CV_{te}$ (8). Similar average reductions in $\%CV_{te}$ were observed for the vertical RFD variables, however, these reductions did not show worthwhile improvements in levels of reliability across remaining foot drills.

The final aim of this study was to determine the test–retest reliability of foot-drill force data to provide additional information to make decisions regarding the number of trials of data required to achieve stable levels of performance, and to accurately track changes in foot drill performance over time. However, it should be noted that ICC values at which test–retest reliability are deemed poor (ICC ≤0.75), moderate (ICC 0.75–0.85), and strong (ICC ≥0.85) are arbitrary values (8,16). Nevertheless, the ICC is defined as more of an objective means of assessing the number of trials required to establish the stability of performance than other measures (i.e., sequential averaging), as it involves fewer arbitrary decisions when assessing performance stability (8,20).

The initial interpretation of the ICC analyses shows that the vGRF Halt, QM, SaA, and Walk condition achieved moderate to strong levels of test–retest reliability, with only SaE failing to achieve an ICC value ≥0.75. Maximum ICC values for the vertical RFD variable range from 0.62 for SaA to 0.80 for QM, illustrating poor to strong levels of test–retest reliability. However, strong levels of test–retest reliability were only achieved in QM and Walk. The QM, SaE, and Walk vertical RFD values achieved moderate levels of test–retest reliability, with Halt (range = 0.36–0.67) and SaA (range = 0.24–0.62) failing to achieve an ICC value ≥0.75 (16). This finding suggests that multiple trials of foot-drill force data (mean ± *SD*: vGRF = 8.5 ± 6.7 trials, RFD = 13.7 ± 12.9 trials) are required before maximum ICC values can be obtained.

It is recommended that ICC data should not be considered in isolation, rather, within-subject variability data should also be taken into account when making decisions regarding the minimum number of trials required to accurately represent the GRF of foot-drill data as data can be adversely influenced by the homogeneity of the test sample, which will affect any interpretation of reliability (3,8,16,19,23). Also, by considering the magnitude of the within-subject variation, the number of trials required to ensure a reliable assessment of each force variable can provide a measure of accuracy with which any future changes in vGRF and/or vertical RFD of foot-drill performance can be monitored (8).

This study has reported foot drill mean peak vGRF and vertical RFD data similar to those reported in previous foot drill research (5,9) and are comparable with peak vGRF and vertical RFD apparent in high level plyometric drills (29); demonstrating that foot drill represents a substantial mechanical load placed on the MSK structures of the lower-limbs. The Halt foot drill exhibited the greatest mean peak vGRF (5.3 ± 0.6) and vertical RFD (313.9 ± 30.2) when compared with the remaining foot drills, with SaE and SaA exhibiting vGRF and vertical RFD in excess of 4.9 BW and 278.1 BW$\cdot$s$^{-1}$, respectively. In addition, selective participants were found to produce vGRF and vertical RFD values relative to the Halt foot drill of 6.9 BW and 825.1 BW$\cdot$s$^{-1}$, respectively.

Recently, QM has been shown to exhibit comparable vGRF and vertical RFD values to running speeds of 3 (1.6 BW) to 3.5 m$\cdot$s$^{-1}$ (1.3 BW) (25). In this study, QM was found to exhibit greater vGRF (1.8 BW) and vertical RFD (69.3 BW$\cdot$s$^{-1}$) values when compared with a normal walking gait (vGRF = 1.2 BW, vertical RFD = 7.3 BW$\cdot$s$^{-1}$). Previous (in vivo) research (22) has shown that high repetitive impact loading forces (≥3.0 BW) may produce tensile, shear, and compressive strain-rates that may initiate bone damage at a microstructural level, resulting in single or multiple lower-limb stress fractures. Thus, the magnitude of forces and repetitive skeletal loading of foot drill may significantly contribute to the high incidence rates of lower-limb MSK overuse injuries sustained by untrained male recruits, and significantly increase the risk of sustaining one or more lower-limb bone stress fractures during the initial weeks of BMT.

One limitation of the current investigation is the all-male sample. Previous biomechanical studies have demonstrated that recreationally active females exhibit distinct loading mechanics and lower-limb kinematics when compared with their male counterparts (5,29). Thus, it is unlikely that these results can be generalizable to a recreationally active female population. In addition, study participants performed foot drill in a training shoe, whereas, foot drill is usually performed in the combat boot. Due to a lack of CB readily available for this study, the kinetic variables of foot drill reported may not truly reflect those experienced when wearing the CB. Nevertheless, the peak vGRF and vertical RFD of foot drill are similar in magnitude to those reported previously in untrained samples (5,9).

## Practical Applications

A pragmatic approach is recommended when deciding on the number of trials used to represent foot drill force data (8,19) considering the requirement of high test–retest reliability and acceptable levels of within-subject variation concurrently with the economic, practical, and logistical concerns of collecting repeated trials/sessions of foot drill data. As previously mentioned, the greatest increases in stability and reliability are shown within the initial changes in the number of trials used to calculate the mean ICC and $\%CV_{te}$ value; with diminishing returns in reductions in $\%CV_{te}$ data observed beyond 8 trials, with the achievement of a moderate level of test–retest reliability for each foot drill of the vGRF variable, excluding SaE. Each one of the foot drills (excluding SaE) relative to the vGRF variable demonstrated acceptable levels of reliability. However, in accordance with previous reliability literature, (3,8,19) the magnitude of a variable's stability and reproducibility depends on its intended use, and subsequently, the researcher must determine whether it is sufficiently reliable to measure the smallest worthwhile change in an individual's performance.

The findings of the present study support the inclusion of a single familiarization session specific to the SaA and SaE foot drills. It was determined that the vertical RFD variables exhibited poor levels of reliability across foot drills. Similar levels of reliability of the vertical RFD variable have been reported in previous literature (10,14). Nevertheless, it was determined that an average of 8-trials is required to achieve moderate to strong levels of reliability of foot drill GRF data. The reliability of the vGRF and vertical RFD variable differed notably. However, in the majority of foot drills there was a consistent trend for reliability to marginally improve when the average score of multiple trials was used as the measurement of interest.

## References


1. Ministry of Defence, Issued by: Defence Statistics (Health). *Annual Medical Discharges in the UK Regular Armed Forces 2010/11–2014/15.* pp: 1–26, 2015.
2. *British Army Drill Instructor Manual (BADIM) [CD-ROM].* ATM-Media, 2009.
3. Atkinson, G and Nevill, A. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 26: 217–238, 1998.
4. Baechle, TR and Earle, RW. *Essentials of Strength and Training and Conditioning* (3rd ed.). Champaign, IL: Human Kinetics, 2008.
5. Carden, PPJ, Izard, RM, Greeves, JP, Lake, JP, and Myers, SD. Force and acceleration characteristics of military foot Drill: Implications for injury risk in recruits. *BMJ Open Sport Exerc Med* 0: 1–7, 2015.
6. Challis, JH. The variability in running gait cause by force plate targeting. *J App Biomech* 17: 77–83, 2001.
7. Chandler, DG. *The Oxford History of the British Army* (1st ed.). St Ives, United Kingdom: Oxford University Press, 1994.
8. Connaboy, C, Coleman, S, Moir, G, and Sanders, R. Measures of reliability in the kinematics of maximal undulatory underwater swimming. *Med Sci Sport Exerc* 42: 762–770, 2010.
9. Connaboy, C, Lyall, N, Simpson, R, Murray-Graham, S, Florida-James, G, and 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, 2011. pp: 142.
10. Copic, N, Dopsaj, M, Ivanovic, J, Nesic, G, and Jaric, S. Body composition and muscle strength predictors of jumping performance: Differences between elite female volleyball competitors and nontrained individuals. *J Strength Cond Res* 28: 2709–2716, 2014.
11. Decker, MJ, Torry, MR, Wyland, DJ, Sterett, WI, and Steadman, JR. Gender difference in lower extremity kinematics, kinetics and energy absorption during landing. *Sci Direct* 18: 662–669, 2003.
12. Dixon, SJ and Stiles, VH. Impact absorption of tennis shoe-surface combinations. *Sports Eng* 6: 1–10, 2003.
13. Ebben, WP, Fauth, ML, Kaufmann, CE, and Petushek, EJ. Magnitude of rate of mechanical loading of a variety of exercise modes. *J Strength Cond Res* 24: 213–217, 2010.
14. Floria, P, Gomez-Landero, LA, and Harrison, AJ. Variability in the application of force during the vertical jump in children and adults. *J App Biomech* 30: 679–684, 2014.
15. Hansen, KT, Cronin, JB, and Newton, MJ. The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes. *J Strength Cond Res* 25: 1447–1456, 2011.
16. Hopkins, W. Measures of reliability in sports medicine and science. *Sports Med* 30: 1–15, 2000.
17. Hopkins, WG, Schabort, EJ, and Hawley, JA. Reliability of power in physical performance tests. *Sports Med* 31: 211–234, 2001.
18. Hori, N, Newton, RU, Kawamori, N, McGuigan, MR, Kraemer, WJ, and Nosaka, K. Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *J Strength Cond Res* 23: 874–882, 2009.
19. Hunter, JP, Marshall, RN, and McNair, P. Reliability of biomechanical variables of sprint running. *App Sci* 26: 859–861, 2004.
20. James, CR, Herman, JA, Dufek, JA, and Bates, BT. Number of trials necessary to achieve performance stability of selected ground reaction force variables during landing. *J Sports Sci Med* 6: 126–134, 2007.
21. Jones, BH, Cowan, DN, Tomlinson, P, Robinson, JR, Polly, DW, and Frykman, PN. Epidemiology of injuries associated with physical training among young men in the army. *Med Sci Sports Exerc* 25: 197–203, 1993.
22. Milgrom, C, Finestone, A, Levi, Y, Simkin, A, Ekenman, I, Mendelson, S, Milgrom, M, Nyska, M, Benjuya, N, and Burr, D. Do high impact exercise produce higher tibial strains than running? *Br J Sports Med* 34: 195–199, 2000.
23. Moir, G, Shastri, P, and Connaboy, C. Intersession reliability of vertical jump height in women and men. *J Strength Cond Res* 22: 1779–1784, 2008.
24. Molloy, JM, Feltwell, DN, Scott, SJ, and Niebuhr, DW. Physical training injuries and interventions for military recruits. *Mil Med* 177: 500–553, 2012.
25. Munro, CF, Miler, DI, and Fuglevand, AJ. Ground reaction forces in running: A re-examination. *J Biomech* 20: 147–155, 1987.
26. Puddle, D and Maulder, PS. Ground reaction forces and loading rates associated with parkour and traditional drop landing techniques. *J Sports Sci Med* 12: 122–129, 2013.
27. Rosendale, L, Langberg, H, Skov-Jensen, A, and Kjaer, M. Incidence of injury and physical performance adaptations during military training. *Clin J Sports Med* 13: 157–163, 2003.
28. Sinclair, J and Taylor, P. Influence of new military athletic footwear on the kinetics and kinematics of running in relation to army boots. *J Strength Cond Res* 28: 2900–2908, 2014.
29. Stalborn, M, Holm, DJ, Cronin, JB, and Keogh, JWL. Reliability of kinematics and kinetics associated with horizontal single leg jump assessment. A brief report. *J Sports Sci Med* 6: 261–264, 2007.
30. Wallace, BJ, Kernozek, TW, White, JM, Kline, DE, Wright, GA, Peng, H, and Huang, C. Quantification of vertical ground reaction forces of popular bilateral plyometric exercises. *J Strength Cond Res* 24: 207–212, 2010.
31. White, R, Agouris, I, Selbie, RD, and Kirkpatrick, M. The variability of force platform data in normal and cerebral palsy gait. *Clin Biomech* 14: 185–192, 1992.
32. Windle, CM, Gregory, SM, and Dixon, SJ. The shock attenuation characteristics of four difference insoles when worn in a military boot during running and marching. *Gait and Posture* 9: 31–37, 1999.
33. Winter, DA. *Biomechanics and Motor Control of Human Movement* (4th ed.). Hoboken, NJ: John Wiley and Sons, 2009.