# Title: Altered dynamic postural stability and joint position sense following British Army foot-drill

Running head: Effects of Foot Drill on Ankle Proprioception and Dynamic Postural Control

Authors: Alex J Rawcliffe1\*, Katrina L Hinde2, Scott M Graham3, Russell Martindale3, Andrew Morrison4, Kellen T. Krajewski5 and Chris Connaboy5

# Institutional affiliations:

1HQ Army Recruiting and Initial Training Command, Ministry of Defence, UK

2Defence Science and Technology Laboratory, Porton Down, UK

3School of Applied Sciences,Edinburgh Napier University, UK

4Cambridge Centre for Sport and Exercise Sciences, Anglia Ruskin University, UK

5Neuromuscular Research Laboratory, University of Pittsburgh, USA

# Corresponding author:

Name: Alex J Rawcliffe\*

Address HQ Army Recruiting and Initial Training Command

Trenchard Lines

Upavon

SN9 6BE

Email: Alex.Rawcliffe103@mod.gov.uk

Phone number: 01980 615764

# Abstract

Impaired proprioceptive acuity negatively affects both joint position sense and postural control and is a risk factor for lower-extremity musculoskeletal injury in athletes and military personnel. British Army foot-drill is an occupational military activity involving cyclical high impact loading forces greater than those observed in athletes during high level plyometrics. Foot-drill may contribute to the high rates of lower-extremity overuse injuries observed in recruits during basic training. There is limited research investigating foot-drill specific injury risk factors in women, despite greater incidences of musculoskeletal injury reported in women (522 vs 417 per 1000 personnel, OR: 1.53) when compared to men during basic training. This study aimed to quantify changes in ankle joint proprioception and dynamic postural stability following a period of British Army foot-drill. Fourteen women of similar age to British Army female recruits underwent pre-post foot-drill measures of frontal plane ankle joint position sense (JPS) and dynamic postural stability using the dynamic postural stability index (DPSI). Passive ankle JPS was assessed from relative test angles of inversion 30% (IN30%) and eversion 30% (EV30%) and IN60% of participants range of motion using an isokinetic dynamometer. The DPSI and the individual stability indices (medio-lateral [MLSI], anterior-posterior [APSI] and vertical [VSI]) were calculated from lateral and forward jump-landing conditions using force plates. Foot-drill was conducted by a serving British Army drill instructor. Significantly greater absolute mean JPS error for IN30% and EV30% was observed post foot-drill (*p* ≤ 0.016, *d* ≥ 0.70). For both the lateral and forward jump-landing conditions, significantly greater stability index scores were observed for MLSI, APSI and DPSI (*p* ≤ 0.017, *d* ≥ 0.52). Significantly greater JPS error and stability index scores are associated with the demands of British Army foot-drill. These results provide evidence that foot-drill negatively affects lower-extremity proprioceptive acuity in recruit age-matched women, which has implications for increased injury risk during subsequent military physical activity, occurring in a normal training cycle.

Key terms: injury risk; female recruits; balance; occupational military activity

# Introduction

The aim of initial military training or Phase one Basic Training (BT) is to transform civilians into trained soldiers. The British Army provides several intense physical training programmes that prepares recruits for combat. Part of the BT syllabus involves recruits performing many hours of British Army foot-drill, or foot-drill training; a fundamental occupational military activity that is frequently practiced by recruits during BT (Rawcliffe et al., 2020). Foot-drill has been suggested as a potential contributing risk factor for lower-extremity musculoskeletal injury. British Army foot-drills are characterised by their own unique movement patterns; quick-march involves marching at two paces per second whilst impacting the ground with an exaggerated heel strike; stand-at-attention, stand-at-ease, halt and about-turn (left and right) all involve raising the active limb to 90-degree (°) hip flexion and forcefully stamping down onto the ground with an extended-knee (i.e., straight-leg landing). It is these regimental movement patterns that have been implicated in the high impact loading forces and tibial accelerations of foot-drill irrespective of sex, experience (i.e., trained [soldiers] vs untrained [recruits]) (Carden et al., 2015) and footwear (drill shoe vs combat boot and gym training shoe) (Rawcliffe et al., 2020).

Carden et al., (2015) investigated the force and acceleration characteristics of foot-drill in trained (i.e., soldiers) and untrained (i.e., recruits) men and women, reporting peak vertical ground reaction forces (vGRF) (1.3-6.6 bodyweights (BW)), loading rates (42-983 BW/sec) and peak tibial impact accelerations (23-207 m/s2). Rawcliffe et al., (2020), Rawcliffe et al., (2016) and Connaboy, (2011) all reported similar magnitudes of impact loading forces for recruit age-matched civilian men and women. However, these studies used observational lab-based study designs and assessed foot-drills independent of each other, therefore lacking ecological validity of the cumulative impact loading forces of foot-drill. To date, only one study has assessed cumulative lower-extremity loading of foot-drill in real-time during BT. Rice et al., (2018) used shank-mounted (tri-axial) tibial accelerometers to quantify estimates of lower-extremity loading in the field. Repetitive impacts at high (>10 gravitational accelerations (g)) and very high (>15g) tibial shock magnitudes were observed for both male and female recruits, with peak positive accelerations and mean peak positive accelerations exceeding the g threshold of the device (±16g). Despite known limitations of extrapolation (i.e., accuracy), these values repeatedly exceeded 16g and are greater than values reported during running (Lafortune, 1991) and plyometric exercises (i.e., single-leg drop landings) (Coventry et al., 2006); the latter being a training modality more commonly associated with more experienced and better conditioned athletes (Connaboy, 2011) due to the high risk of MSK injury associated with this type of activity (Davies et al., 2015).

Altered and/or diminished joint proprioception and postural stability, as measured by joint positional sense (JPS) and the dynamic postural stability index (DPSI), have been prospectively identified as risk factors for lower-extremity injury in athletic and recreational active populations (McGuine et al., 2000; Sell *et al.*, 2013; Mckeon and Hertel, 2008; Ross *et al.*, 2009; Trojian and McKeag, 2006; LaGoy et al., 2020) and are likely key risk factors for injury in military recruits during BT. Prospective studies have reported significant reductions in joint proprioceptive acuity and postural stability following military specific exercise (Sell *et al.*, 2013; Mohammadi *et al.*, 2013) and during high impact activity (i.e., plyometrics) similar to that of foot-drill (Twist et al., 2008). Indeed, latent impairments in lower-extremity neuromuscular function following high impact activity have been reported (Twist et al., 2008). However, it is unknown whether the high impact loading forces and regimented movement patterns of British Army foot-drill attenuate the acuity of lower-extremity neuromuscular control, which may have implications for the use of skill-based activities (i.e., obstacle course) and increased injury risk during subsequent BT activities.

Research investigating military training-related injury risk factors specific to female recruits is limited, despite female recruits demonstrating a two-to-three times greater risk of lower-extremity musculoskeletal injury during BT when compared to their male counterparts (Strowbridge and Burgess, 2002; Blacker et al., 2008; Wilkinson et al., 2011; Interim Health Report [UK MoD], 2016). This is corroborated in the athletic literature, where athletic females demonstrate a four-to-six times greater incidence of anterior cruciate ligament injury (Arendt et al., 1999) and lateral ankle sprains (Hosea et al., 2000) while participating in the same sporting activities as men. Lower-limb sex differences demonstrate that exercising females are generally ligament dominant (i.e., the absence of muscle control of medio-lateral joint motion resulting in greater joint torques and vGRF) (Hewett et al., 2002), employ different landing strategies (Wikstrom et al., 2006), and demonstrate neuromuscular imbalances between dominant and non-dominant lower-limbs (Decker et al., 2003). These predisposing injury risk factors may place female recruits at greater risk of impaired neuromuscular control as measured by JPS and the DPSI following British Army foot-drill training.

The aim of this study was to quantify changes in ankle JPS acuity and DPSI (including stability indices [medio-lateral and anterior-posterior]) pre and immediately post a period of British Army foot-drill in women of similar age to female recruits. It was hypothesised that women would experience significantly greater absolute JPS error of the ankle joint and increased dynamic postural variability from DPSI (and stability indices) post foot-drill.

# Methods

## Participants

Participants aged between 18 and 32 years (as per British Army basic adult solider entry age requirements) were considered for this study. Fourteen women (university students) of similar age to British Army female recruits (*n* = 14, age: 26 ± 3 yrs, height: 179.2 ± 6.2 cm, body mass: 74.4 ± 2.6 kg) were successfully recruited for this study. All participants were recreationally active, taking part in moderate physical activity or sport a minimum of two-to-three times per week, defined as “untrained” as participants obtained no prior experience of British Army foot-drill. Participants reported no injuries or pathological lower-limb, hip or spinal conditions prior to testing, no prior history of balance, jump-landing or foot-drill training, no neurological or vascular compromise, and no known pregnancy at the time of testing. All but two participants of this study were right foot dominant. Ethical approval was gained from Edinburgh Napier University’s local ethics committee.

## Experimental Design

This observational study quantified changes in ankle joint proprioception and dynamic postural stability pre and post a period of British Army foot-drill training. To mitigate potential learning effects, participants performed a single familiarisation session involving multiple practice trials of ankle JPS and dynamic postural stability (Hopkins, 2000) whilst wearing standard issue British Amy footwear (combat boots) the day before data collection. Ankle JPS and dynamic postural stability data were collected and analysed from the dominant limb only, defined as the limb used to strike a ball. Measures of ankle JPS were conducted prior to DPSI as to mitigate the effects of jump-landing activity on measures of ankle JPS.

## British Army Foot-drill Training

A serving British Army foot-drill instructor conducted each standardised foot-drill session, relative to the British Army foot-drill instructor manual. Each session lasted approximately 88 min (Table 1) with JPS and DPSI conducted pre and immediately post foot-drill training. Foot-drills are characterised by their own unique key performance markers (The Rifles Drill Manual, 2017). For example, quick-march involves marching at two paces per second whilst impacting the ground with an exaggerated heel strike. The stand-at-attention, stand-at-ease , right-turn, about-turn (left-leg), left-turn, and halt foot-drill (right-leg) involves raising the active limb approximately 90° hip flexion and forcefully stamping onto the ground, with an extended-knee (straight-leg) landing. During each foot-drill session, participants wore standard issue British Army footwear provided by the research team.

## **Table 1**

Frequency (repetitions), duration (time) and the total *n* of impacts performed with the right and left leg during the standardised period of foot-drill.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **British Army Foot-drill** | | |
| **Foot-Drill** | Duration(mins) | *n* left foot impacts | *n* right foot impacts |
| Stand-at-attention | 11 | 42 | - |
| Stand-at-ease | 9 | 28 | - |
| Right-turn | 12 | 48 | - |
| Left-turn | 9 | - | 32 |
| About-turn | 10 | 26 | - |
| Halt | 18 | - | 39 |
| March | 12 | 128 | 118 |
| Rest | 7 | - | - |
| Total | 88 | 272 | 189 |

## Ankle Joint Position Sense (passive)

Frontal plane (Inversion/Eversion (IN/EV)) ankle JPS was quantified using a Biodex dynamometer (Biodex Medical Systems, Shirley, New York, USA) using methods described previously (Sefton *et al.*, 2009; Brown *et al*., 2004). Ankle JPS was assessed in the frontal plane rather than the sagittal plane as most injuries occur around the anterior-posterior axis (i.e., lateral ankle sprain). The test ankle was positioned in a clinically designated neutral or 0° position, achieving 90° between the foot and tibia. Participants were blindfolded and wore headphones to eliminate any contribution of visual and audio cues to the positioning of the test ankle. Participants were given a 45 second (sec) recovery between trials to mitigate fatigue and to assist with concentration. Ankle IN/EV range of motion (ROM) was determined prior to testing. From which, 30% and 60% of full inversion ROM and 30% of full eversion ROM of each participant was calculated and utilised as JPS test angles. This accounted for relative ankle joint flexibility whilst reducing the effect of additional sensory input from cutaneous receptors at extreme ROM (Burke *et al*., 1988). At random, the test ankle was passively moved into one of three test positions, 30% and 60% IN and 30% EV. Each test angle was locked in position for 10 sec and passively moved through its respective ROM (60°/sec) before returning to neutral (0°). Participants were required to match the previously presented test angle and press a handheld trigger that recorded the absolute degrees of error (°) between the test angle and reproduced angle. The mean of three trials from each IN/EV JPS condition pre-post foot-drill training was collected and processed for further analysis.

## Dynamic Postural Stability

Similar to methods used previously (Sell *et al.*, 2013), ground reaction force (GRF) data was collected at 1000Hz via a Kistler force plate (Kistler Instruments AG, 9281CA, Switzerland). The DPSI has been found to have a high intra-session reliability and to be a precise measure (ICC -0.86, SEM=0.01) (Sell et al., 2013). Dynamic postural stability was assessed from an anterior-posterior (A/P) and medio-lateral (M/L) jump-landing task and analysed using the DPSI. Relative to the A/P and M/L jump-landings, female participants stood bilaterally at a distance of 40% and 33% of their standing height from the middle of the force plate, respectively. When instructed, participants jumped anteriorly (A/P jump) or laterally (M/L jump) off both legs, over a 12inch (A/P jump) or 6inch (M/L jump) hurdle, landing on the force plate with the dominant-limb (single-leg landing). Participants were asked to stabilize immediately after landing, placing both hands on hips and balancing for 13 sec(Wikstrom *et al.*, 2005). Upper-limb movement was not restricted during the take-off or flight phase of each task. Dynamic trials were discarded and repeated if the participants’ non-stance limb contacted the stance limb or the ground surrounding the force plate. The mean of three trials from each jump-landing condition (A/P and M/L) pre-post foot-drill training was collected. Ground reaction force data was extracted from the force plate using Bioware® (5.3.0.7 systems) for subsequent analysis.

# Data Analysis

## Dynamic Postural Stability Index

All dynamic postural stability data were treated using a 4th order (zero-lag) low pass Butterworth filter with a cut-off frequency of 20Hz(Williams *et al.*, 2016). The DPSI and its directional components [stability index: medial lateral (MLSI), anterior-posterior (APSI), vertical (VSI)] were analysed using a custom Matlab script file. These indices are mean square deviations assessing fluctuations around a 0 point, rather than SDs assessing fluctuations around a group mean (Sell *et al.*, 2013). The MLSI and APSI directional components analyse the fluctuations from zero along the X (A/P) and Y (M/L) axis. The VSI assesses the fluctuations from the participant’s bodyweight (as a zero point) along the Z (vertical) axis of the force plate (Eq 1-3). The DPSI is a composite of the MLSI, APSI, and VSI, therefore is sensitive to changes in each directional component and is a unitless measure. The DPSI was determined from using the first three seconds of the GRF immediately following initial contact, identified as the instant the vGRF exceeded 5% BW. Greater stability index (SI) scores reflect greater variability and potentially altered dynamic postural stability, with MLSI, APSI, VSI, and DPSI calculated as (BW in newtons[N]);

MLSI = ÷ BW Eq1.

APSI = ÷ BW Eq2.

VSI = ÷ BW Eq3.

DPSI = ÷ BW Eq4.

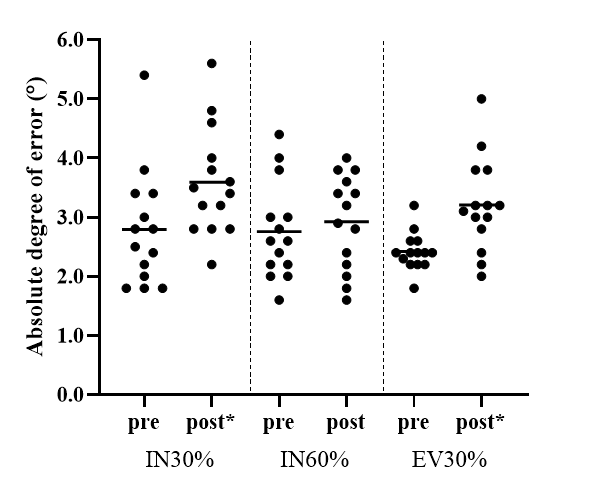
# Statistical Analysis

Mohammadi et al., (2013) demonstrated significantly greater absolute ankle JPS error following military specific exercise reporting large effects (∆% = 29%, *d* ≥ 1.0). Similarly, LaGoy et al., (2020) reported significantly greater dynamic postural stability index scores during military specific exercise (∆% = 10%, *d* = 0.83) reporting large effects. Based on these findings, an *a priori* G\*Power (v3.1.9.2, Germany) calculation was used to estimate sample size for two-sided paired-samples t-test to statistically determine differences in JPS and dynamic postural stability pre - post a period of British Army foot-drill. With an estimated 20% probability (power=0.80) of a type II error, an alpha level set at 0.05, and an estimated effect size of 0.83 (LaGoy et al., 2020), it was estimated that a sample size of 14 female participants would be sufficient to detect a significant difference from zero. Mean ± SD for each dependant variable (DV) were calculated (Figure 1 and Table 2). Each DV was examined for normality. Data were analysed from the dominant limb only and averaged across three-trials for each JPS test angle and dynamic postural stability jump-landing condition. A series of paired samples t-tests were conducted to determine differences in JPS data and differences in dynamic postural stability (pre vs post foot-drill). Cohens d effects sizes were also calculated using the following criteria (0.2= small, 0.5= medium, 0.8= large, >0.8= very large) (Cohen, 1988). Statistical significance was accepted as p ≤ 0.05.

# Results

## Joint Positional Sense (JPS)

Figure 1 shows the mean absolute JPS error for each test angle pre - post foot-drill. Significant increases in IN30% (mean difference = 0.80 °, p <0.01, d = 0.84, 95%CI: 0.04, 1.58) and EV30% (mean difference = 0.79 °, p = 0.009, d = 1.72, 95%CI: 0.81, 2.54) were observed post foot-drill. There was no significant change in IN60% values (mean difference = 0.16 °, p = 0.618, d = 0.24, 95%CI: 0.51, 0.98).



## **Figure 1**

Absolute degree of error (°) for IN30%, IN60% and EV30% pre - post foot-drill. Mean data is shown by a solid horizontal line. \* denotes a significant increase in JPS score post foot-drill.

## Dynamic Postural Stability Index (DPSI)

Table 2 shows the A/P jump-landing condition, MLSI (p < 0.001, d = 6.45, 95%CI: 4.04, 7.74), APSI (p < 0.001, d = 10.46, 95%CI: 7.19, 13.16) and DPSI (p = 0.006, d = 0.70, 95%CI: 0.16, 1.48) were significantly greater post foot-drill. Similarly, MLSI (p < 0.001, d = 13.38, 95%CI: 9.18, 16.66), APSI (p < 0.001, d = 5.38, 95%CI: 3.25, 6.43) and DPSI (p = 0.017, d = 0.52, 95%CI: 0.17, 1.47) were significantly greater post foot-drill for the M/L jump landing condition. There were no significant changes in VSI for the A/P (p = 0.906, d = 0.03, 95%CI: -0.83, 0.77) or M/L jump-landing conditions (p = 0.871, d = 0.03, 95%CI: -0.83, 0.77).

## **Table 2**

Normalised mean ± SD for DPSI and stability indices pre - post foot-drill for M/L and A/P jump-landing conditions (A/P=anterior-posterior, M/L=medio-lateral). adenotes a significant difference from pre-values (*p* < 0.05); mean ± SD percentage change (%Δ).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Stability Index** | | | |
| **Jump Condition** |  | MLSI | APSI | VSI | DPSI |
| M/L Jump | Pre | 0.019 ± 0.002 | 0.008 ± 0.003 | 0.289 ± 0.033 | 0.284 ± 0.032 |
| Post | 0.097 ± 0.008 a | 0.035 ± 0.007 a | 0.290 ± 0.041 | 0.308 ± 0.039 a |
|  | %Δ (*pre-post)* | *433.0 ± 88.2* | *410.4 ± 147.6* | *0.4 ± 8.4* | *6.6 ± 8.1* |
| A/P Jump | Pre | 0.006 ± 0.001 | 0.023 ± 0.002 | 0.304 ± 0.037 | 0.305 ± 0.037 |
| Post | 0.028 ± 0.005a | 0.121 ± 0.013 a | 0.305 ± 0.033 | 0.329 ± 0.033 a |
|  | %Δ (*pre-post*) | *382.2 ± 100.8* | *422.0 ± 67.0* | *0.8 ± 9.0* | *8.7 ± 9.0* |

# Discussion

This is the first study to examine potential deficits in lower-extremity neuromuscular function following a period of British Army foot-drill. In agreement with our hypothesis, significantly greater absolute JPS error was observed for IN30% and EV30% post foot-drill, demonstrating a large effect of foot-drill on smaller (*d* ≥ 0.84) versus larger (*d* =0.24) JPS test angles. Participants demonstrated a 29% and 32% increase in absolute JPS error post foot-drill for IN30% and EV30%, respectively. Although an increase in absolute JPS error for IN60% (6%) was observed, no significant differences were reported, and the size of the effect was considered trivial. Significantly greater GRF variability following foot-drill in DPSI, MLSI and APSI for both the M/L and A/P jump-landing conditions was observed. The magnitude of differences (%) in pre-post foot-drill measures of dynamic postural stability were very high (see Table 2), with effect sizes ranging from medium to very large (*d* = 0.52 – 13.38). The differences in the composite DPSI (an overall score reflective of changes in directional components) are likely from changes in the APSI and MLSI, as no significant differences were observed for VSI post foot-drill for either of the jump-landing conditions.

Ankle injury is among the most common MSK injuries reported in athletes and Army recruits during routine training conditions (Andersen *et al.*, 2016). Joint position sense is commonly used as a functional measure of proprioception as it plays a key role in maintaining dynamic stability of lower-extremity joints and has been shown to predict ankle injury in uninjured male and female athletic populations (Payne et al., 1997; Willems *et al.*, 2005). Acute trauma is a key factor in some injury cases, resulting in high rates of recurrence and frequently leading to disruption of ligamentous joint afferents and loss of proprioceptive acuity (Willems *et al.*, 2002; Röijezon et al., 2015). However, many lower-extremity injuries reported in BT result from the cumulative effects of microtraumatic forces associated with overtraining, repetitive and high impact movements, extreme joint positions and prolonged static positioning (Hauret *et al.*, 2010; Mohammadi *et al.*, 2013). This is common for British Army foot-drill, involving long and frequent periods of static upright positioning and impacting the ground repeatedly with extreme joint positions (i.e., extended-knee landings while intentionally mitigating hip and knee flexion at impact).

Studies investigating changes in lower-extremity neuromuscular function relative to military specific exercises are limited. However, to the authors knowledge, only one other study has investigated changes in absolute JPS error following military specific exercise. Mohammadi et al., (2013) reported significantly greater absolute JPS error of the ankle joint (using similar methods) in military conscripts immediately following military specific exercise. In our study, participants demonstrated a 0.80° increase in absolute JPS error for both IN30% and EV30% following foot-drill, with large effect sizes. Similarly, Mohammadi *et al.*, (2013) reported significant differences and large effect sizes for increases in absolute JPS error of 0.70° immediately post military specific exercise. It was further (descriptively) reported that conscripts who sustained an injury after 8- weeks of BT (hamstring and ankle sprains, ACL rupture and stress fracture of the metatarsals) demonstrated significantly greater absolute JPS error (mean ∆ = 2°) compared to uninjured conscripts. Indeed, deficits in proprioception are shown to be predictive of injury in uninjured, physically active populations (Payne et al., 1997). However, due to insufficient study power (i.e., small sample, *n* = 8) reported by Mohammadi *et al.*, (2013), it is unknown whether an increase in absolute JPS error is predictive of ankle MSK injury in military recruits during BT. Additionally, the specific type of military exercises that led to reductions in ankle JPS acuity were not reported, and in turn, limits our understanding of the potential effects of common military specific exercises on injury risk. We must consider that although a significant increase in JPS error was observed post foot-drill, this increase was <1° and the clinical implications of this small increase in absolute JPS error remain unclear.

Comparable to our study, South and George, (2007) reported no significant mean differences in absolute JPS error for larger (90% of ROM) IN test angles pre-post fatiguing activity. A possible explanation for the smaller absolute JPS error (0.16°) observed for IN60% post foot-drill may be due to greater joint torque found with greater test angle positions. Studies show that as joint torque demand increases, there is a high potential to increase proprioceptive acuity (Bullock-Saxton et al., 2001; Suprak *et al.*, 2007; Lyons and Lyons, 2017). In our study, it is possible that the added weight from the foot-plate (and gravity) combined with the greater test angle of IN60% produced a greater theoretical moment arm, resulting in greater joint torque and tension of surrounding muscles. With increased joint torque, an increase in muscle activation (specifically alpha and gamma motor neurons) is observed, thereby increasing the sensitivity of intramuscular receptors (i.e., GTO) that relay proprioceptive feedback during movement. Test angles near to maximum ROM (i.e., 90%IN/EV) are defined as extreme test angles and are considered a limitation due to the effect of additional sensory input from cutaneous receptors on the ability to reproduce the test angle (Burke et al., 1988). The average IN/EV ROM has been identified as 30° and 18°, respectively (Ball and Johnson, 1996). In our study, we employed test angles of IN60% and IN/EV30% of each participants ROM, which corresponds to an approximate 18° IN and 9° EV test angle based on the average IN/EV ROM. Although IN60% is not considered an extreme test angle, this test angle lies much closer to the ankles average end ROM than 30%. Therefore, the reduced absolute JPS error for IN60% observed in our study is likely associated with increased muscle activation from greater joint torque demand at this position. Furthermore, these data suggest, in part, that as inversion angles approach their end ROM, an individual’s JPS acuity will improve (i.e., reduced absolute JPS error). It is acknowledged, however, that this study was unable to collect data to determine the precise mechanisms associated with the greater and lower absolute JPS error for IN/EV 30% and IN60% respectively, post foot-drill.

To date, no study has quantified changes in measures of dynamic postural stability post military specific exercise. However, changes in dynamic postural stability have been reported for military related tasks. Sell et al., (2013) reported significantly greater stability index scores with the addition of body armour. Increases were identified in all stability indices, including VSI, indicating that with the addition of tactical body armour (~12kg) greater GRF variability is observed, inferring diminished dynamic postural stability. In our study, no significant changes in the VSI were found, only significantly greater stability index scores (reflecting greater GRFs) were observed for MLSI, APSI and DPSI for both the M/L and A/P jump landing conditions. The greater stability index scores observed post foot-drill for MLSI and APSI during the M/L and A/P jump landing condition respectively, may have placed participants closer to their limits of stability, reflecting greater displacement of the centre of mass and necessitating greater frontal and sagittal plane control (Meardon et al., 2016). As mentioned earlier, differences in the composite DPSI appear to largely reflect changes in the APSI and MLSI as no differences in VSI were observed post foot-drill. The significantly greater VSI reported by Sell et al., (2013) is likely related to the additional load from the body armour. However, it is possible that changes in dynamic postural stability reported in our study may be due, in part, to the effects of fatigue resulting in potential changes in muscle activation patterns and lower-extremity jump-landing kinematics (Meardon et al., 2016; Sell *et al.*, 2013; Wikstrom *et al.*, 2005). Indeed, the effects of fatigue on lower-extremity kinematics during jump-landing activities has been well reported in athletic females (Benjaminse *et al.*, 2007; Cortes *et al.*, 2013; Lessi *et al.*, 2017; Luccia et al., 2011). Since lower-extremity kinematic and EMG data were not collected during our study, we cannot confirm whether increased dynamic postural stability index scores (inferring impaired stability) observed post foot-drill was related to the effects of fatigue on landing kinematics and muscle activation patterns. Therefore, further research is warranted to elucidate these claims.

A greater dynamic postural stability index infers increased GRF variability during stabilisation following a landing task (Wikstrom *et al.*, 2005). Greater stability indices are typically considered as an indicator of poorer postural stability and impaired neuromuscular function (Sell *et al.*, 2013). This presumption is supported by others reporting increased variability with increased balance task demand (Goldie et al., 1989). Additionally, increased dynamic postural stability has been identified as a risk factor for lower-extremity MSK injury and shown to predict injury in uninjured athletic populations (McGuine et al., 2000; Trojian and McKeag, 2006; Wang *et al.*, 2006; Willems and Mahieu, 2005). Recently, traditional perspectives of increased variability within biological systems has been challenged based on non-linear dynamics, commonly referred to as the chaos theory, which associates high variability with a more functional and adaptable system (Van Emmerik and Van Wegen, 2002; Meardon et al., 2016). Therefore, it is recommended that the interpretation of these variability measures be considered in conjunction with other validated measures of neuromuscular function.

A number of limitations of this study are acknowledged. In our study, we did not collect data from British Army recruits on repeated measures of JPS and dynamic postural stability to quantify the transient effects of foot-drill on neuromuscular function. However, based on the literature, it is possible that military recruits may experience prolonged impairments in neuromuscular function as a consequence of foot-drill training (Paschalis *et al.*, 2007; Yaggie and McGregor, 2002). As such, further research is warranted to determine the extent of change in joint movement and position in recruits specifically, as these results may have important implications for subsequent skill-based military activities (i.e., obstacle course), scheduling of high intense training and recovery sessions, and injury risk. Although foot-drill is considered an injury risk factor in both men and women, our study did not compare pre-post foot-drill measures of JPS and dynamic postural stability between sex. However, women generally demonstrate greater risk and incidence of injury compared to their male counterparts (Wikstrom et al., 2006), and research investigating female specific injury risk factors associated with the demands of foot-drill and other occupational military activities are limited, despite the growing role of women in the Armed Forces. It is acknowledged, however, that understanding the risk of injury associated with the demands of occupational military activities (such as foot-drill) using robust methodology is challenging to implement in a military setting, due to the additional burden and disruption to military training programmes, while controlling for many other confounding factors that are likely to contribute to the risk of injury during BT

Impaired neuromuscular function has been shown to alter lower-extremity kinematics associated with injury risk (Benjaminse *et al.*, 2007; Cortes *et al.*, 2013; Lessi *et al.*, 2017; Luccia et al., 2011). Unfortunately, we did not collect data on lower-extremity kinematics and muscle activation patterns, nor did we determine the level of fatigue (both cognitive and physiological) of participants post foot-drill. In our study, the effects of muscle fatigue have been implicated in the greater absolute JPS error and dynamic postural stability observed post foot-drill. Given that both muscle and cognitive fatigue have been linked with reductions in neuromuscular function and altered lower-extremity biomechanics, further study is warranted to better understand the extent of change in predictors of injury risk following foot-drill with participants in a fatigued state, as losses in neuromuscular function and increases in attentional demand (Bisson et al., 2011) may be exacerbated which has implications for additional risk and increased severity of injury.

# Conclusion

Significantly greater absolute JPS error and greater dynamic postural stability index scores (inferring poorer postural stability) was observed in a cohort of female participants following a period of British Army foot-drill, as evidenced by greater absolute JPS error and increased GRF variability in MLSI, APSI and DPSI for the M/L and A/P jump-landing conditions. As such, our study suggests that following a period of British Army foot-drill, female recruits may be at an increased risk of lower-extremity injury due to reductions in neuromuscular function observed post foot-drill. These results have implications for the scheduling of subsequent skill-based military activities and recovery sessions to reduce the potential risk of musculoskeletal injury following British Army foot-drill training. .

# References

Allen TJ and Proske U. (2006). Effect of muscle fatigue on the sense of limb position and movement. *Experimental Brain Research*, 170(1), 30-38.

Andersen KA, Grimshaw PN, Kelso RM, Bentley DJ. (2016). Musculoskeletal Lower Limb Injury Risk in Army Populations, *Sports Medicine - Open*, 2(1), 2-22.

Arendt EA, Agel J and Dick R. (1999). Anterior cruciate ligament injury patterns among collegiate men and women. Journal of Athletic Training, 34(2), 86-92.

Ball P and Johnson GR. (1996). Technique for the measurement of hindfoot inversion and eversion and its use to study a normal population. *Clinical Biomechanics*, 11(3), 165–169.

Benjaminse A, Habu A, Sell TC, Abt JP, Fu FH, Myers JB and Lephart SM. (2007). Fatigue alters lower extremity kinematics during a single-leg stop-jump task. *Knee Surgery Sports Traumatology Arthroscopy,*16(4), 400-407.

Bisson J, McEwena D, Lajoie Y and Bilodeau M. (2011). Effects of ankle and hip muscle fatigue on postrual sway and attentional demands during unipedal stance. *Gait and Posture*, 33, 83-87.

Blacker SD, Wilkinson DM, Bilzon JL and Rayson MP. (2008). Risk factors for training injuries among British Army recruits. Military Medicine, 173(3), 278-286.

Brown CN, Ross SE, Mynark R and Guskiewicz KM. (2004). Assessing functional ankle instability with joint position sense, time to stabilization, and electromyography, *Journal of Sports Rehabilitation*, 13(2), 122–134.

Bullock-Saxton JE, Wong WJ and Hogan N. (2001). The influence of age on weight-bearing joint reposition sense of the knee. *Experimental Brain Research*, 136(3), 400–406.

Burke D, Gandevia SC and Macefield G. (1988). Responses to passive movement of receptors in joint, skin and muscle of the human hand. *Journal of physiology*, 402(1), 347–361.

Clark NC, Röijezon U and Treleaven J. (2015). Proprioception in musculoskeletal rehabilitation. Part 2: Clinical assessment and intervention. *Manual Therapy*, 20(3), 378–387.

Cohen J. (1988). Statistical power analysis for the behavioral science*s*, *Hillsdale, NJ: Lawrence Erlbaum Associates*.

Connaboy C, Lyall N, Simpson R, Murray-Graham S, Florida-James G and Coleman S. (2011). Soldiers as tactical athletes: Incorporating military drill within a periodised training programme. 2nd International Congress on Soldiers' Physical Performance, In Congress Proceedings, 142, Jyväskylä, Finland.

Cortes N, Greska E, Kollock R, Ambegaonkar J and Onate AJ. (2013). Changes in lower extremity biomechanics due to a short-term fatigue protocol. *Journal of Athletic Training*, 48(3), 306–313.

Coventry E, O’Connor KM, Hart BA, Earl JE and Ebersole KT. (2006). The effect of lower extremity fatigue on shock attenuation during single-leg landing. *Clinical Biomechanic*s, 21(10), 1090-1097.

Davies G, Riemann BL and Manske R. (2015). Current concepts of plyometric exercise. *International Journal of Sports Physical Therapy*, 10(6), 760-786.

Decker MJ, Torry MR, Wyland DJ, Sterett WI and Steadman JR. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics*, 18(7), 662-669.

Department of Manning (British Army) (2016). Interim report on the health risks to women in ground close combat roles. WGCC/Interim-Report/10/.

Van Emmerik REA and Van Wegen EEH. (2002). On the functional aspects of variability in postural control. *Exercise and Sport Sciences Reviews*, 30(4), 177–183.

Forestier N, Teasdale N and Nougier V. (2002). Alteration of the position sense at the ankle induced by muscular fatigue in humans. *Medicine and Science in Sports and Exercise*, 34(1), 117–122.

Goldie PA, Bach TM and Evans OM. (1989). Force platform measures for evaluating postural control: reliability and validity. *Archives of Physical Medicine and Rehabilitation*, 70(7), 510-517.

Hauret KG, Jones BH, Bullock SH, Canham-Chervak M and Canada S. (2010). Musculoskeletal injuries: description of an under-recognized injury problem among military personnel. *American Journal of Preventive Medicine*, 38(1), 61-70.

Hewett TE, Paterno MV and Myer GD. (2002). Strategies for enhancing proprioception and neuromuscular control of the knee. *Clinical Orthopaedics and Related Research*, 402, 76-94.

Hopkins WG. (2000). Measures of Reliability in Sports Medicine and Science, *Sports Medicine*, 30(1), 1–15.

Hosea TM, Carey CC and Harrer MF. (2000). The gender issue: epidemiology of ankle injuries in athletes who participate in basketball. *Clinical Orthopaedics and Related Research*, 372, 45-49.

Johanson E Brumagne S, Janssens L, Pijnenburg M, Claeys K and Pääsuke M.(2011). The effect of acute back muscle fatigue on postural control strategy in people with and without recurrent low back pain. *European Spine Journal*, 20(12), 2152–2159.

LaFortune MA. (1991). Three-dimensional acceleration of the tibia during walking and running. *Journal of Biomechanics*, 24(10), 877-886.

LaGoy AD, Johnson CD, Allison KF, Flanagan SD, Lovalekar MT, Nagai T, Connaboy C. (2020). Impact of increased load carriage magnitude on dynamic postural stability of men and women. *Journal of Applied Biomechanics,* 36(1), 27–32.

Lessi GC, Santos AFD, Batista LF, de Oliveira GC and Viadanna Serrão FV. (2017). Effects of fatigue on lower limb, pelvis and trunk kinematics and muscle activation: Gender differences. *Journal of Electromyography and Kinesiology*, 32, 9–14.

Lyons SM and Lyons S. (2017). The effect of knee extension angle on knee joint position sense between genders. *WWU Masters Thesis Collection*, 561.

Massion J, Alexandrov A and Frolov A. (2004). Why and how are posture and movement coordinated? *Progress in Brain Research*, 143, 13–27.

McGuine TA, Greene JJ, Best TLG. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sports Medicine*, 10(4), 239–244.

Mckeon PO and Hertel J. (2008). Systematic review of postural control and lateral ankle instability, Part I: Can deficits be detected with instrumented testing? *Jounral of Athltic Training,* 43(3), 293-304.

Meardon S, Klusendorf A and Kernozek T. (2016). Influence of injury on dynamic postural control in runners. *International Journal of Sports Physical Therapy*, 11(3), 366–77.

Ministry of Defence (British Army). (2017). The rifles drill manual. Ministry of Defence, UK.

Mohammadi F, Azma K, Naseh I, Emadifard R and Etemadi Y. (2013). Military exercises, knee and ankle joint position sense, and injury in male conscripts: A pilot study. *Journal of Athletic Training,* 48(6), 790–796.

Paschalis V, Nikolaidis MG, Giakas G, Jamurtas AZ, Pappas A and Koutedakis Y. (2007). The effect of eccentric exercise on position sense and joint reaction angle of the lower limbs. *Muscle and Nerve*, 35(4), 496–503.

Payne KA, Berg K and Latin RW. (1997). Ankle injuries and ankle strength, flexibility, and proprioception in college basketball players. *Journal of Athletic Training,* 32(3), 221-225.

Rawcliffe AJ, Graham SM, Simpson RJ, Moir GL, Martindale RJJ, Psycharakis SG and 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*, 34(3), 754-762.

Rawcliffe AJ, Simpson RJ, Graham SM, Psycharakis SG, Moir GL and Connaboy C. (2016). Reliability of the kinetics of British Army foot drill in untrained personnel. *Journal of Strength and Conditioning Research*, 3(2), 435-444.

Rice HM, Saunders SC, McGuire SJ, O’Leary TJ and Izard RM. (2018). Estimates of tibial shock magnitude in men and women at the start and end of a military drill training programme. *Military Medicine*, 183(9-10), 392-398.

Röijezon U, Clark NC and Treleaven J. (2015). Proprioception in musculoskeletal rehabilitation: Part 1: Basic science and principles of assessment and clinical interventions'. *Manual Therapy*, 20(3), 368–377.

Ross SE, Guskiewicz KM, Gross MT and Yu B. (2009). Balance measures for discriminating between functionally unstable and stable ankles. *Medicine and Science in Sports and Exercise*, 41(2), 399–407.

Sefton JM, Hicks-Little CA, Hubbard TJ, Clemens MG, Yengo CM, Koceja DM, Cordova ML. (2009). Sensorimotor function as a predictor of chronic ankle instability. *Clinical Biomechanics*, 24(5), 451–458.

Sell TC, Pederson JJ, Abt JP, Nagai T, Deluzio J, Wirt MD, McCord LJ and Lephart SM. (2013). The addition of body amor diminishes dynamic postural stability in military soldiers. *Military Medicine,* 178(1), 76-81.

Strowbridge NF and Burgess KR. (2002). Sports and training injuries in British soldiers: the Colchester garrison sports injury and rehabilitation centre. *BMJ Military Health,* 148(3), 236-243.

Luccia S, Cortes N, Van Lunena B, Ringlebc S and Onate J. (2011). Knee and hip sagittal and transverse plane changes after two fatigue protocols. *Journal of Science and Medicine in Sport*, 14(5), 453–459.

South M and George KP. (2007). The effect of peroneal muscle fatigue on ankle joint position sense. *Physical Therapy in Sport*, 8, 82–87.

Suprak DN, Osternig LR, Donkelaar P and Karduna AR. (2007). Shoulder joint position sense improves with external load. *Journal of Motor Behavior*, 39(6), 517–525.

Trojian TH and McKeag DB. (2006). Single leg balance test to identify risk of ankle sprains. *British Journal of Sports Medicine*, 40(7), 610–613.

Twist C, Gleeson N and Eston R. (2008). The effects of plyometric exercise on unilateral balance performance. *Journal of Sports Sciences*, 26(10), 1073–1080.

Wang HK, Chen CH, Shiang TY, Jan MH and Lin KH. (2006). Risk factor analysis of high school basketball player ankle injuries: A prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Archives of Physical Medicine Rehabilitation*, 87(6), 821-825.

Wikstrom EA, Tillman MD, Smit AN and A Borsa PA. (2005). A new force-plate technology measure of dynamic postural stability: The dynamic postural stability index. *Journal of Athletic Training*, 40(4), 305–309.

Wikstrom EA, Tillman MD, Kline KJ and Borsa PA. (2006). Gender and limb differences in dynamic postural stability during landing. *Clinical Journal of Sport Medicine,* 16(4), 311-315.

Wilkinson DM, Blacker SD, Richmond VL, Horner FE, Rayson MP, Spiess A and Knapik JJ. (2011). Injuries and injury risk factors among British Army infantry soldiers during predeployment training. *Injury Prevention*, 17(6), 381-387.

Willems T, Witvrouw E, Verstuyft J, Vaes P and De Clercq D. (2002). Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *Journal of Athletic Training*, 37(4), 487-493.

Willems TM, Witvrouw E, Verstuyft J, Vaes P and De Clercq D. (2005). Intrinsic risk factors for inversion ankle sprains in females - A prospective study. *Scandinavian Journal of Medicine and Science in Sports*, 15(5), 336–345.

Willems TM, Witvrouw E, Delbaere K, Mahieu N, Bourdeaudhuij LD and De Clercq D. (2005). Intrinsic risk factors for inversion ankle sprains in male subjects: A prospective study*. The American Journal of Sports Medicine*, 33(3), 415-423.

Williams VJ, Nagai T, Sell TC, Abt JP, Rowe RS, McGrail MA and Lephart SM. (2016). Prediction of dynamic postural stability during single-leg jump landings by ankle and knee flexibility and strength. *Journal of Sports Rehabilitation,* 25(3), 266-272.

Yaggie JA and McGregor SJ. (2002). Effects of isokinetic ankle fatigue on the maintenance of balance and postural limits. *Archives of Physical Medicine and Rehabilitation*, 83(2), 224–228.