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

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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. This study aimed to quantify changes in ankle joint proprioception and dynamic postural stability following a period of British Army foot-drill. Fourteen recruit age-matched women 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 (IN) and eversion (EV) 30% and IN60% 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 ($p \leq 0.016$, $d \geq 0.70$). For both the lateral and forward jump-landing conditions, significantly greater stability index scores were observed for MLSI, APSI and DPSI ($p \leq 0.017$, $d \geq 0.52$). 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: dynamic postural stability; joint position sense; foot-drill; neuromuscular function

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 (MSK) injury. British Army foot-drills are characterised by their own unique movement patterns; quick-march (QM) involves marching at two paces per second whilst impacting the ground with an exaggerated heel strike; stand-at-attention (SaA), stand-at-ease (SaE), 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 vGRF, loading rates and peak tibial impact accelerations between 1.3-6.6 bodyweights (BW), 42-983 BW/sec and 23-207 m/s^2, respectively. Rawcliffe et al., (2020) and Connaboy, (2011) both 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 (PPA) and mean PPA 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), 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 MSK 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 and Carey, 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 joint proprioception and dynamic postural stability 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 recruit age-matched women. 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

Fourteen recruit age-matched women (n = 14, age: 26 ± 3 yrs, height: 179.2 ± 6.2 cm, bodymass: 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 six-months 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. 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). 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 (BADIM, 2009). For example, QM involves marching at two paces per second whilst impacting the ground with an exaggerated heel strike. The SaA, SaE, 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. All participants wore the standardised British Amy black leather Combat Boot (CB) during their respective foot-drill training provided by the research team.

Table 1: Illustrates the 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
SaA	11	42	-
SaE	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 attempted to reproduce the test angle and orientation of the foot by actively pressing a handheld trigger recording the absolute degrees of error (°) between the test and reproduced angle. The mean of five trials from each IN/EV JPS condition at BL, and 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). 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 made contact with the stance limb or the ground out-with the force plate. 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.*, 2015). 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. 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);

MLSI = $$\sqrt{\left(\frac{\sum(0 - GRFx)^2}{number\ of\ data\ points}\right)} \div \mathrm{BW}$$ Eq1.

APSI = $$\sqrt{\left(\frac{\sum(0 - GRFy)^2}{number\ of\ data\ points}\right)} \div \mathrm{BW}$$ Eq2.

VSI = $$\sqrt{\left(\frac{\sum(BW - GRFz)^2}{number\ of\ data\ points}\right)} \div \mathrm{BW}$$ Eq3.

DPSI = $$\sqrt{\left(\frac{\sum(0 - GRFx)^2 + \sum(0 - GRFy)^2 + \sum(0 - GRFz)^2}{number\ of\ data\ points}\right)} \div \mathrm{BW}$$ Eq4.

Statistical Analysis

Mean ± SD for each dependant variable (DV) were calculated (Figure 1 and Table 1). Each DV was examined for normality. Data were analysed from the dominant limb only and averaged across three-trials for each JPS 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 $p \leq 0.05$.

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 = 0.78 °, p = 0.019, d = 0.76) and EV30% (mean difference = 0.78 °, p = 0.024, d = 1.18) were observed post foot-drill. There was no significant change in IN60% values (mean difference = 0.17 °, p = 0.668, d = 0.19).

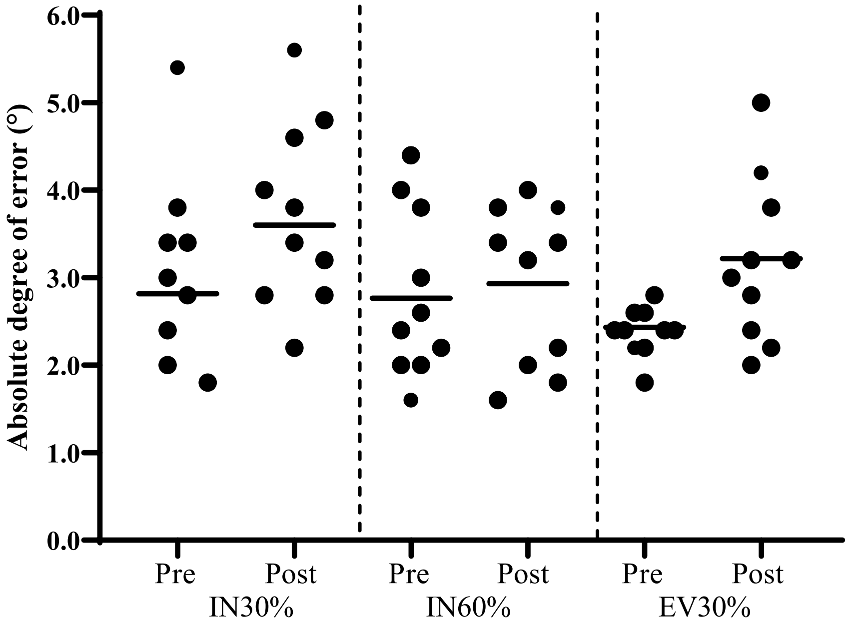

Figure 1: Absolute degree of error (°) for IN30%, IN60% and EV30% pre - post foot-drill. Mean data is shown by a solid horizontal line. * denotes a significant increase in JPS score post foot-drill.

Dynamic Postural Stability Index (DPSI)

The DPSI and its directional components quantified dynamic postural stability during a forward (A/P) and lateral (M/L) jump-landing. Table 2 shows the A/P jump-landing condition, MLSI ($p < 0.001$, d = 6.45), APSI ($p < 0.001$, d = 10.46) and DPSI (p = 0.006, d = 0.70) were significantly greater post foot-drill. Similarly, MLSI (p < 0.001, d = 13.38), APSI (p < 0.001, d = 5.38) and DPSI (p = 0.017, d = 0.52) 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) or M/L jump-landing conditions (p = 0.871, d = 0.03).

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). [a]denotes 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 ± 0.005[a]	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 measured by passive JPS of the ankle and dynamic postural stability 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 medium to large effect of foot-drill on smaller ($d \geq 0.76$) versus larger ($d = 0.19$) JPS test angles. Participants demonstrated a 28% 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. It is acknowledged that efficient movement execution requires an adequate postural stability (Massion et al., 2004). Similarly, the significance of balance to joint function, stability and injury prevention is well documented (Twist et al., 2008)

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 athletes (Payne et al., 1997; Willems *et al.*, 2005). Although acute trauma is a key factor in some injury cases, resulting in high rates of recurrence, frequently leading to disruption of ligamentous joint afferents and loss of proprioceptive acuity (Willems *et al.*, 2002; Röijezon et al., 2015), 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 0.78° increase in absolute JPS error for both IN30% and EV30% following foot-drill, with medium-to-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 $\Delta = 2°$) 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) 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.

We were unable to determine the precise mechanisms associated with the greater and lower absolute JPS error for IN/EV30% and IN60% respectively, post foot-drill. However, we postulate that the losses in JPS acuity observed for IN/EV30% are associated with the effects of fatigue from foot-drill (Forestier et al., 2002; South and George, 2007; Mohammadi *et al.*, 2013). Specifically, it is probable that a combination of both central and peripheral mechanisms contributed to exacerbating JPS performance post foot-drill. Research indicates that muscle spindles and Golgi tendon organs (GTO) may become desensitised as a result of fatiguing (Röijezon et al., 2015; Clark et al., 2015; Johanson *et al.*, 2011). These intramuscular receptors play a key role in controlling joint position and movement; therefore, it is plausible that foot-drill may have led to reduced intramuscular (afferent) receptor activity of stabilising structures which led to significant reductions in JPS acuity for smaller test angles compared to larger test angles (Röijezon et al., 2015; Twist et al., 2008; Allen and Proske, 2006).

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, 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. 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).

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, Klusendorf and Kernozek, 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 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 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.

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 of participants post foot-drill. In our study, the effects of fatigue have been implicated in the greater absolute JPS error and dynamic postural stability observed post foot-drill. Given that fatigue is associated 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 may be exacerbated which has implications for additional risk and increased severity of injury.

Conclusion

Significantly greater absolute JPS error and dynamic 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. Irrespective of sex, increased absolute JPS error and dynamic postural stability has been identified as risk factors for lower-extremity MSK injury and shown to predict injury in uninjured populations. 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 subsequent skill-based military activities and scheduling of high intense training and recovery sessions, and injury risk.

Understanding the risk of injury associated with the demands of occupational military activities using robust methodology (i.e., randomised controlled trials) is very difficult 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.

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