The Foot 24 (2014) 6–10

Contents lists available at ScienceDirect

The Foot

journal homepage: www.elsevier.com/locate/foot

Can RSScan footscan® D3D™ software predict injury in a military population following plantar pressure assessment? A prospective cohort study

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ARTICLE INFO

Article history:
Received 10 December 2012
Received in revised form
23 September 2013
Accepted 1 November 2013

Keywords:
Lower limb injuries
Injury prediction
Military training
Injury prevention
Gait assessment

ABSTRACT

Background: Injury in initial military training is common with incidences from 25 to 65% of recruits sustaining musculoskeletal injury. Risk factors for injury include extrinsic factors such as rapid onset of high volume training, but intrinsic factors such as lower limb biomechanics and foot type. Prediction of injury would allow more effective training delivery, reduce manpower wastage and improve duty of care to individuals by addressing potential interventions. Plantar pressure interpretation of footfall has been shown to reflect biomechanical intrinsic abnormality although no quantifiable method of risk stratification exists.
Objective: To identify if pressure plate assessment of walking gait is predictive of injury in a military population.
Method: 200 male subjects commencing Naval Officer training were assessed by plantar pressure plate recording, of foot contact pressures. A software interpretation, D3D™, stratified the interpretation to measure 4 specific areas of potential correction. Participants were graded as to high, medium and low risk of injury and subsequently followed up for injury through their basic training.
Results: Seventy two percent of all injuries were attributed to subjects in the high and medium risk of injury as defined by the risk categorization. 47% of all injuries were sustained in the high-risk group. Participants categorized in the high-risk group for injury were significantly more likely to sustain injury than in medium or low groups ($p < 0.001$, OR 5.28 with 95% CI 2.88, 9.70).
Conclusions: Plantar pressure assessment of risk for overuse lower limb injury can be predictive of sustaining an overuse injury in a controlled training environment.

1. Introduction

Overuse lower limb injuries (OLLI) are common in both the recreational runner and in those undergoing initial military training with incidences reported between 25 and 82% [1–5]. OLLI includes a range of diagnoses including medial tibial stress syndrome, stress fractures, anterior knee and patello-femoral pain, achilles tendinopathy and plantar fasciitis.

In the military training environment, although controlled, extrinsic risks are more difficult to modify; level of fitness [6] increase in running intensity and mileage [7], along with the terrain, load carrying [8] and wearing of military combat boots [9–11] have all been attributed as causative of lower limb injury.

Intrinsic risk factors relate to the anatomical morphology and joint kinematics of the individual and include the magnitude of impact [12], the pulse of impact [13] and magnitude of toe off [14], along with a rapid rate of mid foot pronation rather then degree [1,15,16], although there has been little quantitative prospective data [17,18]. Cowan et al. [19] attempted to correlate anatomical morphology including Q angle, limb lengths and knee extension flexion angle with injury in a cohort of US Army infantry recruits and found significant association's between some of the variables. Bredewig highlights asymmetry in kinetics [20] as a causative factor and limb length, Gluteal muscle control and foot arch height [21] have been identified as a risk factor. Interestingly, Bennet [22] reports an association with MTSS and rate of mid foot pronation and Willems [23] suggests plantar pressure differences in MTSS and stress fractures identifiable in the gait cycle. Van Ginkel reports laterally directed force distribution in mid stance as a predisposing factor for achilles tendinopathy [24].

Foot kinematics and kinetics can be interpreted by visual inspection, video, motion capture along with plantar pressure data

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http://dx.doi.org/10.1016/j.foot.2013.11.002

[23,25,26]. Plantar pressure measurement has been demonstrated to be reliable in test–retest reliability [27] and allows interpretation of the rate of loading of the foot and estimate of arch height [28] contact time and contact area by utilizing a masking algorithm which assigns the distinct areas of the foot bony landmarks with the plantar pressure data [29,30]. Plantar pressure data has been shown to correlate with Foot Posture Index scoring confirming its usefulness [31]. RSScan footscan® technology has shown good intraclass correlation coefficients with Force plate comparison [32].

In the military, the cost to the individual of sustaining an OLLI can be significant due to the time spent in rehabilitation and failure to progress through basic training, resulting in career ending consequences but also to the employer with high injury rates representing significant investment in training and loss to service.

The quantification of prospective risk is difficult and no validated method of grading kinematic or kinetic abnormality exists, less so plantar pressure data interpretation, in terms of risk of injury. There is however evidence that plantar pressure data can correlate with intrinsic biomechanical abnormality [33] and that may imply that the greater the perceived abnormality, the greater the risk of injury [34]. Formal screening of initial military recruits is rare and where this has been performed it represents a potential injury prevention strategy [35].

1.1. Objective

This study aimed to demonstrate whether an individuals risk of injury could be correlated with a simplified interpretation of walking plantar pressure measurement, based on comparison of pressure interpretation with D3D™ (RSScan Ltd) software assessment, and whether this correlation could predict an individual's risk of sustaining injury during initial military training.

The end goal being a simple interpretation of risk, following a gait assessment which might be employed as an injury risk reduction strategy by the prescription of orthotic intervention by non-expert clinicians.

2. Method

2.1. Environment

Britannia Royal Naval College is the Royal Navy's Officer training school. New entry trainees follow a progressive gym based, and running programme based around personal fitness. They are given a standardized pre-joining training programme, compliance with this programme was not assessed, but all participants met the minimum fitness standard for joining. Minimum personal fitness standards require the completion of a 1 mile and a half run in under 11 min 13 s for 25 year olds and under 11 min 38 s for 26–30 year olds.

As part of the curriculum, daily physical training is carried out including gymnasium based activities in running shoes, and squad running, outdoor marching and load carrying in boots, daily load and mileage increases gradually to a maximum of 27 miles in 48 h, carrying a personal load of 30 kg at the end of 7 weeks. The remainder of the programme is classroom or riverboat based activity. Whilst the daily activity is carried out over a 10-h period, only 2 h a day would be spent undergoing physically stressful training. Across the 7-week initial entry course 70 h of physical training would be typical.

2.1.1. Participants

200 male subjects accepted for initial officer training at Britannia Royal Naval College, consented to participate. The subjects were recruited from successive intakes to Young Officer training between July 2007 and December 2007. Subjects' age, gender, height, weight, body mass index and shoe size was recorded (Table 1).

Table 1
Anthropometric characteristics of cohort.

Number	200
Sex	Male
Age mean (95% CI)	24.7 (24.62–24.77)
Height mean (95% CI)	1.80 (1.72–1.87)
Weight mean (95% CI)	77.2 (77.13–77.30)
BMI mean (95% CI)	24.08 (24.03–24.17)
Shoe size mean (95% CI)	9.5 (9.43–9.57)

All participants gave their written consent to take part in the study, and the Ministry of Defence Research Ethics Committee gave ethical approval for the undertaking of the study. Participants were excluded from the trial if they disclosed, wearing or having worn orthotics in the past, had an existing lower limb injury or withheld consent. Subjects were withdrawn from the trial if it was discovered that they had not disclosed information about a pre existing condition, if they withdraw their consent, if they sustained other injury preventing them participating in the trial or if they were withdrawn from training for academic reasons.

2.1.2. Injury risk assessment

Injury risk assessment was carried out by plantar pressure recording. The initial pressure plate measurements were taken in the week of commencement of training of all young officers. A 1 m footscan® pressure plate (RS Scan International, Belgium) 1 m × 0.4 m × 0.02 m, 64 lines at 500 Hz and 3 sensors per cm^2 (Total of 8192 sensors) placed flush in the centre of an 18 m track of 0.02 m EVA covered in a 0.005 m rubber track cover was used. All participants were asked to walk over the test track on a number of acclimatization walks at natural gait until they felt comfortable. Participants were then asked to walk across the apparatus at a natural gait, barefoot, a minimum of 5 times on both right and left feet. The run was considered valid when a heel strike pattern was captured with only right or left foot strike pattern recorded per run. The mean data from 5 recordings was taken for each foot to improve reliability.

No physical exercise sessions were carried out in the 24 h prior to testing.

Self selected walking pace rather than running gait was assessed due to potential confounding factors as standardizing running velocity has been shown to affect walking and running gait [36] and it is accepted the incidence of abnormality under or over reported if repeated at running gait. Barefoot assessment was carried out to more accurately identify differences in plantar pressure measurement as shod conditions are poorly represented due to attenuation of the footwear on plantar pressure variables [37,38].

2.1.3. D3D™ Software Risk categorisation

D3D™ Software (RSScan International, Belgium) utilizes the raw plantar pressure data from plantar pressure assessment to make an orthotic prescription recommendation. Eight anatomical areas are automatically identified by the plantar pressure software using a masking algorithm (Fig. 1) (footscan® 7.0 Gait 2nd Generation, RSScan International) based on peak pressure footprint. These areas are defined as Medial heel (H_M), Lateral heel (H_L), Metatarsal Heads M_1,M_2,M_3,M_4,M_5 and the Hallux, T_1. Temporal data on time to peak pressure, peak pressure and initial contact is recorded for each of these areas.

Based upon the ratios of loading for 4 regions of the foot: Heel, Mid foot (medial and lateral) and Forefoot (Fig. 2) a correction is automatically recommended in this area of foot contact, if the range of ratio is exceeded within the software programme [39].

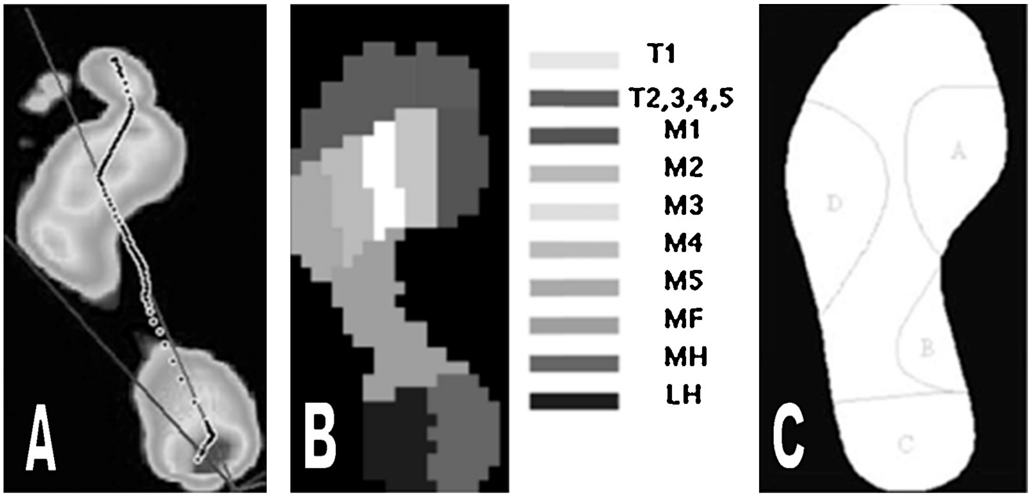

Fig. 1. (A) Plantar pressure map with axis of central pressure. (B) The 10 Anatomical masking areas. (C) The 4 areas of potential correction.

This would result in a correction being applied to a custom orthoses (Fig. 1).

No orthotics were prescribed in this study but the "prescription" was interpreted to determine possible risk. For the purposes of this study, participants were risk quantified as to the number of corrections recommended, 0 (no correction, participant fell within normal limits) to 4 (maximum number of corrections applied to participant). Given the previous intrinsic potential risk mechanisms it was hypothesized that no recommended corrections represented low risk of abnormality and hence injury, medium risk of injury was taken to represent one correction recommendation, and high risk being two corrections or more.

The subject was blind as to their risk categorisation and offered no intervention. The clinician was also blinded as to the injury risk of the subjects until after the trial.

2.2. Statistical analysis

Pilot studies [40] showed, a background injury rate of 1 injury per 1719 h of training (1:1719 injuries/h of training). Power calculations demonstrated a sample size of 180 was sufficient to detect a difference between groups for α 0.05 with a power of 80% (McNemars, PASS 2005). 200 subjects were recruited to allow for 10% dropout.

Statistical analysis was performed with SPSS Version 17 (SPSS Inc., Chicago, IL, USA). Chi-squared test was applied to the association between injury and biomechanical risk, to determine whether a predictive relationship was present, and logistic regression analysis was performed. Odds ratio, sensitivity and specificity were also calculated to assess validity of this relationship.

Correction	Calculation
A+ Fore Foot correction (anti-pronation)	(M1+M2)/(M1+M2+M3+M4+M5)
DF-, Anti inversion element, lateral stabiliser	(M3+M4+M5)/(M1+M2+M3+M4+M5)
B+, Mid foot correction(Anti-pronation)	(M1+M2+HM)/(M1+M2+M3+M4+M5+HM+HL)
C, Rearfoot Correction Anti-valgus	(HM)/(HM+HL)

Fig. 2. The areas of Correction and the ratio calculation formulae.

2.2.1. Outcome measures

A lower limb injury was defined as an injury, which resulted in removal of the subject from physical training for 2 days or more, caused, by pain presenting from knee to foot. Overuse lower limb injuries included in this definition comprised stress fracture, medial tibial stress, chronic exertional compartment syndrome, anterior knee pain, ilio-tibial band syndrome, achilles tendinopathy, and plantar fasciitis.

2.2.2. Injury reporting

The participant's medical records were searched on completion of initial training for injury reported up to the 7-week point. Where no diagnosis of injury had been made, a manual search, of the electronic record, over the same 7-week period was conducted. All conditions were diagnosed by the same sports medicine clinician and confirmed by a second musculo-skeletal clinician. Injuries were recorded using the primary care EMIS (Egton Medical Information System, Egton plc) computer based medical record, used across Military primary care facilities in the UK, and after the reporting period participants who sustained a OLLI injury were compared with the original D3D^{TM} data risk assessment.

3. Results

The participant's anthropometric data is reported in Table 1. Within the 200 subjects, 57 (28.5%) sustained injuries and 143 (71.5%) sustained no injuries (Table 3). The high-risk subjects were responsible for 47.4% of all injuries, and the medium risks a further 24.6%. Low risk subjects sustained 28.1% of all injuries (Table 3).

The most frequent injuries seen were anterior knee pain and medial tibial stress syndrome (Table 2).

Table 2
Injury breakdown by classification.

Injury	*n* (57)	% ($n/57 \times 100$)
Plantar fasciitis	5	9
Tibial stress fracture	6	10
Anterior knee pain	16	28
Iliotibial band syndrome	7	12
MTSS	18	31
CECS	2	3
Achilles tendonopathy	3	5

MTSS – medial tibial stress syndrome, CECS – chronic exertional compartment syndrome.

Table 3
Injuries sustained per risk categorization.

Risk category	Number of participants $n = 200$	% of total	Number of injuries sustained $n = 57$	% of total	Combined	%
High	42	21	27	47	41	72
Medium	56	28	14	25		
Low	102	51	16	28	16	28

Fishers test – high risk vs. Medium $p < 0.0002$, high vs. low $p < 0.0001$, combined vs. low $p < 0.0001$.

A likelihood ratio Chi-square test indicated a statistically significant association between the 3 risk categories and the 2 injury categories ($\chi^2 = 32.693$, $p < .001$). The observed frequency of injuries in the high-risk category was over two times greater than the expected frequency and subjects in the high-risk category exhibited a significantly higher likelihood of sustaining injury than subjects in the medium and low risk categories ($p < 0.001$).

Logistic regression analysis demonstrated that participants categorized in the High-risk group for injury were significantly more likely to sustain injury than in medium or low groups ($p = 0.001$, OR 5.28 with 95% CI 2.88, 9.70).

The sensitivity $= F_1/(F_1 + F_2)$, where F_1 = frequency of injuries sustained in the high-risk category and F_2 = the frequency of injuries sustained in the medium or low risk categories was calculated. The sensitivities with respect to the medium and low risk categories using the frequencies in Table 3 were $27/(27 + 14) = .659$ and $27/(27 + 16) = .628$ respectively.

The specificity $= F_3/(F_3 + F_4)$ where F_3 = the frequency of no injuries sustained in the low risk category and F_4 = the frequency of no injuries sustained in the medium or high-risk categories was also calculated. The specificities with respect to the medium and high-risk categories using the frequencies in Table 3 were $86/(86 + 42) = .672$ and $86/(86 + 15) = .851$ respectively.

4. Discussion

This is the first study to demonstrate that dynamic pressure plate interpretation of gait can be predictive in terms of lower limb injury risk.

The reliability of pressure plates in the assessment of foot type has been confirmed [41], along with the reliability of temporal plantar pressure variables [42]. Furthermore the interpretation of risk factors has also been studied successfully with plantar pressure data [43].

Although the High-risk group demonstrates a predictive association for sustaining injury ($p < 0.001$), there were a greater number of injuries in the low risk group than the medium risk category. This does suggest a weakness in the classification of risk as designated by the authors, and that one correction is insufficient to differentiate between risks, this does not detract from the high-risk categorization and association with injury risk. Future work may concentrate on the high-risk group and its stratification as to individual plantar pressure characteristics and injury association. There was insufficient power in this study to draw any subgroup analysis between risk and specific injury.

The training load and conditions in the initial 7 week period are extremely reproducible and the injuries encountered representative, with perhaps the exception of a reduced lower limb stress fracture occurrence when compared with the literature [44]. Whilst BRNC is an initial military training facility, the physical demands on a young naval officer are significantly less than those in basic infantry training, in which much existing work has been performed and as such extrapolation to this environment should be interpreted with caution.

No existing risk classification existed in terms of breaking down the plantar pressure data, the authors in designing the classification looked at unpublished data from British Army research [45] along with information form the manufacturers [23]. It could be argued that this classification is arbitrary and requires refinement to identify more subtle predictors of specific injury. The authors would argue however that this is precisely what the study attempted to avoid. By looking specifically at an all risks group we were able to demonstrate a predictive score for injury risk, based on a reproducible test. This is not in itself a weakness of the study, which set out to determine whether an interpretation of the prescription provided by the D3D™ software could be used to assess risk of OLLI and it was successful in this aim.

There are many confounding variables in lower limb injuries causation outside gait and many studies have attempted to quantify them. Training load variables are certainly contributory, in particular rapid increases in weekly distance [17], it is recognized that this is a confounding variable but attempts were made to standardize the training load within and across groups. Other associations between stretching [46], running surface and shoes [16] are less well quantified. The participants were older than many in basic military training due to the acceptance criteria for Naval Officer training.

Associations between prior injury [47], menstrual dysfunction [48,49] sensorimotor control [50], joint hypermobility [51], smoking [52], age and previous performance/training level [53] are all confounding variables. This study did not attempt to identify non-gait related risk factors and confined itself to gait assessment and those related associations.

5. Conclusion

This is the first study to identify all cause injury risk prospectively by pressure plate assessment of gait using a simple and relatively low cost method of screening large numbers of military recruits. The use of D3D™ prescription to grade risk appears successful and injury prevention studies should be designed to determine whether corrective intervention in the identified risk groups can reduce the incidence of OLLI.

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