Gait retraining and incidence of medial tibial stress syndrome in Army Recruits

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Abstract

Purpose: Gait retraining, comprising bio-feedback and/or an exercise intervention, might reduce the risk of musculoskeletal conditions. The purpose was to examine the effect of a gait retraining program on medial tibial stress syndrome incidence during a 26 week basic military training regimen.

Methods: A total of 450 British Army recruits volunteered. On the basis of a baseline plantar pressure variable (mean foot balance during the first 10% of stance), participants classified as at-risk of developing medial tibial stress syndrome (n = 166) were randomly allocated to an intervention (n = 83) or control (n = 83) group. The intervention involved supervised gait retraining, including exercises to increase neuromuscular control and flexibility (3 sessions per week) and bio-feedback enabling internalization of the foot balance variable (1 session per week). Both groups continued with the usual military training regimen. Diagnoses of medial tibial stress syndrome over the 26 week regimen were made by physicians blinded to group assignment. Data were modelled in a survival analysis using Cox regression, adjusting for baseline foot balance and time to peak heel rotation.

Results: The intervention was associated with a substantially reduced instantaneous relative risk of medial tibial stress syndrome versus control, with an adjusted hazard ratio of 0.25 (95% confidence interval, 0.05 to 0.53). The number needed to treat to observe one additional injury-free recruit in intervention versus control at 20 weeks was 14 (11 to 23) participants. Baseline foot balance was a nonspecific predictor of injury, with a hazard ratio per 2-SD increment of 5.2 (1.6 to 53.6). Conclusions: The intervention was effective in reducing incidence of medial tibial stress syndrome in an at-risk military sample.

Keywords: Military training; musculoskeletal injury; bio-feedback; exercise intervention; injury prevention; overuse injury

Introduction

Paragraph 1: Musculoskeletal injuries acquired during military training regimens are a common problem (22). Medial tibial stress syndrome is a pain experienced along the posterior-medial border of the tibia while performing exercise and which is not caused by ischemic disorders or stress fractures (43). The syndrome can be diagnosed as shin splints, shin pain, periostitis and/or exercise-related lower leg pain (14). Currently, the most effective management of medial tibial stress syndrome is prolonged rest followed by a graduated return to fitness (43) which in military populations leads to a loss of training days, increased cost of medical support and a reduction in operational readiness. On the basis of the number of training days missed due to injury, medial tibial stress syndrome is highlighted as being one of the more impactful overuse injuries experienced in the armed forces (27).

Paragraph 2: Not surprisingly given its impact there have been several intervention-based studies designed to prevent medial tibial stress syndrome during military training. However, for the most part the effects of these interventions on the prevention of injury are not clear (27). Gait retraining combining bio-feedback and/or exercise intervention has become a viable alternative to traditional injury management. For example, limb-load monitoring by providing visual feedback on forces through the legs has enabled lower-limb amputees (11) and hip-replacement patients (40) to improve the symmetry of their movement. More recently, bio-feedback has been adopted for injury prevention. For example, haptic bio-feedback on the tibia orientation has been used to encourage a toe-in form of gait to reduce the knee adduction moment in osteoarthritis patients (34). In addition, bio-feedback of tibia shock, a risk factor for tibia stress fracture, has enabled runners to modify their gait mechanics to reduce the risk of injury (10). Importantly, in the latter study, the participants were able to retain these new motor skills for at least a month after the intervention (10) and it has been suggested that gait retraining, by addressing the underlying biomechanics, could

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reduce the risk of other running-related injuries (28). In addition to bio-feedback, gait retraining could also be supplemented with conditioning exercises designed to target areas of muscular deficiency. It is notable that balance training (26) and multi-faceted exercise programs (7) have been shown to improve neuromuscular strength/control and are recommended for the reduction of risk factors associated with other musculoskeletal injuries (26).

Paragraph 3: Although several interventions have been employed to attempt to reduce the incidence of medial tibial stress syndrome, the effectiveness of gait retraining on injury incidence has yet to be examined. As with any gait retraining program, the first step is to identify the putative risk factor. A commonly cited risk factor for medial tibial stress syndrome is foot pronation (27) but unfortunately foot pronation is difficult to measure, being a highly complex movement combining eversion, adduction and dorsi-flexion about three non-orthogonal and non-stationary axes. Fortunately, foot balance, the difference in plantar pressure between the medial and lateral sides (medial pressure minus lateral pressure) of the foot, can provide a useful proxy measure of pronation and has been shown to be an important risk factor for a variety of exercise-related lower limb overuse injuries in recreational athletes (41, 42). Moreover, average foot balance during the early stages of the stance phase of gait was found to be a primary risk factor for medial tibial stress syndrome in a previous cohort of military recruits from the same infantry training centre as in the current study (33). Therefore, by using foot balance score during the early stages of stance as the targeted risk factor, the aim of this study is to examine whether a gait retraining program can reduce medial tibial stress syndrome incidence during a 26-wk military training regimen.

Methods

Paragraph 4: **Design and participants.** The design of this exploratory study was a prospective randomised controlled trial. As appropriate for an exploratory trial, we did not conduct formal sample size estimation a priori. Rather, the power and precision in our study is indicated directly by the confidence interval presented for the primary effect. The participant flow through the trial is shown in Figure 1. Briefly, 450 British infantry recruits were assessed for eligibility and 284 did not meet the eligibility criteria for the study. Eligible participants were drawn from the population of all new Line Regiment recruits. Participants were excluded if they had any existing or prior lower limb injury affecting gait pattern in the previous 3 weeks, had any neurological dysfunction, were users of orthotics, or declined to participate/withdrew consent. Participants were included if they met the criteria for 'at risk' of medial tibial stress syndrome, as detailed below. The study was approved by the Ethics Committee of Teesside University, UK and written informed consent was obtained from all participants. During the obligatory initial medical assessment as part of the research process the new trainees underwent a 3-minute treadmill barefoot walking session while being observed by a trained physiotherapist. The physiotherapists involved all had at least 5 years of practice in the clinic and were under instructions to identify trainees with abnormal gait using the gait component of a published screening tool (12). Specifically, they looked for any obvious abnormal deviation from the ideal gait pattern such as signs of hip-drop, line of progression, foot angle with respect to direction of travel and hip and tibial rotation, and any abnormal foot pronation, as well as supination during treadmill walking (12). Those with observable abnormal gait patterns were then referred for plantar pressure analysis. A pressure plate (RsScan International, Belgium, plate size = 200 cm × 40 cm, sensor size = 0.5cm × 0.7cm and sampling frequency = 126 Hz) was hidden in the middle of a 9 m long purpose-built walkway (Figure 2a). Following a weight calibration stage, the subjects walked

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overground and barefoot across the pressure plate at their natural walking speed. Each trial enabled us to capture 2-3 pressure footprints, depending on the landing position of the first foot. The trials were repeated until a minimum of six left and six right plantar pressure distributions during the stance phase of gait were recorded. Plantar pressure analysis software (Footscan software 7.0, RsScan International) was configured to extract local pressures ($N \cdot cm^{-2}$) on the plantar surfaces of the feet. The plantar pressure data for each foot were segmented into nine regions. These local pressures were; medial heel (HM), lateral heel (HL), five metatarsals (M1–5), hallux (T1) and the other toes (T2–5). The data calculated using the pressure plate software were foot balance (=M1+M2+HM-M3-M4-M5-HL) which is effectively a pressure differential between medial and lateral sides of the foot ($N \cdot cm^{-2}$) during stance. During the heel landing phase this variable is effectively a measure of the medial-lateral pressure difference across the heel. In a previous study, we found average foot balance during the first 20% of stance was a primary risk factor for medial tibial stress syndrome (33). Unpublished data from that study on medial tibial stress syndrome, revealed that the same parameter but taken at the first 10% was likely to be a better discriminator between those that developed medial tibial stress syndrome and those that did not (see Figure 1a of Sharma et al. (33)). Therefore, in the current study we elected to report the foot balance score as the average value of foot balance during the first 10% of stance. A further outcome variable, which was also shown to be a discriminator between injured and non-injured groups, was time to reach peak heel rotation (Figure 1c of Sharma et al. (33)). This variable is the percentage of the stance phase of gait, at which the heel rotation variable (=HM-HL) peaked. Participants who recorded foot balance scores, as defined above, greater than 1 SD away from the mean of previously collected normative data were judged to be at risk of developing medial tibial stress syndrome (33). Unfortunately, time constraints did not allow us to record the self-selected walking speeds. These participants then took part in the main

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trial (n = 166; mean (SD) age 20.1 ± 2.0 years; height 167.0 ± 1.4 cm; body mass 67.0 ± 2.4 kg). Participants were assigned to groups using a blocked randomization schedule, with the six possible permutations of a fixed block size of four - containing two control and two intervention assignments - selected at random to create the allocation sequence. The sequence was concealed from the investigator assigning participants using opaque sealed envelopes.

Paragraph 5: **Intervention.** A system for providing bio-feedback using the plantar pressure system (33) was developed in this study (Figure 2). Specifically, participants were encouraged to walk barefoot and overground with their head and chest up, a slight anterior tilt of the pelvis and with only moderate movements of the centre of mass in the vertical direction (Figure 2a). Hidden in the walkway was the pressure plate connected to a laptop PC. Local plantar pressures on the foot were measured for each overground walking trial and on-screen colored contour plots of the peak of these localised pressures were displayed (Figure 2b). The time delay between walking and visualizing the feedback was approximately 6-10 s (i.e. the time it took for the participant to walk back to the laptop PC). When visualising the pressure data, the attention of the participant was drawn by the lead investigator to the medial-lateral component of the trajectory of the centre of pressure which is due to imbalances in heel pressure (Figure 2c). In cases where the participants landed on the medial heel or where there were high medial pressures on the heel (i.e. foot balance score remained high), the participants were encouraged to focus on landing more lightly, on the lateral side of the heel and to control foot eversion during landing so as to reduce the foot balance score (i.e. the putative risk factor for medial tibial stress syndrome). In cases where the foot balance score was low the participants were encouraged to repeat the walking pattern. Each bio-feedback session lasted approximately 30 minutes, consisted of 7-8 overground walking trials, and each trial was followed with bio-feedback. These biofeedback

sessions were delivered once a week in weeks 1-12 and once every two weeks in weeks 12-24.

Paragraph 6: The gait retraining program was supplemented with exercises to increase strength, flexibility and neuromuscular control in areas of potential musculoskeletal deficiency. The regions targeted were the foot, leg and lumbo-pelvic complex. The retraining program consisted of several exercises based on the existing literature (Table 1) and was designed to target musculoskeletal deficiencies reported to be risk factors associated with lower limb overuse injuries (13). Since the origins of training injury are clearly complex and multifactorial (19), a multifaceted training strategy was used (20). The stretching exercises were as follows; hip flexor stretch (7), hamstrings stretch (16) and calf stretch (30). The exercises to target neuromuscular control were as follows; birddog (17), gluteus medius (7), small knee bend progressing to single-leg squats (6), calf raise (24), tibialis posterior control (23), intrinsic foot muscle control (31) and a double leg jump (36). The balance exercises were the star excursion stability exercise (5), single-limb hops to stabilization (26) and unanticipated hop to stabilization (26). The training sessions were scheduled 3 times per week and the load was gradually increased by increasing the number of repetitions. The program consisted of 10 exercises performed in sets of 10 in weeks 1-12 and 14 in week 12-24 (7). Each session lasted for approximately 30 minutes. Supervision by the physiotherapy staff was gradually reduced over the training period. In weeks 1-4, 5-6, 7-10 and 11-24, supervised sessions were conducted 3, 2, 1 and 0.5 times (i.e. fortnightly), respectively. Participants were encouraged to practice these exercises in their own time and to focus on the quality of the movements to compensate for the gradual reduction in supervision.

Paragraph 7: **Outcomes.** Injury data, which included the clinical diagnosis and the timing of the injury (weeks), were collected prospectively over the entire training regimen (26 weeks).

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Clinical diagnoses were made at the Army Medical Centre by military physicians who were blinded to group assignment. For possible cases of medial tibial stress syndrome, patients having ischemic disorders or tibia stress fractures (including those possibly being preceded by medial tibial stress syndrome), X-ray, MRI scan and intra-compartmental pressure measurements were used to confirm/reject the medial tibial stress syndrome diagnosis (8). Post-intervention measures of foot balance and time to reach peak heel rotation were collected at 26 weeks.

Paragraph 8: **Data analysis.** Injury data (primary outcome) were analysed using Cox proportional hazards regression with medial tibial stress syndrome injury as the event variable, survival time (in weeks), group (control, intervention) as the predictor and baseline foot balance and time to peak heel rotation as covariates. The proportional hazards assumption was checked using a global test plus separate tests for the predictor and each covariate (35). The effect of each continuous covariate was considered as the effect of twice its standard deviation (18). Time-to-event data are presented in an ascending survival probability plot (29). We derived adjusted hazard ratios for intervention versus control and for the covariates. Due to a low ratio of events to predictor variables, confidence intervals for the hazard ratio were obtained using a bias-corrected and accelerated bootstrap resampling method (5000 resamples with replacement) (38). We estimated the number needed to treat at the 20-week timepoint using methods described by Altman and Andersen (1). This timepoint was chosen to allow sufficient time spent in military training for a substantial number of medial tibial stress syndrome events to accrue. By convention the number needed to treat and its lower and upper confidence intervals were rounded up to the nearest whole number. Mixed effects linear modelling was used to analyse the effect of the intervention on the secondary outcomes (foot balance and time to reach peak heel rotation) allowing for - and

quantifying as a SD - the individual differences in response to the intervention. Effects were adjusted for baseline value of the outcomes to account for chance imbalance at baseline (37).

Paragraph 9: We made probabilistic magnitude-based inferences about the true population value of the effects, based on the likelihood that the effect was substantially beneficial or substantially harmful. For the hazard ratio, thresholds of 0.9, 0.7, 0.5 and 0.3, and 0.1 – or their reciprocal - defined small, medium, large, very large, or extremely large effects; the equivalent thresholds for continuous outcomes expressed as standardised mean differences are 0.2, 0.6 and 1.2, 2.0, and 4.0 SDs, respectively (18). Inferences were then based on the disposition of the confidence interval for the mean effect to these thresholds and were derived using the following scale: <0.5%, most unlikely; 0.5–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; >99.5%, most likely (18). A clinically unclear effect is defined as one where the effect is possibly beneficial (probability > 0.25) but also has an unacceptable risk of harm (probability > 0.005); all other effects are clinically clear (18). All analyses were conducted using IBM SPSS (v.21.0, IBM Corp, Armonk, NY) and Stata (v12.1, StataCorp LP, College Station, TX) software. Effects are reported together with 95% confidence intervals.

Results

Paragraph 10: The proportional hazards assumption was satisfied for all variables combined (global test) and separately for each variable. There was a possibly very large/ likely large beneficial reduction in instantaneous relative risk of injury associated with the intervention (hazard ratio 0.25; 95% confidence interval, 0.05 to 0.53). Figure 3 presents the ascending survival probability plot for the intervention and control groups. The number needed to treat to observe one additional injury-free recruit in intervention versus control at 20 weeks was 14 (11 to 23) participants. A 2-SD increase in the baseline foot balance score was associated

with a likely very large harmful effect on risk of injury (hazard ratio = 5.2; 1.6 to 53.6). This effect did not depend substantially on group. The effect of baseline time to peak heel rotation was unclear (hazard ratio = 0.61; 0.18 to 1.8). For the secondary outcomes, the effect of the intervention (versus control) was a most likely moderate effect (possibly large) on foot balance (-14 N·cm^{-2}; -17 to -11 N·cm^{-2}) and a likely moderate effect on time to reach peak heel rotation (2.8%; 1.5 to 4.1%, expressed as a percentage of stance phase). The SD of the individual responses was 4.2 (-5.0 to 7.7) N·cm^{-2} and 3.0 (2.0 to 4.4) % for foot balance and time to reach peak heel rotation, respectively.

Discussion

Paragraph 11: Despite the widespread problem of medial tibial stress syndrome in military trainees, there is currently no consensus on the most effective injury prevention strategy. Gait retraining is emerging as a potential strategy to reduce risk factors associated with musculoskeletal conditions. By targeting risk factors associated with this syndrome we examined the effectiveness of gait retraining in reducing the risk of medial tibial stress syndrome using a randomized controlled trial design. Our main finding was that army recruits who undertook the gait retraining program had one quarter the instantaneous relative risk of medial tibial stress syndrome at any timepoint across the 26-week intervention when compared to the control group (a risk reduction of 75%) - likely to be a large beneficial population effect. The number needed to treat, derived from the hazard ratio and control group survival probability, revealed that on average the intervention would have to be delivered to 14 recruits to observe one additional injury-free recruit in intervention versus control at 20 weeks into the 26-week training program. We did not include health-economics modelling in this exploratory trial, and whether this number needed to treat indicates a cost-effective intervention, given the impact of injury on lost training days, medical support costs,

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and reduction in operational readiness set against the costs of delivering the intervention, requires formal evaluation in future research. A further finding was that the gait retraining had moderately beneficial effects on putative risk factors for medial tibial stress syndrome. An additional observation was that there were no obvious side-effects due to the intervention. Specifically, similar numbers (Figure 1) of recruits were lost due to follow-up in both groups which includes those lost to non-MTSS injuries. Thus, we have no reason to believe that the gait retraining programme resulted in detrimental effects on other parts of the body. Consequently, the findings of this exploratory trial lend support to the hypothesis that gait retraining is a viable strategy for reducing the impact of medial tibial stress syndrome in military recruits and, if the findings can be extrapolated to a wider population, could have implications for anyone about to embark on a sudden increase in training load.

Paragraph 12: There have been several interventions designed to prevent medial tibial stress syndrome during military training; for example, the effects of additional calcium intake (32) and supplementary strength and conditioning programs (2) have been examined. However, the effects of these interventions were not clear. Other studies have examined the effects of foot orthoses on general lower limb injuries in Danish conscripts (25) and British Naval recruits (14). In the former the actual use of orthoses was found to reduce the risk of lower-limb injury but relatively few conscripts sought this type of injury prevention. Thus, the effect in terms of actual days lost was unclear and the authors concluded that this form of intervention was not economically viable for this population (25). From data presented in Table 3 of the randomized trial in British Naval recruits (14) the rate of medial tibial stress syndrome injury in men only in the control group was 13.2% versus 1.6% in the orthoses group. The absolute risk reduction was 11.6% (95% confidence interval 5.5 to 17.7%) giving a number needed to treat to prevent one additional injury of 9 (6 to 18) participants. This beneficial effect is similar to that observed in the current study, notwithstanding a shorter

follow up of just seven weeks. At present, we do not consider gait retraining and orthoses interventions as mutually exclusive; potentially they could be used in combination (e.g. gradual phasing out of the orthoses) to provide short- and longer-term benefits in terms of injury avoidance.

Paragraph 13: The gait retraining program included bio-feedback on risk factors and a battery of exercises to improve neuromuscular condition. We suggest that the bio-feedback component might be a key contributor to the injury reduction observed. Although there are no previous bio-feedback studies on actual injury incidence to support this suggestion, there have been several studies examining the effects of bio-feedback on risk factors. It is generally regarded as a useful technique, and most relevant to this study is that bio-feedback almost halved the magnitude of acceleration of the tibia during running (10), which is a previously suggested risk factor for tibia stress fracture (similar to medial tibial stress syndrome in terms of aetiology). We also believe that the exercise component might be an important contributor to the reduced incidence of injury. We acknowledge that the effect of previous exercise interventions for medial tibial stress syndrome have been unclear (2); however, arguably the current exercise program is not comparable to the interventions delivered in these previous studies. The current program includes additional elements of neuromuscular training, some of which have already been shown to contribute to other injury prevention programs (7, 26). Thus, it is plausible that the exercise program was a substantial contributor to the success of the current intervention.

Paragraph 14: An interesting additional finding was that the baseline foot balance measure was a strong nonspecific predictor of outcome (21); that is, it is predictive of medial tibial stress syndrome injury in both the intervention and control groups. A 2-SD increase in foot balance increases the instantaneous relative risk of medial tibial stress syndrome over 5-fold -

likely to be a very large harmful population effect. This findings lends support to the growing consensus that over-pronation of the foot during landing is important in the development of medial tibial stress syndrome (27). However, it should be reiterated that the foot balance variable measured in this study is a proxy measure of pronation. A measure of pronation with higher fidelity would require the use of 3-dimensional motion capture of the foot, requiring calibration and installation. In contrast, the foot balance variable can be captured from plantar pressure plates in a five-minute time slot and is much more feasible in this clinical setting. A further potential advantage of the foot balance variable – as the difference between the medial and lateral pressures on the heel during the early stages of stance – is that it has both kinematic and kinetic components. Interestingly, recent findings regarding the internal biomechanical causes of medial tibial stress syndrome on a tissue level indicate that the injury is caused by bending stresses exerted on the tibia (27), the magnitude of which will be highly dependent on the magnitude and direction of kinetic forces. Notably, differences in loading patterns (i.e. more medially directed forces) were found for tibia stress fracture patients when compared with healthy controls (9). Thus, counter-intuitively, it is plausible that the foot balance variable analysed in this study, with its kinetic component, could be more clinically relevant than the purely kinematic variable (pronation) that it is representing.

Paragraph 15: It is important to acknowledge the limitations of this study. First, it is not possible to blind participants to a gait retraining intervention. While a previous study (2) has overcome this limitation using a placebo exercise program consisting of upper body exercise, such an approach was not feasible given the holistic nature of our exercise program. In the current study, however, outcome assessors were blind to group assignment. Second, following the positive findings of Coppack et al. (7) we chose to target a specific injury (i.e. medial tibial stress syndrome) and hence did not attempt to examine intervention effects on other injuries. Although this targeted approach allowed us to design a medial tibial stress

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syndrome-specific intervention - which we believe was a major reason for the success - the consequence was that only a small number of injury events occurred resulting in a low events: predictor variables ratio for the Cox regression. A guideline of a minimum events-per-variable ratio of 5-9 is regarded as acceptable (38). We observed 12 events (9 in control, 3 intervention) with 3 predictor variables; a ratio of 4. Consequently we derived robust confidence intervals for the hazard ratios using bootstrapping, as recommended (38). In addition, if we omitted the time to peak heel rotation variable from the model – providing an events-per-variable ratio of 6 – it did not materially affect the hazard ratios for the intervention effect or the foot balance variable. Therefore, we are confident that the findings presented are not confounded by the low events-to-variables ratio. Third, our sample taken from the Line Regiment is all male and very homogeneous even in comparison to other regiments of the British Army. It is therefore very difficult to predict how these findings might translate to other populations. It is noteworthy that female recruits are four times more likely to be discharged from British Army due to chronic injuries of the lower back and lower-limb (15) which presumably is in part due to the reduced strength and cortical thickness of the bones in females (39). From this perspective, strategies to reduce injury risk in other regiments would be well-received. Similarly, the findings may also have relevance to non-military populations such as those required to undergo increases in physical activity for a variety of reason; for example those with sedentary lifestyles trying to increase their daily energy expenditure or athletic populations moving from sub-elite/amateur to elite/professional level. Unfortunately, the homogeneous nature of our sample makes it difficult to predict how these other populations would respond to the gait retraining intervention. Nonetheless, overuse injuries are hugely de-motivating irrespective of occupation, age, sex and performance-level and an effective injury prevention strategy to work across these different population groups would be desirable. Fourth, the five minute

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timeslot allocated for baseline data collection required us to minimise the number of measures taken from the recruits. Consequently, it was not possible to record the self-selected walking speeds during the trials and thus, potential differences in walking speed (3) when examining differences in foot balance cannot be eliminated. However, these potential differences between groups would be expected to affect foot balance more at baseline than at the 26 week timepoint. Specifically, by 26 weeks the recruits have been habituated to walk at the same speed through repeated marching. To reiterate, the differences in foot balance at baseline, i.e. when differences in speed are more likely, were trivial. In contrast the differences in foot balance at 26 weeks, i.e. when differences in speed are less likely, were substantial. Thus, while it recognised that between group differences in walking speed cannot be eliminated, it is suggested that these potential differences do not substantially affect the results. On this basis it is suggested that the differences in foot balance were due primarily to the gait retraining intervention and not due to a chance imbalance in walking speed.

Paragraph 16: Given the complexity of the intervention and the considerable time required to deliver it in its current form, an obvious question arises regarding the specific reason for the success of this intervention. More simply, could the intervention be simplified or cheaper to run yet retain the active ingredient/s? Unfortunately, since the trial was performed in a clinical setting in which there were no opportunities to isolate and discriminate the effects of the individual components of the intervention, it is impossible to address that question with any certainty. From this perspective it might be that the exercise component of the gait-retraining intervention, which requires a lot of time to deliver, is secondary to bio-feedback in terms of importance. However, until more is known regarding the biomechanics of movement and injury and the isolated effects of the intervention we recommend that the intervention should remain in its current form. Further work using additional gait assessment tools, on

establishing the causal pathway of medial tibial stress syndrome and quantification of the cost-effectiveness of the intervention could give future direction to such endeavours.

Conclusion

Paragraph 17: The gait retraining program was effective in reducing medial tibial stress syndrome incidence and two putative risk factors associated with this disorder. These findings must be confirmed in a large, multicenter definitive trial, focusing on the effectiveness across a more diverse population and also on the cost-effectiveness of the intervention.

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Figure Captions

Figure 1. Participant flow. DAOR = Discharged as of Right, MD = Medical Discharge, Transfer = Transferred to another training centre, and Admin = Administration discharge from Army for other reasons (*e.g.* service no longer required, disciplinary)

Figure 2. Structure of the bio-feedback sessions.

     a) The participant walked overground and barefoot over the pressure plate (hidden in the walkway and adjacent to the laptop PC).

     b) The graphics display consisted of the plantar pressures and points/vectors of interest when describing the movements of the foot. On the left is an instantaneous snapshot of pressure distribution beneath the right foot captured during the first 10% of gait. In the middle is a 3-step footprint pattern (left foot, right foot, left foot) for the whole trial. On the right is the peak pressure for both feet captured during the same trial. The peak pressure variables displayed are the maximum plantar pressure reached over the entire trial at each plantar location. Dark and light pixels represent low and high pressures, respectively. Also shown is the trajectory of the centre of pressure and the foot axis. The foot axis is defined as the line connecting the intersection between medial and lateral regions of the heel and the intersection between the 2nd and 3rd metatarsal heads (4). These variables were generated using the commercial software (RsScan, Belgium)

     c) The participant then returned to the graphics display area to visualize the pressure plots and movements of the centre of pressure during the first 10% of the gait cycle and receive verbal feedback from the lead investigator.

Figure 3. Survival plot for medial tibial stress syndrome over 26 weeks. Solid line = control, dashed line = intervention.