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Gait retraining reduces vertical ground reaction forces in running shoes and military boots

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Gait retraining can lead to persistent changes in vertical ground reaction forces while running in shoes. No studies describe gait retraining in military boots. The aim of this prospective cohort study was to evaluate the difference between running in sports shoes and boots, before and after gait retraining, for selected biomechanical parameters, in service members with chronic exercise-related leg pain. Measurements of interest were stride length, cadence, maximal force (N), and maximal pressure (N/cm^2) in three sections of the foot. Forty-one cases were analyzed. At intake, maximal force at the heel and maximal pressure in all sections of the foot were greater in boots. The median duration of the outpatient treatment program was 143 days (IQR 95), containing five gait retraining sessions (range 4-6), with four gait retraining cues repeated in all training sessions. These cues produced reduction in stride length, increase in cadence, reduction in force, and pressure in the heel, and force reduction and pressure increase in the forefoot. However, in boots maximal force and pressure in the mid foot increased. We concluded that the same gait retraining cues can be used to optimize ground reaction forces in running shoes and in military boots.

KEYWORDS
chronic exertional compartment syndrome, conservative treatment, medial tibial stress syndrome, military, occupational

1 | INTRODUCTION

Exercise-related leg pain (ERLP) is a regional pain syndrome described as pain between the knee and ankle which occurs with exercise. Medial tibial stress syndrome (MTSS), chronic exertional compartment syndrome (CECS), tibial and fibular stress fractures, tendinopathy, nerve entrapment, and vascular pathology are the diagnoses that are usually included in the ERLP group.[1] The diagnosis biomechanical overload syndrome (BOS), used in patients with chronic exertional anterior compartment pain with low intramuscular pressures, is a new edition to the ERLP group.[2] In the military, ERLP is a common complaint and MTSS is considered to be the overuse injury with the largest impact on basic military training.[3]

The evidence for an association between ground reaction forces and musculoskeletal injuries in runners from both retrospective and prospective data is now considered "compelling."[4] Gait retraining as a treatment for ERLP is presumably widely practiced, but reports in the literature were sparse until recently.[5] The goal of gait retraining can be reducing vertical ground reaction forces (eg, for MTSS) or to reduce muscular activity of a symptomatic muscle group (eg, for anterior CECS). Cues commonly recommended by experts to reduce vertical ground reaction forces while running are as follows: (a) Change from heel strike to a forefoot strike landing; (b) Increase cadence to 180 steps/min; (c) Stand up taller, don't bend over at the waist (trunk and pelvic position).[5]

Two military studies have shown that service members with MTSS can benefit from gait retraining when given as part of a comprehensive treatment program.[6,7] These studies have been performed in running shoes. Both running in shoes and running in military boots are common occupational tasks for service members. Among other factors, military boots differ from running shoes in design (shaft), weight (heavier), and sole flexibility (stiffer).[8] In studies comparing running in shoes versus running in military boots at 10 km/h on a treadmill, conflicting results were presented; one research group found no significant differences in stride length, cadence, and maximal vertical ground reaction forces,[9,10] but in one other study running at 14.4 km/h in army boots was associated with significantly greater loading impact compared with cross-trainer and running type shoes.[11] The goal of conservative treatment of ERLP in military patients is to help them return to military duties, including running in boots, without re-injury. Reduction in ground reaction forces while running in military boots may contribute to treatment effectiveness. No study reports on retraining of running technique in military boots. It is not known whether the same cues used to retrain biomechanics of running in running shoes can also lead to reduction in vertical ground reaction forces while running in military boots. Increased knowledge on gait retraining in boots could improve conservative treatment results for military ERLP patients. The objectives of this study were as follows: (a) to determine the difference in stride length, cadence, and vertical ground reaction forces while running in sports shoes versus running in military boots before gait retraining and (b) to determine the same differences after gait retraining, provided as part of a comprehensive treatment program.

2 | MATERIALS AND METHODS

Prospective cohort study, performed at the Department of Military Sports Medicine, Royal Dutch Army, Utrecht, The Netherlands. This study was presented to the medical ethics board Brabant, The Netherlands and approved under number NW2017-01. All subjects gave permission in writing for aggregate, anonymous use of their treatment data.

2.1 | Organization of care

The Royal Netherlands Armed Forces has a diagnostic and treatment protocol for ERLP coordinating physicians and physical therapists working in outlying primary care clinics with sports medicine and other specialists in the Central Medical Hospital (CMH). This protocol describes that service members with ERLP be referred to the CMH if conservative therapy has not been successful within 6 months.[2] Since 2011, the CMH has offered a specialty clinic for service members with ERLP. A multidisciplinary team of surgery, primary care sports medicine, and physiatry evaluates patients in a one-stop shop setting. All patients are screened using a detailed intake template for history, physical examination, diagnostic testing, and treatment prescription. All patients are asked to run on a treadmill and score their ERLP symptoms according to the Running Leg Pain Profile, and all patients receive diagnostic intracompartmental pressure measurements in the first minute post-exercise, as described previously in detail.[2] Figure S1 shows the diagnostic flowchart used in this study and the five potential diagnoses in the ERLP group: (a) MTSS; (b) CECS; (c) BOS; (d) MTSS + BOS; (e) MTSS + CECS. Based on the evaluations, patients may be referred to any of four treatment arms: surgery in the CMH, outpatient conservative treatment in the Military Sports Medicine department, inpatient conservative treatment in the Military Rehabilitation Center, or referral back to their original military base to re-engage with primary care.

2.2 | Subjects

Potentially all patients with chronic ERLP, who were assigned to a comprehensive outpatient treatment program in the Military Sports Medicine department, who received gait retraining both in running shoes and military boots between September 2017 and September 2018, were eligible for analysis in this study. Exclusion criteria for analysis were as follows: (a) Age > 30 years; (b) Previous gait retraining; (c) Fasciotomy of a leg <1 year ago; (d) Concurrent psychological treatment or other lower extremity injury with a potential impact on gait retraining; (e) Incomplete gait retraining measurements in running shoes and military boots, at intake or at evaluation.

2.3 | Measurements at intake (T_{in})

As part of the intake procedure (T_{in}), age (years), height (m), weight (kg), duration of symptoms (months), and repeat ERLP episode (yes/no) were collected. In addition, two running conditions were recorded on an instrumented treadmill, running in shoes and running in military boots, each for a 30-seconds segment and at a speed of 10 km/h and an incline of 1%, without any corrective instruction and with a very short accommodation time (±15 seconds) to prevent onset of symptoms.

The treadmill used in this study (H/P/Cosmos Mercury, Nussdorf-Traunstein, Germany) was serviced yearly. The gait analysis software (version 2013; Zebris Medical, Isny, Germany) allowed for measurements of stride length, cadence, forces, and pressures in three zones of the foot: heel (rear foot), mid foot, and forefoot. Both the treadmill and the gait analysis software have been certified according to European standards for sports, fitness, medical, and rehabilitation equipment.

Patients' running strike technique (heel, mid foot, or forefoot striker) was determined based on visual evaluation of slow-motion camera images and treadmill vertical force measurement. A heel striker was defined as a visual heel striker at initial contact, plus a maximal force on the heels >400 N.[7,12] Objective outcome measurements were stride length (centimeter); stride length was defined as the distance covered from initial contact to initial contact of the same foot and equal to the sum of the lengths of two steps, cadence (steps/min), maximum force (N), and maximum pressure (N/cm^2) per segment of the foot. The single assessment numeric evaluation score (SANE) was used to describe patient's subjective evaluation of leg taxability.[13] The SANE score uses a 0-100 scale, with 100 being normal. The SANE score was developed and validated in a military health care setting.

2.4 | Gait retraining and standard care

Gait retraining was introduced on the treadmill, by a senior sports medicine physician and two medical students, all with ample experience with the study protocol and gait retraining for this particular group of patients. Four basic verbal instructions were repeated throughout the gait retraining sessions (Video S1)[5]:

1. Change from heel strike to a ball-of-the foot landing (when applicable);
2. Increase cadence to 180 steps/min (at a constant training speed of 10 km/h);

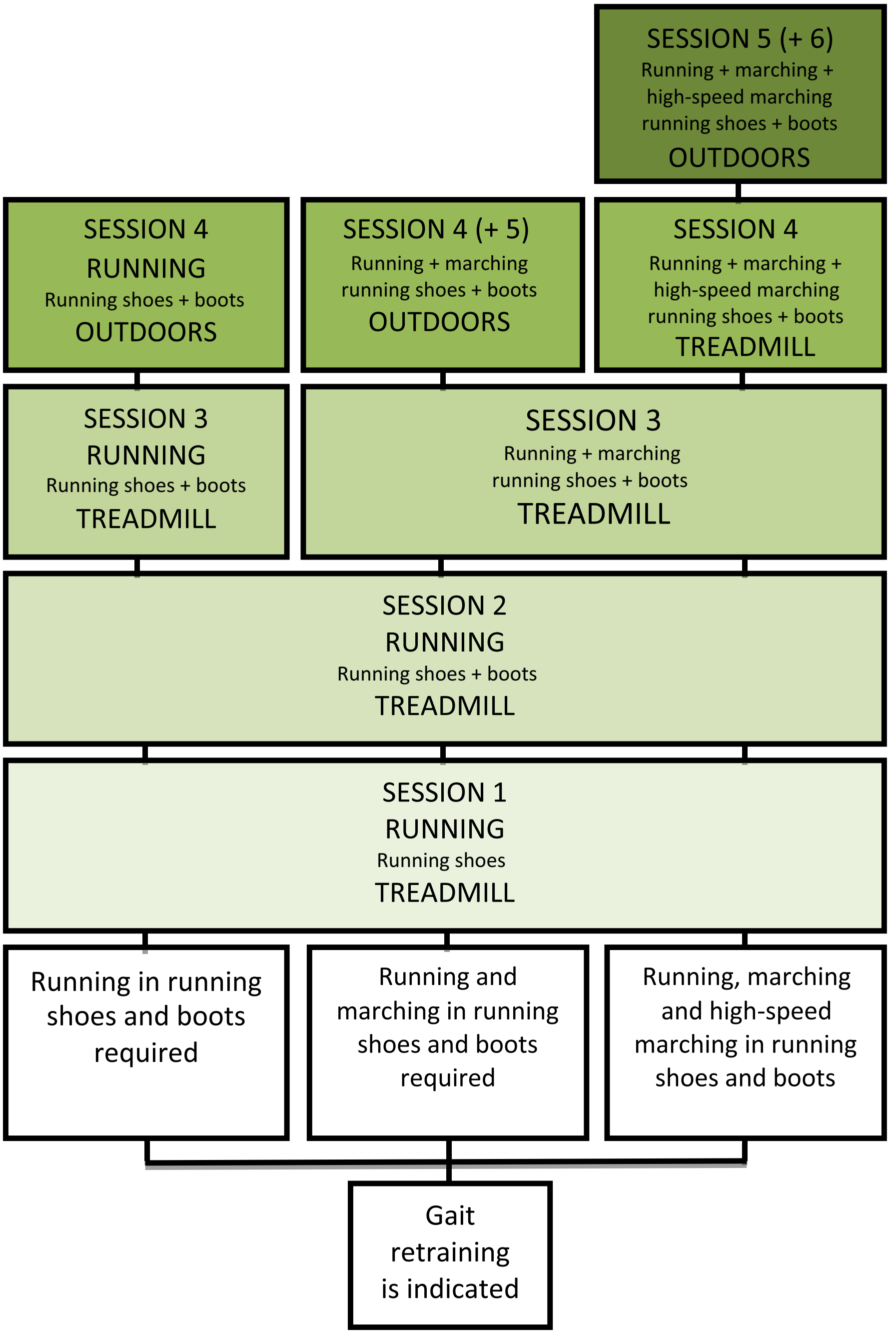

FIGURE 1 Gait retraining sessions offered in this study [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Characteristics of patients analyzed

	Men 33	SD/%	Women 8	SD/%
Age (years)	23.0	2.9	22.9	3.3
Height (m)	1.79	0.07	1.69	0.04
Weight (kg)	82.6	10.0	74.4	4.8
BMI	25.8	3.2	26.0	2.2
Duration of complaints (months)[a]	9.0	13.0	6.0	4.8
Re-injury (yes/no)	15	45.5%	1	12.5%
Diagnosis MTSS	5	15.2%	4	50.0%
Diagnosis CECS	12	36.4%	0	0.0%
Diagnosis MTSS + BOS	3	9.1%	1	12.5%
Diagnosis MTSS + CECS	13	39.4%	3	37.5%
Treatment duration (days)[a]	133	77	180	98
SANE in	50	15	51	16
SANE out	77	16	77	21

BMI, body mass index; BOS, biomechanical overload syndrome; CECS, chronic exertional compartment syndrome; MTSS, medial tibial stress syndrome; SANE, single assessment numeric evaluation.
[a]Median and interquartile range

3. Stand up taller, don't bend over at the waist or look down;
4. Increase knee-lift by 1-2 cm and relax the foot that is in the air, so that it points towards the floor.

Patients received at least four and maximally six individual gait retraining sessions during a training period of minimally 6 weeks. Figure 1 shows the gait retraining sessions offered in this study. Depending on the military specialty, and therefore the goals of rehabilitation, training also addressed marching in military boots and high-speed marching in gait retraining session four through six. For feedback, during short moments of rest, all participants were shown a video recording of their original and new running mechanics and the measurements of the instrumented treadmill to learn the reduction in impact forces they achieved. In addition, patients received written information, to perform self-controlled training assignments, two to three training sessions a week, to acquire the new running technique.

Gait retraining was not the only intervention offered to these patients with ERLP. Each patient received standard care, that is, an individualized treatment program (Appendix S1, Table S1).

2.5 | Measurements at evaluation (T_{out})

When the treatment program for chronic ERLP in the sports medicine department was completed, the same two running conditions on the treadmill were measured again, recording stride length (cm), cadence (steps/min), maximum Force (N), and maximum Pressure (N/cm^2) per segment of the foot (10 km/h; 1% incline), during 30 second periods, without additional corrective instruction and with a very short accommodation time (±15 seconds). Patients' postintervention running technique in running shoes (type of striker) was determined with the same criteria as used at T_{in}. Subjective evaluation of leg taxability at T_{out} was the SANE score.

2.6 | Statistics

Baseline characteristics were described with appropriate measures of central tendency and dispersion. The SANE score at T_{out}, duration of treatment, number of gait retraining sessions received, and type of striker at T_{out} were presented to describe the studied population. Normality of the data was checked visually by means of histograms, boxplots, and QQ-plots. The biomechanical measurements of running in sports shoes and in military boots at intake (T_{in}) and (T_{out}) were described with averages and 95% confidence intervals. The delta scores were calculated ($T_{out} - T_{in}$) to determine the changes in running biomechanics for running shoes and military boots. These scores were also presented with averages and 95% confidence intervals. All statistical tests were performed using SPSS version 24.0 (IBM, Armonk, NY, USA).

3 | RESULTS

3.1 | Subjects

In total, 41 cases with chronic ERLP were available for analysis. Table 1 shows characteristics of these service members.

3.2 | Running biomechanics at intake (T_{in})

Table 2 shows measurements of the running technique in running shoes and military boots at T_{in}. Average stride length, cadence, and maximum force (N) on the mid foot and forefoot were similar for running shoes and military boots. Maximum force on the heel and maximum pressure (N/cm^2) on the heel, mid foot, and forefoot were larger in military boots. At intake, before gait retraining, 39/41 (95.1%) of the service members were classified as heel strikers.

3.3 | Running biomechanics after gait retraining (T_{out})

The median gait retraining sessions patients received was 5.0 (minimum 4.0, maximum 6.0). Table 2 shows measurements of the running technique in running shoes and military boots at T_{out} and the change in measurements between T_{out} and T_{in}. The changes in running biomechanics achieved at T_{out} show similar tendencies for running shoes and military boots:

TABLE 2 Selected biomechanical parameters of two running conditions at T_{in} (intake) and T_{out} (exit); all measurements at 10 km/h and 1% incline on an instrumented treadmill; (A) men, (B) women

	Tin		Tout		Tout − Tin	
	Average	95% CI	Average	95% CI	Average	95% CI
(A) Men (n = 33)						
Running shoes						
Stride length (cm)	207.1	203.1, 211.1	186.1	182.8, 189.3	−21.0	−25.0, −17.0
Cadence (steps/min)	160.1	157.2, 163.1	178.2	175.2, 181.3	18.1	14.8, 21.4
Max force heel (N)	656.2	622.1, 690.2	241.8	213.3, 270.4	−414.3	−463.4, −365.3
Max force mid foot (N)	640.0	596.0, 683.9	629.5	583.0, 676.0	−10.5	−47.6, 26.7
Max force forefoot (N)	1101.9	1034.7, 1167.0	1073.04	1017.9, 1128.2	−27.8	−69.7, 14.2
Max pressure heel (N/cm^2)	30.3	27.3, 33.3	17.6	15.5, 19.7	−12.7	−15.4, −10.0
Max pressure mid foot (N/cm^2)	29.5	25.8, 33.3	25.1	23.0, 27.1	−4.5	−8.2, −0.7
Max pressure forefoot (N/cm^2)	26.7	25.3, 28.2	30.5	28.5, 32.5	3.8	2.2, 5.3
Military boots						
Stride length (cm)	208.3	204.5, 212.1	187.9	184.5, 191.3	−20.4	−24.0, −16.8
Cadence (steps/min)	159.9	156.8, 162.9	176.9	173.7, 180.1	17.0	13.7, 20.3
Max force heel (N)	753.0	716.6, 789.4	265.2	232.1, 298.4	−487.7	−542.1, −433.4
Max force mid foot (N)	554.4	510.5, 598.4	803.2	749.5, 856.9	248.8	185.1, 312.4
Max force forefoot (N)	1150.0	1082.8, 1217.2	990.9	928.8, 1053.0	−159.1	−217.9, −100.3
Max pressure heel (N/cm^2)	49.2	46.6, 51.8	28.0	24.7, 31.3	−21.2	−25.3, −17.1
Max pressure mid foot (N/cm^2)	45.6	42.7, 48.5	48.9	46.1, 51.8	3.3	1.2, 5.5
Max pressure forefoot (N/cm^2)	48.60	45.2, 52.0	49.8	46.5, 53.1	1.2	−1.3, 3.7
(B) Women (n = 8)						
Running shoes						
Stride length (cm)	203.6	197.2, 210.0	185.4	182.6, 188.2	−18.3	−24.9, −11.6
Cadence (steps/min)	163.0	157.8, 168.2	179.00	176.1, 181.9	16.0	10.6, 21.4
Max force heel (N)	495.9	444.0, 547.8	200.2	143.9, 256.4	−295.7	−368.1, −223.4
Max force mid foot (N)	507.2	419.7, 594.7	553.6	467.8, 639.3	46.3	−44.4, 137.1
Max force forefoot (N)	1027.5	918.1, 113.9	973.7	878.7, 1068.6	−53.8	−210.0, 102.4
Max pressure heel (N/cm^2)	25.1	20.0, 30.3	17.1	13.9, 20.2	−8.1	−16.3, 0.1
Max pressure mid foot (N/cm^2)	30.9	26.1, 35.7	27.1	23.2, 31.0	−3.8	−9.7, 2.1
Max pressure forefoot (N/cm^2)	29.7	26.2, 33.3	33.4	30.1, 36.8	3.7	0.7, 6.7
Military boots						
Stride length (cm)	202.8	196.8, 208.7	186.8	183.3, 190.2	−16.0	−22.9, −9.1
Cadence (steps/min)	163.1	158.7, 167.6	177.6	174.3, 180.9	14.5	9.1, 19.9
Max force heel (N)	646.5	582.0, 711.1	224.7	165.8, 283.6	−421.8	−490.0, −353.6
Max force mid foot (N)	486.8	430.9, 542.7	785.0	688.3, 881.7	298.3	184.9, 411.5
Max force forefoot (N)	1040.9	956.5, 1125.3	829.6	757.0, 902.2	−211.3	−350.5, −72.2
Max pressure heel (N/cm^2)	49.3	44.1, 54.5	29.0	23.5, 34.6	−20.3	−28.1, −12.4
Max pressure mid foot (N/cm^2)	42.7	39.1, 46.30	47.5	42.3, 46.3	4.8	−3.4, 13.0
Max pressure forefoot (N/cm^2)	46.7	41.0, 52.4	48.0	43.6, 52.3	1.2	−5.7, 8.1

95% CI, 95% confidence interval.

reduction in stride length, increase in cadence, reduction in force, and pressure on the heel, force reduction and pressure increase in the forefoot. However, in boots the new running technique increased maximal force and pressure in the mid foot by 44.9% and 7.3%, respectively, for men and 61.3% and 11.3% for women. Changes in selected biomechanical

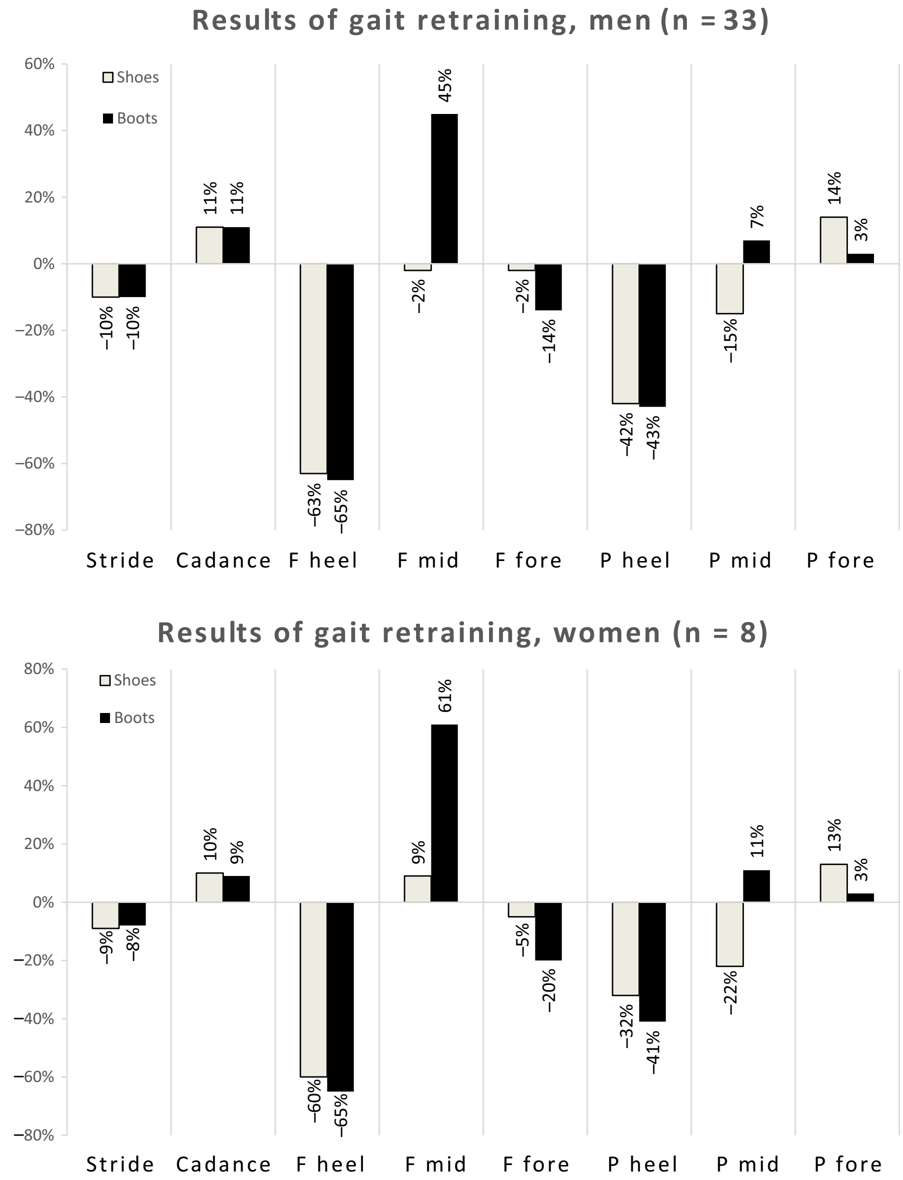

FIGURE 2 (A and B) Results of gait retraining (T_{out}) for shoes and boots, expressed as a percentage change from intake (intake = 0). Note reductions in force (*F*) and pressure (*P*) in the heel; note increase in force (*F*) and pressure (*P*) in the mid foot in boots; note similarity of changes between men and women

parameters achieved by gait retraining are similar for men and women (Figure 2). At T_{out}, one of the 41 patients was categorized as a heel striker (2.4%), a difference of 92.7% compared with intake.

3.4 | Treatment evaluation

The median duration of the treatment program was 133 days for men (IQR 77) and 180 days for women (IQR 98). The average SANE score increased from 50 ± 15 to 77 ± 16 for men and from 51 ± 16 to 77 ± 21 for women.

4 | DISCUSSION

To the best of our knowledge, this is the first study to report on gait retraining in military boots for patients with chronic ERLP. Our most significant finding is that the same gait retraining cues can be used in shoe or boot shod runners to achieve similar optimizations in stride length (reduction), cadence (increase), force and pressure on the heel (reduction), and in the forefoot (force reduction, pressure increase). However, in military boots the new running technique increased maximal force and pressure in the mid foot.

Comparing intake measurements (before gait retraining) to the literature, our results confirmed the findings by Paisis et al that stride length, cadence, and maximal vertical ground reaction forces do not differ significantly when running at 10 km/h between running shoes and military boots.[9,10] In their studies, using the same treadmill, participants were running at a 5% incline; in the current study, 1% incline was used. However, in our study, force (N) on the heel and pressure on all sections of the foot were significantly greater in military boots. This finding was not reported in previous work,[10] but may be explained by the different shape, materials, and composition of the sole between running shoes and military boots.[14]

Comparing measurements after gait retraining to the literature, this study reconfirmed that biomechanical parameters can be altered by running modification training programs, even in military boots.[15] Changes in stride length and cadence achieved by gait retraining in military boots were similar to the changes in running shoes.[7] However, changes in vertical ground reaction forces in the mid foot were elevated for boots compared to shoes. This novel finding may be causal in explaining why running in military boots is less comfortable than running in running shoes.[10]

In this study, 39/41 (95.1%) of service members with ERLP presented with a heel strike running technique. This percentage is even higher than previously reported by Warr, who observed that 83% of service members were heel strikers.[12] A possible explanation is that our cases were chronic ERLP patients and his cases were healthy. Encouragingly, in our study only one of the 41 patients who completed the treatment program was still categorized as a heel striker (2.4%) at post-testing; in our previous study 25% of ERLP patients were still heel strikers postintervention.[7] One possible explanation for the increased percentage of strike change is an increase in the number of training sessions offered, from average 2.4 to average 5.0 sessions per patient.

One of the limitations of this study is that patients received a different number of gait retraining sessions (four-six), over a different number of treatment days. In a gait retraining study with healthy subjects, these variable factors could be equalized; however, the overall goal of this study was to improve conservative treatment procedures for military patients with ERLP and this can best be done by working with that particular group of patients. An omission and recommendation for future study are that body weight was not measured at T_{out}. If patient's body weight changed significantly during the rehabilitation period, vertical ground reaction forces while running may have been influenced. Another potential limitation is that several different brands of military boots were used. 26/41 subjects (63.4%) wore the standard issued military boots (Meindl), the rest wore individually acquired boots from other brands (ie, Lowa, Bates, Magnum and Alt-berg). However, comparison of results showed that different brands of military boots demonstrated similar changes in running parameters, including the increased force and pressure in the mid foot. Women make up a small proportion of our study population, as is frequently observed in military studies. Women make up approximately 10% of the Royal Netherlands Armed Forces. In our study, 8/41 (19.5%) injured warrior athletes were women. This may reflect the fact that women have a higher relative risk of developing ERLP in the Dutch armed forces.[16] Although not an objective of our study, our findings indicate that the effects of gait retraining are not different for men and women. Finally, this study reports the results of gait retraining in a controlled indoor setting, mostly on an instrumented treadmill and under full-time supervision. Running on a treadmill is biomechanically not the same as running outdoor, and the kinetics/kinematics of observed running may be quite different from habitual, unobserved running. However, for the sake of research, the laboratory setting is considered acceptable and widely used, as long as results are interpreted with caution.[17] As reflected by Figure 1, every patient received at least one gait retraining session outdoors, to facilitate the transfer from the lab environment (treadmill) to over ground running. We look forward to future studies using wearable technology to more accurately characterize changes in the natural running state.

Accepting the aforementioned limitations, the strength of this study is that it presents new and practical information on gait retraining in military boots. Additionally, the number of included subjects is large compared to most gait retraining studies and completely composed of a patient group for whom gait retraining would be particularly recommended. In addition to using wearable technology to document changes in natural running state, future research is warranted to identify which gait retraining cues contribute most to beneficial gait changes, both in athletic shoes and in military boots.

5 | CONCLUSION

Gait retraining in military boots achieved similar changes in stride length (reduction), cadence (increase), force and pressure in the heel (reduction) and in the forefoot (force reduction, pressure increase) compared to running shoes. However, in boots mid foot maximal force and pressure increased.

6 | PERSPECTIVE

ERLP is an important occupational problem in the military. Information from this study can be useful for medical professionals treating soldiers with ERLP and also for those treating civilian athletes, who have constrained types of footwear (ie, hikers, climbers, wrestlers). Our previous studies have shown that gait retraining can reduce vertical ground reaction forces in running shoes and can contribute to the treatment program of service members with chronic ERLP.[7,18] The same gait retraining cues can be used to achieve reductions in vertical ground reaction forces while running in military boots and perhaps in other types of shod running. Adding gait retraining sessions in boots to the treatment program of service members with ERLP may be warranted to improve treatment outcomes.

CONFLICT OF INTEREST

No conflicts reported by the authors.

AUTHOR CONTRIBUTIONS

WZ: research initiative, gait retraining, first author and guarantor; NvV: gait retraining, data collection, data analysis, tables and figures, supplemental video; CL: gait retraining, data collection, data analysis; AB: scientific support, significant reviewer/reviser; RH: significant reviewer/reviser; EB: scientific support, statistics, significant reviewer/reviser.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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