# The effects of increasing cadence on vertical ground reaction forces when walking in military boots

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## Abstract

### *Background and purpose*

**Road marching is a common military task. It is associated with a risk of developing overuse injuries of the lower extremities. From 2016 onward, gait retraining of marching in military boots has been introduced in regular care for service members with exercise related leg pain. The purpose of this study was to evaluate regular care, in this case, measure vertical ground reaction forces and bone load when walking in military boots, at self-preferred cadence and at five percent increase.**

### *Study design*

**Within-subject Design (repeated measures in a laboratory setting).**

### *Methods*

**Service members (n=21) performed two walking trials (15 minutes each) in military boots on an instrumented treadmill, while wearing a load sensor on both legs, at 5 km/h and 1% incline. During the first trial all subjects walked using their preferred walking style. During the second trial half of the subjects received a single cue (group 1): “increase cadence by 5%”. The other half received two cues (group 2): “increase cadence by 5%” and “try to reduce heel strike”. Walking comfort was assessed by survey.**

### *Results*

**All vertical ground reaction variables decreased in trial 2 by 2.2 - 9.0 percent. Not all reductions were statistically significant. Adding the cue “try to reduce heel strike” did not result in a larger reduction of the parameters of interest. The intervention did not lead to a reduction of bone load in group 1 or group 2. Subjectively most patients were comfortable with the five percent cadence increase.**

### *Conclusion*

**Increasing cadence by five percent when walking in military boots, reduced vertical ground reaction forces by 2.2 - 9.0 percent per step. A reduction of bone load was not found; the reduced vertical ground reaction forces per step and the increased number of steps performed may neutralize the effects on bone load. Subjectively most patients were comfortable with the five percent increase of cadence.**

## Introduction

Service members are required to maintain a high level of physical fitness in order to perform their tasks in various environments and conditions. They achieve their fitness through mandatory physical training with the unit and optional physical training during personal time. Road marching is part of the mandatory training in the Royal Netherlands Army. It is an endurance activity that can be done on any terrain, involving walking a specific distance, often while carrying weight in a military backpack. The goal of road marching is to improve task specific stamina and strength. This type of marching has been associated with a variety of musculoskeletal overuse injuries, particularly of the lower extremities[1-3]. Exercise related leg pain is a group of overuse injuries that frequently result in termination of a military training course[4]. Consequently, a loss of manpower, training time and high costs for medical care are encountered[2,5]. In the Netherlands armed forces Medial Tibial Stress Syndrome, Chronic Exertional Compartment Syndrome and a combination of these two are the most common diagnoses in the exercise related leg pain group[4].

Recently gait retraining of running has been introduced as treatment for service members with exercise related leg pain[6,7]. In a military setting two shod conditions are relevant: shoes and boots[8]. Strategies for gait retraining comprise among others: 1. Increase cadence; 2. Change foot strike pattern; 3. Adjust body position (stand up taller). To the best of our knowledge, only one study looked into the effect of modifying marching technique as a treatment for service members with exercise related leg pain[9]. This study was performed in our own department. Service members with exercise related leg pain were trained during five weeks to reduce step length and reduce the force of striking the heel on the ground. Post intervention reductions of lower leg symptoms and an increase in marching performance was found. From 2016 onward, increasing cadence of walking has been part of regular care for service members with exercise related leg pain. In this study we set out to measure the immediate effects of increasing walking cadence by five percent on vertical ground reaction forces and bone load in a group of military patients diagnosed with exercise related leg pain.

## Methods and materials

This study was performed at the Department of Military Sports Medicine of the Royal Netherlands Army in Utrecht, The Netherlands (TGTF). The department is a secondary care institution. This study was executed as part of regular care for service members diagnosed with exercise related leg pain. National law does not require consultation of a medical ethics board for this type of study. Patients were informed regarding the nature of the study and gave written informed consent. The collected data were processed anonymously.

### Participants

From September through November 2018, 21 patients in a conservative treatment program for exercise related leg pain were asked to participate in this study. Inclusion criteria were: 1. Age between 18 and 30 years old; 2. The patient indicated marching was a relevant task for their military specialty. Exclusion criterion was: it was likely that the participant could not perform the marching trials without pain. From the medical records the following information was obtained: age (years), height (cm), weight (kg), diagnosis, duration of symptoms (months), brand of military boots (name).

### Experimental Procedure

First, all participants were asked to walk on an instrumented treadmill at 5-km/h and 1% incline, for one minute and they were instructed to walk according to their personal style. During the last 30 seconds of this minute, the preferred cadence (steps per minute) of the subject was determined. Five km/h is the required speed for the yearly mandatory marching test for all military personnel. Subsequently, all subjects performed two marching trials, each lasting 15 minutes, on an instrumented treadmill. Each time, speed was set at 5-km/h with an incline of 1%. Figure 1 shows the study procedure.

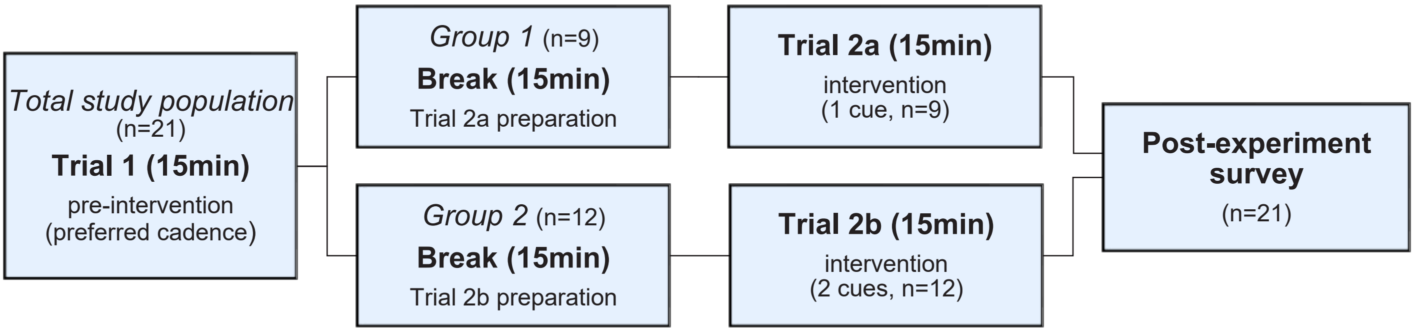


**Figure 1. Study procedure. All participants (n = 21) perform trial 1. Nine participants perform trial 2a, 12 participants perform trial 2b; all participants are surveyed.**

### *Trial 1*

All subjects performed the first marching trial with the following instruction: "walk comfortably on preferred cadence". To assure steady cadence, subjects had visual and audible feedback from a

metronome on a smart phone that was set on subjects preferred cadence.
The following parameters were measured during two minutes of the 15-minute trial (minute 1.00-2.00 and minute 13.00-14.00): Cadence (steps per minute), stride length (cm), Peak Force (N) and Peak Pressure (N/cm$^2$) in three different sections of the foot; fore-foot, mid-foot and heel (rear foot). Measurements from the second and fourteenth minute were averaged. After trial 1 all subjects had a 15-minute break. During this break the researcher introduced the cues for trial 2a and 2b and subjects had a 60-second period to practice on the treadmill in preparation for the second trial.

***Trial 2***

For the second 15-minute marching trial, subjects were divided into two groups: Group 1 and Group 2. Subjects in group 1 (trial 2a) received a single cue: increase cadence by five percent. Subjects in group 2 (trial 2b) received two cues: increase cadence by five percent and try to alter your strike pattern to reduce the force of heel strike. The verbal cue "try to reduce heel strike" was given once every five minutes (three times) to remind patients to decrease the force of heel strike. During trial 2a and 2b the exact same parameters were measured as during trial 1.

**Instrumented treadmill**

The treadmill used in this study, H/P/Cosmos Mercury, is serviced yearly. The gait analysis software (Zebris Medical, Isny, Germany, version 2013) allowed for kinetic and kinematic measurements in three sections of the foot, as described earlier (Figure 2).

**IMeasureU (IMU) sensors**

During all trials, subjects wore two IMU sensors (Vicon Motion Systems, Oxford, UK), one on each lower leg, directly above the military boot, on the flat surface of the distal tibia. The IMU sensors, or accelerometers, placed on the tibia, measured peak impact accelerations. These measurements are thought to represent the loads experienced by the underlying musculoskeletal tissue[10,11].
IMU sensors work at 1000 Hz (frames/sec). With the accompanying software, the Accumulative Bone Load was calculated. Accumulative bone load theoretically depends on: 1. The total number of steps taken 2. The size of the impact derived from each step. In this article where bone load is written, accumulative bone load is meant. During each marching trial, IMU sensors recorded bone load for 15 consecutive minutes. With one sensor on each leg, each trial yielded two bone load values.

**Figure 2. Subject on the instrumented treadmill.**
Note: the IMU sensors (accelerometers = load monitors) are covered by the socks and therefore not visible. The researcher is at the computer desk.

**Subjective measurements**

A verbal numeric pain rating scale (0-10) was used 10 minutes into all marching trials to assure subjects performed the trials without pain. After trial 2, all subjects were requested to fill in a two question survey regarding level of comfort (on a 1-5 scale) during the walking trials and the applicability of the new walking technique.

### Statistics

Descriptive analyses were used to present measurements of trial 1 and trial 2.
Statistical analysis was performed (SPSS Statistics 23, IBM, USA) to test for significant differences in variables between trial 1 and trial 2a, and trial 1 and trial 2b. For this, paired samples T-Tests were used and the level of significance was set at 0.05, power 0.80.

## Results

Twenty-one subjects were enrolled in this study. Table 1 presents baseline characteristics of the study population. None of the subjects reported pain during both trials.
Table 2 shows that group 1 and group 2 both increased cadence and reduced stride length equally. Overall, all vertical ground reaction forces measured with the instrumented treadmill were lower in Trial 2 than in Trial 1, but not all reached a statistically significant reduction. The reductions in force and pressure achieved with additional cues (group 2, trial 2b) were not greater than those achieved with a five percent cadence increase only (group 1, trial 2a).
The IMU-sensor measurements are presented in Table 3. The step count as measured by the IMU sensors showed unexpected right versus left leg discrepancies, within individuals, in several cases. It was decided to only use measurements where the step count did not differ more than 1.5% between the left and right leg. Furthermore, the trials were designed to increase step count by 5%. If the sensors were of by > 1.5%, i.e. recorded less than 3.5 percent increase or more than 6.5 percent increase, measurements were also dropped. Therefore, only 14 left and 14 right sensor outcomes where used for final analysis. The bone load values for group 1 were inconclusive: the left leg sensors measured a 2.9% decrease, the right leg sensors a 4.9% increase.
Table 4 shows the results of the two question survey. The level of comfort while walking with the new technique averaged 3.6 ± 0.5 in group 1, and 3.6 ± 0.9 in group 2. All but one subject scored the level of comfort a 3 or higher, which is indicative for a neutral level of comfort. When subjects were asked if they could maintain the new marching technique for more than one hour, 15/18 (71%) answered they would have no difficulties. None of the subjects reported pain during both trials.

| Factor | Total (n = 21) |
|---|---|
| Age | 22.9 ± 3.2 (19,29) |
| Male<br>Female | 17 (81%)<br>4 (19%) |
| Height Male<br>Height Female | 182.9 ± 6.3 (166,191)<br>167.0 ± 4.3 (163,173) |
| Weight Male<br>Weight Female | 90.2 ± 10.7 (70,118)<br>65.3 ± 7.5 (58,75) |
| Diagnosis<br>MTSS<br>CECS<br>BOS<br>MTSS + CECS<br>MTSS + BOS | <br>5 (23.8%)<br>1 (4.8%)<br>2 (9.5%)<br>10 (47.6%)<br>3 (14.3%) |
| Duration of symptoms (months) | 17.5 ± 18.7 (4,60) |
| Brand of boots (standard, Meindl)<br>Brand of boots other | 13 (62%)<br>8 (38%) |

MTSS = Medial Tibial Stress Syndrome, CECS = Chronic Exertional Compartment Syndrome, BOS = Biomechanical Overload Syndrome

**Table 1. Subject Characteristics. Continuous variables are presented as Mean ± Standard Deviation (Minimum Value, Maximum Value).**

## Discussion

The purpose of this study was to assess the immediate effects of increasing cadence (with and without additional cues), when walking in military boots on vertical ground reaction forces and bone load. Participants where service members with exercise related leg pain. Gait retraining of marching, in this case increasing cadence by 5%, was part of regular care. The findings suggest that increasing cadence by five percent causes small reductions of peak force in all three sections of the foot. Larger and statistically significant reductions were

| | Group 1 (n = 9) | | | | Group 2 (n = 12) | | | |
|---|---|---|---|---|---|---|---|---|
| | **Trial 1** | **Trial 2a** | **Δ%** | **p-value** | **Trial 1** | **Trial 2b** | **Δ%** | **p-value** |
| Cadence (steps/min) | 110 ± 5 | 116 ± 5 | | | 111 ± 4 | 116 ± 4 | | |
| Stride (cm) | 149.3 ± 6.2 | 142.6 ± 5.7 | | | 149.3 ± 5.0 | 142.2 ± 5.1 | | |
| Peak Force (N) | | | | | | | | |
| Forefoot | 907 ± 131 | 873 ± 137 | -3.8 | 0.02* | 814 ± 114 | 764 ± 104 | -6.1 | <0.01* |
| Midfoot | 382 ± 79 | 366 ± 79 | -4.2 | 0.11 | 325 ± 60 | 318 ± 75 | -2.2 | 0.56 |
| Heel | 590 ± 54 | 574 ± 62 | -2.7 | 0.27 | 514 ± 78 | 501 ± 71 | -2.5 | 0.26 |
| Peak Pressure (N/cm$^2$) | | | | | | | | |
| Forefoot | 37.8 ± 9.0 | 35.1 ± 8.4 | -7.1 | <0.01* | 43.4 ± 7.5 | 42.0 ± 7.7 | -3.2 | 0.13 |
| Midfoot | 39.0 ± 10.0 | 36.0 ± 9.5 | -7.7 | <0.01* | 38.1 ± 5.9 | 35.6 ± 5.5 | -6.6 | <0.01* |
| Heel | 41.5 ± 9.1 | 37.9 ± 8.6 | -8.8 | <0.01* | 42.3 ± 6.0 | 38.5 ± 5.7 | -9.0 | <0.01* |

* indicates significant difference between pre- and post-intervention trial.

**Table 2. Measurements of Trial 2a vs Trial 1 (Group 1) and Trial 2b vs Trial 1 (Group 2), Mean ± Standard Deviation.**

Note: all Forces and Pressures measured were lower in Trial 2a and 2b vs Trial 1, but not all reached statistical significance.

| | Left leg sensor | | | Right leg sensor | | |
|---|---|---|---|---|---|---|
| | **Trial 1** | **Trial 2** | **Δ%** | **Trial 1** | **Trial 2** | **Δ%** |
| Group 1 | 108.7 ± 20.4 | 105.6 ± 9.1 | -2.9 | 98.6 ± 9.7 | 103.4 ± 10.1 | +4.9 |
| Group 2 | 102.2 ± 14.0 | 95.2 ± 9.7 | -6.8 | 105.0 ± 14.1 | 103.1 ± 12.2 | -1.8 |

**Table 3. Accumulative Bone Load values as measured with the IMU-sensors.**

Note: the difference in bone load reported for the same trial by the left and right sensors
(e.g. Group 1, Trial 1, left leg sensor 108.7; Group 1, Trial 1, right leg sensor 98.6; etc.).

| | Q1, level of comfort 1 - 5 | | | | | Q2, maintainable for > 1 hour? | | |
|---|---|---|---|---|---|---|---|---|
| **Group** | **1** | **2** | **3** | **4** | **5** | **Yes** | **No** | **Don't know** |
| 1 (n = 9) | 0 | 0 | 4 | 5 | 0 | 7 | 1 | 1 |
| 2 (n = 12) | 0 | 1 | 5 | 4 | 1 | 8 | 2 | 2 |

Q1 = Question 1; Q2 = Question 2.
1 = extremely uncomfortable; 2 = moderately uncomfortable; 3 = neutral; 4 = moderately comfortable; 5 = extremely comfortable.

**Table 4. Survey results (n = 21); presented as the number of answers obtained on two questions.**

observed in peak pressures. The differences in force reduction between study groups 1 and 2 were small, indicating that adding the second cue, “try to reduce heel strike”, did not result in a larger reduction of vertical ground reaction forces in this experiment. From the survey it was learned that most patients were comfortable with the increased marching cadence.

The effects of increasing cadence on bone load were small and inconclusive. In some cases, within one individual, a decrease in one leg and an increase in the other was recorded. Accumulative bone load theoretically depends on two factors: the number of steps, and the intensity of impact of each step. In trial 2 a five percent increase of steps was planned. The fact that bone load overall did not increase, may imply that the bone load reduction obtained by less forces per step was neutralized by the bone load increase caused by the increased number of steps.

The findings of this study are similar to those reported previously by Helmhout et al.[9]. In their studies, a five-week gait retraining program of marching was given to six patients with CECS. At evaluation a five percent increase in cadence was achieved. No differences were seen in peak force, and peak pressure at the heel decreased by 3.3%. The most important finding of that study was the improved self-assessed leg condition and marching performance. Combining the studies it seems that a five percent increase in cadence when walking in military boots has a larger effect on subjective, self-assessment scores of leg condition, than on objective vertical ground reaction forces.

The findings of this study can also be compared to studies on gait retraining of running. Wellenkotter et al. found that a five percent increase in cadence while running resulted in small, but statistically significant, effects on total and regional plantar loading variables[12]. However, walking- and running biomechanics differ in many ways, and further comparisons between walking and running must be done very cautiously[13].
It is of importance to acknowledge the limitations of this study. The small sample size reduces the power of the findings. Furthermore, follow-up measurements were not performed. Only the immediate effects of increased walking cadence were studied and participants were given a very short period of training time to work out the gait retraining cues. Executing the second cue: “try to reduce heel strike” was difficult to execute within the given time-frame. During trial 2 the cue “try to reduce heel strike” was given several times as described in the methods section, but no measurements were performed to objectify whether a change in marching technique was actually achieved. Furthermore, the IMU sensors used in this study were not validated to our methods of research and unfortunately, the results were unreliable in 14 of 42 measurements (33.3%). Despite several discussions with the manufacturer, it was not possible to find out the exact origin of the measurement aberrations encountered. Consequently, a large percentage of measurements had to be discarded. A final limitation of this study is related to the fact that all our subjects performed the trials in their own military boots. Thirteen/21 subjects (62%) wore the standard boot supplied by the Royal Netherlands Armed Forces (Meindl, Germany). This boot weighs slightly less than 1 kg per foot. The other subjects wore boots of several different brands, with different design properties and mostly lower weight. Boot design is known to have an influence on shock attenuation and walking biomechanics and should be controlled for in future studies[14]. Despite the limitations, this study provides practical information for therapists and physicians treating patients with marching related overuse injuries of the lower extremities.
For future research the following recommendations can be made: 1. use a larger sample size; 2. provide all subjects with the same military boots; 3. Perform follow up measurements after a period of habituation to the new marching cadence (e.g. 4-6 weeks); 4. Vary cadence increases, try 7, 8 or 10 percent; 5. Measure load with more reliable instruments.

## Conclusion

Increasing cadence by five percent when walking in military boots, reduced vertical ground reaction forces by 2.2 - 9.0 percent per step. A reduction of bone load was not found. A reduction of overall bone load achieved by less vertical forces per step may be neutralized by the increased number of steps performed. Subjectively most patients were comfortable with the five percent increase of cadence. This information is relevant to therapists and physicians who treat patients with overuse injuries from walking and marching.


## Acknowledgements

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## SAMENVATTING

## HET EFFECT VAN HET VERHOGEN VAN DE PASFREQUENTIE BIJ HET MARSEN OP MILITAIRE LAARZEN

### Achtergrond en doelstelling

Marsen (‘verplaatsen te voet’) is inherent aan het militaire beroep. Het is bekend dat marsen kan leiden tot overbelastingsblessures van met name de onderste extremiteiten. Vanaf 2016 is ‘marsles’ een vast onderdeel van het behandelprogramma voor militairen met een diagnose in de groep ‘Onderbeenklachten’. De doelstelling van dit onderzoek was een evaluatie van dat

behandelprogramma, met name, een meting van verticale krachten en botbelasting bij wandelen op laarzen met eigen pasfrequentie en met een opgelegde toename van vijf procent.

**Onderzoeksopzet**

Herhaalde metingen bij dezelfde individuen (in een looplaboratorium).

**Methode**

Militairen (n=21) volbrachten twee wandeltesten van 15 minuten elk, op laarzen, op een loopband, die verticale krachten kan meten. De loopsnelheid was steeds 5 km/uur, de helling 1 procent.
Zij droegen ook accelerometers aan beide onderbenen, om botbelasting te meten.
Bij wandeltest 2 kreeg de helft van de deelnemers (Groep 1) één aanwijzing: “breng de stapfrequentie vijf procent omhoog”. De andere deelnemers (Groep 2) kregen twee aanwijzingen: “breng de stapfrequentie vijf procent omhoog” en “probeer minder zwaar op de hak te landen”.
Wandelcomfort werd bevraagd.

**Resultaten**

Alle gemeten verticale krachten werden 2.2 - 9.0 procent minder bij wandeltest 2. Niet alle reducties waren statistisch significant. Het toevoegen van de aanwijzing “probeer minder zwaar op de hak te landen” resulteerde niet in een extra vermindering van verticale krachten. Botbelasting werd niet minder bij wandeltest 2. De meeste proefpersonen ervaarden de vijf procent verhoging van pasfrequentie ‘comfortabel’.

**Conclusie**

Bij het wandelen op militaire laarzen werden de verticale krachten met 2.2 - 9.0 procent verminderd, nadat de pasfrequentie met vijf procent werd opgevoerd. Een vermindering van botbelasting werd echter niet gevonden. De reductie van botbelasting bereikt door minder verticale krachten per stap wordt vermoedelijk tenietgedaan door het toegenomen aantal stappen.
De patiënten ervaren de vijf procent verhoging van pasfrequentie als comfortabel.


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