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Original Article

Comparison of the influence of supportive and sensorimotor insoles in the muscle activity of tibialis anterior and peroneus longus in combat boots

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ABSTRACT

Introduction: Flatfoot is a very common static deformity. It occurs frequently in soldiers and causes problems in the lower extremities. There is a lack of data regarding therapy with insoles, especially with sensorimotor insoles. The objective of this study was to investigate the influence in muscle activity of supporting/correcting and sensorimotor insoles in combat boots in the muscles of the lower limb and thus to draw conclusions according to the benefits of insole therapy in military footwear.

Methods: 73 patients (12 female, 61 males; average age: 30.8 ± 7.9 years) with pes planovalgus deformity were included in this prospective randomized placebo-controlled study. For intervention supporting (N = 23), sensorimotor (N = 28) and placebo insoles (N = 22) were used.

During gait analysis muscle activity was measured by means of surface electromyography (EMG) of the tibialis anterior and peroneus longus muscle in combat boots with and without insoles. Statistical evaluation was performed using two-factor ANOVA with repeated measures.

Results: EMG measures (amplitude, integral, maximum, mean) showed mainly activating effects in the peroneus longus muscle in the case of sensorimotor and activity reductions in supporting insoles. Comparing effects of different kinds of insoles to the peroneus longus muscle, significant differences could be shown. No significant differences in muscular activation were observed for the tibialis anterior muscle.

Conclusion: Even in combat boots effects of sensorimotor insoles on the peroneus longus muscle can be detected. The expected effects, attributed to the different kinds of insole, could be observed, too. While sensorimotor insoles had an activating kind of effect, supportive insoles reduced muscular activity of the peroneus longus. In contrast for the tibialis anterior muscle no clear conclusion could be drawn. Its muscular activity seems not to be influenced by insoles in combat boots. However, it remains unclear whether clinical long term effects, e.g. pain and function, can be improved.

1. Introduction

Pes planovalgus is a misalignment, which is characterized by an eversion of the hindfoot with simultaneous flattening of the medial longitudinal arch of the foot [1]. Footprints reveal the additional load on the medial longitudinal arch, which leads to valgization of the heel [1]. More precisely, pes planovalgus is characterized by a partial or complete loss of the medial longitudinal arch, a tilt of the talus head in the talonavicular joint to the plantar and medial direction, as well as an increased eversion in the subtalar joint, which leads to an excessive valgus position in the heel [2]. Especially in the first years of life, a lack of medial recess in the footprint is normal, since the physiological fat pad (Spitzy fat pad) only atrophies from the 5th to 6th year of life and the footprint resembles that of healthy adults [3]. Approximately 12.5–16.7% of the girls and 12.7–19.6% of the boys have a juvenile pes planovalgus [3]. The frequency decreases to 4% in 10-year-old children

Abbreviations: EMG, surface electromyography; CNS, central nervous system; MVC, maximum voluntary contraction; SD, standard deviation; CI, confidence interval; D, difference; MD, mean difference; bpm, beats per minute.

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[4].

The prevalence in adults is reported between 3–19% [2]. However, there is a high variability between different authors [5,6]. Women are more likely to suffer from pes planovalgus than men [7]. The etiology of the acquired pes planovalgus is described multifactorial [8]. Obesity, increased band laxity and diabetes mellitus increase the risk of the onset of pes planovalgus [9]. However, in each case, the insufficiency of the tibialis posterior muscule can lead to flattening of the medial longitudinal arch of the foot [8]. As a result, increased risk of the appearance of arthrosis in knee and hip joint was reported [10]. Thus, the correction of pes planovalgus is a way to reduce the risk of gonarthrosis in the event of a misalignment [11].

The diagnosis of pes planovalgus is mainly clinical. The so-called "Great Toe Extension Test" is frequently used in the clinical examination [12]. The test is also referred to as "Hubscher maneuvers" [8]. The passive lifting of the great toe leads to an elevation of the medial longitudinal curvature due to the effect of the Windlass mechanism as sign for a flexible deformity, and a lateral torsion of the tibia with simultaneous heel varization can be seen [8,12].

The extent of the pes planovalgus can be described by the valgus index, too. This describes the displacement of the center of the malleolar axis above the calcaneus and is a valid parameter for an objective evaluation of the footprint [12].

Usually, insoles support or correct the foot by placing the foot in the orthograde position. Here, the insoles usually have a high heel socket and they support the sustentaculum tali at the medial arch of the foot [2]. Sensorimotor insoles actively affect the muscles in the lower leg and foot to achieve the desired effects [13]. This type of insole was developed for the therapy of children suffering from cerebral palsy [13]. It also exerted to optimize performance and reduce strain in athletes [14]. Proprioceptive insoles trigger recurrent stimuli due to incorporated bares, which activate muscle spindles on the one hand and Golgi tendon organs on the other. By processing the stimuli in the central nervous system (CNS), the sensorimotor insoles achieve their effects via direct inhibition or activation as well as via modulation from the CNS, stimulating the muscle activity [13,15].

In summary, an increase or decrease in muscle activity can be expected in a neurologically and muscular healthy patient dependent on the position of the incorporated bares [13]. Peroneus longus muscle plays a central role in stabilizing the longitudinal arch, as it supports eversion and pronation in the landing phase, thus ensuring the stability of the lower ankle joint and slowing down the inversion movement of the hindfoot [16,17]. Since an increased activity of the peroneus longus muscle leads to a stabilization of the lower ankle joint, the proprioceptive insole would thus have an active training effect compared to the supporting insole [17–19]. Electromyography (EMG) studies in sneakers showed that a positive effect was detectable, especially in the parameter maximum in the surface EMG of the peroneus muscle [19]. Clinical effects in the therapy of pes planovalgus could not yet be proven valid in adults. Combat boots strongly influence muscular activity of several lower leg muscles [20]. This work is intended to show whether presuppositions can be achieved in combat boots regarding the special conditions of soldiers applying standard footwear and being used during long distance marches. Therefore, the influence of sensorimotor or supporting insoles on the target muscles of the lower extremity was detected and it was observed whether the postulated mode of action is also applicable.

2. Material and methods

2.1. Patients

73 patients (12 women, 61 men) with pes planovalgus deformity were included in this prospective randomized placebo-controlled study between 07/2016 and 03/2019. Table 1 shows characterization of the enrolled patients.

Table 1
Description of the study population. Values are presented by mean ± 1 standard deviation.

	Sensorimotor insole (N = 28)	Supporting/correcting insole (N = 23)	Placebo-insole (N = 22)
Age	29.8 (±7.7)	31.7 (±7.5)	31.4 (±8.8)
BMI	27.3 (±4.6)	26.9 (±3.7)	26.7 (±3.8)
FADI-Score	87.2 (±12.0)	84.1 (±12.0)	83.5 (±10.9)
EQ-5D-Score	0.87 (±0.1)	0.84 (±0.08)	0.87 (±0.09)
Valgusindex	4.1(±1.3)	4.1 (±1.0)	3.9 (±1.0)

Patients with flexible pes planovalgus, discomfort in the foot and lower leg, age over 18 years, no previous treatment with shoe insoles and readiness for follow-up examination were enrolled in this study. Patients with inability to recognize the scope of therapy, unwillingness to wear insoles, rheumatic disease, neuropathy of any genesis, acute trauma, arthrosis of the lower extremity, hallux valgus with clinical hallux valgus angle >30° and distressing of the little toes, fixed pes planovalgus and pes cavus were excluded. The study received a positive vote from the local ethics committee (Reference number: A2016-0009).

2.2. Methods

2.2.1. EMG

The surface EMG (Clinical DTS, MR3 MyoMuscle software, Noraxon, Scottsdale, AZ, USA) of the tibialis anterior muscle and peroneus longus muscle were conducted on both sides. The measured values during gait cycle were compared with the maximum voluntary contraction (MVC). Midstance Phase was detected by parallel determination of the maximum bearing area (pressure measuring plate Zebris, Isny in the Allgäu, Germany). The preparation of the skin was carried out in accordance with the recommendations for the implementation of a surface electromyography [21]. At the beginning, the electrodes were appropriately attached to the most prominent points of the muscle bellies of the tibialis anterior muscle and peroneus longus muscle. To determine the MVC, the patients pulled the foot in the functional direction against a fixed resistance [21]. This process was repeated three times and the maximum value was used for further analysis.

During gait analysis, 7 double steps were performed barefoot as well as in the combat boots with and without insoles. The evaluation was carried out with the software Noraxon MR3 3.10.16 (Fa. Noraxon, Scottsdale, USA). The following parameters were determined in relation to the MVC: maximum, mean, amplitude and integral (area under the curve). For better comparability, patients were encouraged to walk at a cadence of 85 bpm. The frequency was indicated by a metronome. The process was carried out with a straight start (without negative or positive acceleration) in a smooth, natural walking motion.

2.2.2. Insoles

The allocation of the patients to the therapy groups was randomized according to a previously randomly determined sequence. All insoles (Fig. 1), sensorimotor (Springer Aktiv AG, Berlin, Germany); supporting (cork/leather) and placebo (foam cutting; General 4 mm), were always custom-made individually at the time of the intervention by the same orthopaedic technician according to a blueprint. A neutral surface was supplied to the insoles to be visually similar so that neither the patient nor the employee responsible for the measurement could find out the selected type of insole.

2.2.3. Statistical analysis

The descriptive presentation of the data was carried out for continuous variables based on the mean values of ±1 standard deviation (SD) and 95% confidence interval (CI). The normal distribution test was carried out with the Shapiro Wilk test and was graphically tested by QQ-test. The difference in muscle activation within the study-arm when

Fig. 1. Insoles used for intervention: 1: Placebo; 2: supporting/ correcting; 3: sensorimotor insole.

walking in the shoe with and without insole calculated by means of a T-test for paired samples. The significance check regarding the insole effects between the groups (mean difference with and without insole between the groups) was carried out by means of two-factor ANOVA with measurement repetition. The software SPSS version 23.0. (SPSS Inc. Chicago, Illinois, USA) was used for the data evaluation.

3. Results

Table 1 presents an overview of age, BMI, level of clinical complaints (FADI score and EQ-5D score) and the expression of pes planovalgus (valgus index) in different therapy groups. The groups were comparable in terms of the expression of the characteristics.

3.1. *Peroneus longus muscle*

In the comparison of muscle activity in the combat boot with and without insole, significant differences in the parameter mean could be detected in sensorimotor and placebo insoles (Table 2). Although muscular activity trended to be increased by sensorimotor insoles, there was a decrease of muscular activity in the parameter mean in the sensorimotor and the placebo insole. By trend a strong decrease in muscular activity in case of using supporting insoles could be seen in the parameters maximum and amplitude (Table 2). No statistically significant differences could be found for the other parameters.

The comparison of the effects (mean differences) of the insoles between the study-arms showed significant differences in the parameter amplitude between sensorimotor and supportive/corrective insole as well as in the parameters maximum and mean by trend (Table 3). By trend the differences were relevant between sensorimotor and placebo

Table 2
Muscle activity in % MVC or µV of the peroneus longus muscle with and without insole in the shoe. Shown are mean value (MV) ± 1 standard deviation (SD), mean difference between measurement with and without insole (MD), 95% confidence interval (CI) and p-value.

	Maximum in % MVC					
	Sensorimotor insole (N = 56)		Supporting/correcting insole (N = 46)		Placebo-insole (N = 43)	
	Without	With	Without	With	Without	With
MV ± SD	35.6 (±15.3)	36.7 (±15.4)	52.7 (±31.0)	48.3 (±27.1)	47.5 (±23.6)	42.6 (±23.4)
MD	1.1		−4.4		−4.9	
95%CI	−4.8; 2.7		−1.1; 9.8		−0.1; 9.1	
p-Value	0.577		0.113		0.053	
	Mean in % MVC					
	Sensorimotor insole		Supporting/correcting insole		Placebo-insole	
	Without	With	Without	With	Without	With
MV ± SD	21.0 (±10.1)	18.3 (±7.6)	26.3 (±15.6)	25.8 (±17.6)	25.4 (±14.0)	22.2 (±13.0)
MD	−2.7		−0.5		−3.2	
95%CI	0.9; 4.6		−1.8; 2.8		0.4; 5.6	
p-Value	0.003*		0.658		0.024*	
	Integegral in µV					
	Sensorimotor insole		Supporting/correcting insole		Placebo-insole	
	Without	With	Without	With	Without	With
MV ± SD	64.7 (±31.2)	66.8 (±26.7)	72.9 (±16.4)	75.3 (±16.5)	68.4 (±23.2)	66.8 (±29.3)
MD	2.1		2.4		−1.6	
95%CI	−7.8; 3.6		−6.5; 1.7		−3.4; 6.8	
p-Value	0.467		0.243		0.505	

Table 3
Differences in muscular activity in % MVC or µV between the 3 insole types in peroneus longus muscle. The differences (D) between changes caused by insole (Table 2) were used to calculate mean differences (MD) between the different kinds of insoles. Statistical significance was determined by calculating 95% confidence intervals (CI) and p-values.

	Maximum in % MVC					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	1.1	−4.9	−4.4	−4.9	1.1	−4.4
MD	−6.0		−0.5		−5.5	
95%CI	−1.4; 11.2		7.1; 6.1		−0.8; 11.6	
p-Value	0.127		0.880		0.089	
	Amplitude in % MVC					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	1.8	6	−5.2	6.0	1.8 (±14.1)	−5.2 (±11.6)
MD	4.2		11.2		−7.0	
95%CI	−2.4; 10.4		−9.7; 3.7		0.7; 13.3	
p-Value	0.218		0.381		0.031*	
	Mean in % MVC					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	−2.7	−3.2	−0.5	−3.2	−2.7	−0.5
MD	0.5		−2.7		2.2	
95%CI	−3.2; 2.9		−1.12; 5.3		−5.3; 0.8	
p-Value	0.928		0.191		0.140	
	Integral in µV					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	2.1	−1.6	2.4	−1.6	2.1	2.4
MD	3.7		4.0		0.3	
95%CI	−5.3; 9.6		−5.3; 10.3		−7.7; 7.0	
p-Value	0.564		0.526		0.930	

Table 4
Muscle activity in % MVC or µV of the tibialis anterior muscle with and without insole in the shoe. Shown are mean value (MV) ± 1 standard deviation (SD), mean difference between measurement with and without insole (MD), 95% confidence interval (CI) and p-value.

	Maximum in % MVC					
	Sensormotor insole		Supporting/correcting insole		Placebo-insole	
	Without	With	Without	With	Without	With
MV ± SD	38.0 (±36.5)	37.5 (±25.0)	32.5 (±12.4)	32.5 (±13.3)	28.3 (±12.3)	30.2 (±18.1)
MD	−0.5		0.0		1.9	
95%CI	−3.4; 4.9		−2.7; 2.6		−4.9; 1.0	
p-Value	0.712		0.991		0.195	
	Amplitude in % MVC					
	sensormotor insole		Supporting/correcting insole		Placebo-insole	
	Without	With	Without	With	Without	With
MV ± SD	31.5 (±30.7)	31.2 (±19.7)	28.1 (±12.1)	27.5 (±12.6)	24.2 (±10.7)	26.2 (±16.4)
MD	−0.3		−0.6		2.0	
95%CI	−3.6; 4.4		−1.7; 2.9		−5.1; 0.9	
p-Value	0.837		0.619		0.172	
	Mean in % MVC					
	Sensormotor insole		Supporting/correcting insole		Placebo-insole	
	Without	With	Without	With	Without	With
MV ± SD	18.7 (±14.6)	18.1 (±13.6)	15.4 (±5.9)	15.1 (±6.9)	12.6 (±6.4)	12.9 (±8.0)
MD	−0.6		−0.3		0.3	
95%CI	−0.8; 2.2		−1.0; 1.6		−1.6; 1.0	
p-Value	0.355		0.628		0.653	
	Integegral in µV					
	Sensormotor insole		Supporting/correcting insole		Placebo-insole	
	Without	With	Without	With	Without	With
MV ± SD	68.2 (±34.9)	71.8 (±30.4)	81.7 (±17.5)	80.3 (±16.0)	70.8 (±29.6)	65.5 (±26.5)
MD	3.6		−1.4		−5.3	
95%CI	2.0; −3.6		−3.7; 6.6		−0.3; 10.9	
p-Value	0.121		0.567		0.065	

insole in the parameter maximum and between placebo and supporting insole in the parameters mean and amplitude, too (Table 3).

3.2. Tibialis anterior muscle

The evaluation of effects of insoles in combat boots on muscular activity showed an increasing muscular activity by trend in the parameter integral in sensorimotor insoles and a decrease in muscular activity in placebo and supporting insole (Table 4). The differences between the effects on muscular activity between placebo and sensorimotor insole trended to be relevant in all parameters especially in the parameter integral (Table 5). While all other differences between sensorimotor and supporting insoles as well as supporting insole versus placebo showed no significant effects (Table 5).

4. Discussion

The results of this study indicated that sensorimotor insoles in combat boots could have effects on muscular activity of the lower leg. In the peroneus longus muscule, the raw values mainly showed muscle activation by the sensorimotor insole, whereas a reduction in muscle activity could be observed in case of the supporting insole. These effects could be estimated due to the supposed mode of action [13]. A promotion of the active erection by the supporting insole is therefore rather not to be expected, whereas the potential is maintained with the sensorimotor insole, even if the expression in the combat boot is rather small. The effects in sneakers were more pronounced [20]. In the tibialis anterior muscule, no significant effects in combat boots could be detected. But by trend sensorimotor insoles increased muscular activity while placebo and supporting insole decreased it. Since this muscle is strongly influenced by combat boots, as previously shown in other studies, it seems to be possible that the influences of the footwear overweighed the influence of the insole [20].

A pes planovalgus can lead to pain due to overload of the weak foot muscles as well as knee pain, heel spur, intervertebral disc and back problems [18]. These are problems that are common due to the stress on soldiers [20]. Treatment with insoles is often used in conservative therapy of civil patients [2]. Here positive effects regarding pain and function are reported but there is a lack of knowledge regarding effects in military footwear [22]. While Ludwig et al. were able to demonstrate effects on lower leg muscles by sensorimotor insoles in adults, the clinical success is still not proven [18]. The shoe insoles in this study could trigger significant effects in particular a higher activity of the peroneus longus muscle. Accordingly, sensorimotor insoles could be used therapeutically against fatigue effects in the area of the foot and lower leg. Due to the stiffness of military footwear, the effects of sensorimotor insoles are limited, so that the materials of combat boots should be additionally considered for soldiers with stronger foot deformities.

However, the quite complex effects of an insole supply cannot be assessed comprehensively on the base of EMG measurements, since in particular the tibialis posterior muscle, as an essential muscle for the erection of the medial longitudinal arch, cannot be achieved by surface EMG, which is a limitation of this work. The small number of women is another limitation of this study.

Mainly supporting insoles are used in therapy of patients with pain or functional problems due to pes planovalgus [2]. Our study indicated that there was a decrease in muscular activation, what may lead to a loss of muscle strength. This could lead to a vicious circle that can cause addiction to supporting insole because needed muscles were not used and trained and may react with inactivity what can boost the problem of arch flattening to a higher level. A sensorimotor support could possibly prevent this due to the mode of action.

5. Conclusion

The results of this work showed that insoles in combat boots can have effects on the muscular activity in the lower limb in a specific manner. Even in combat boots, effects of sensorimotor insoles on the peroneus longus muscle can be detected. The expected effects, attributed to the

Table 5
Differences in muscular activity in % MVC or μV between the 3 insole types in the tibialis anterior muscle. The differences (D) between changes caused by insole (Table 4) were used to calculate mean differences (MD) between the different kinds of insoles. Statistical significance was determined by calculating 95% confidence intervals (CI) and p-values.

	Maximum in % MVC					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	−0.5	1.9	0.0	1.9	−0.5	0.0
MD	2.4		1.9		0.5	
95%CI	−8.7; 1.1		−7.1; 3.2		−6.7; 3.0	
p-Value	0.127		0.458		0.445	
	Amplitude in % MVC					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	−0.3	2.0	−0.6	2.0	−0.3	−0.6
MD	2.3		2.6		−0.3	
95%CI	−8.1; 1.3		−2.2; 7.5		−5.4; 3.8	
p-Value	0.150		0.286		0.742	
	Mean in % MVC					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	−0.6	0.3	−0.3	0.3	−0.6	−0.3
MD	0.9		0.6		0.3	
95%CI	−3.5; 0.5		−2.7; 1.5		−2.9; 1.0	
p-Value	0.137		0.574		0.361	
	Integral in μV					
	Sensorimotor insole	Placebo insole	Supporting/correcting insole	Placebo insole	Sensorimotor insole	Supporting/correcting insole
D	3.6	−5.3	−1.4	−5.3	3.6	−1.4
MD	8.9		−3.9		−5.0	
95%CI	−1.5; 14.1		−4.4; 12.0		−5.2; 10.2	
p-Value	0.114		0.358		0.527	

different kinds of insole, could be observed, too. While sensorimotor insoles had an activating kind of effect, supportive insoles reduced muscular activity of the peroneus longus. In contrast for the tibialis anterior muscle no clear conclusion could be drawn. Its muscular activity seems not to be influenced by insoles in combat boots. Since a supportive insole does not depend on muscluar activity for its mode of action, this type of insole could still be useful for military footwear whithout activating effects on muscles of the lower limb. However, time dependent effects need to be further investigated with appropriate studies regarding strain of military service and it remains unclear whether clinical conditions, e.g. pain and function, can be improved. So further studies to line out clinical or preventive effects need to be conducted.

Brief summary

What is known:

- Sensorimotor insoles have influence on muscular activity of the tibialis anterior and peroneus longus muscle.
- Different kind of insoles are used in the therapy of flatfoot in children and adults.
- Shape and material of military footwear strongly influence muscular activity of the tibialis anterior muscle.

What is new:

- Muscular activity of the tibialis anterior and peroneus longus muscle is mainly reduced by arch supporting/correcting insoles.
- Sensorimotor insoles have no relevant effect in the tibialis anterior muscle but a moderate effect in the peroneus longus muscle during wearing combat boots.
- Shape and material of footwear overweigh the influence of sensorimotor insole on muscular activity in combat boots.

Data availability

The data that has been used is confidential.

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Conflict of interest statement

All authors declare that there is no conflict of interest.

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