Research Paper

Long-term Exercises on Sand Improved Frequency Spectrum of Lower Limb Muscles During Running in Runners With Over-pronated Feet

Amirali Jafarnezhadgero[1*], Kosar Gadehri[2], Ehsan Fakhri Mirzanag[1]

1. Department of Sport Biomechanics, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran.
2. Department of Sport Biomechanics, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran.

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ABSTRACT

Purpose: Pronated feet (PF) are associated with biomechanical changes during running. It seems that sand training can be a suitable intervention for rehabilitation in individuals with over-pronated feet. This study aims to investigate the effect of long-term exercises on the sand on the frequency of lower limb muscles during running in runners with over-pronated feet.

Methods: The current study was a quasi-experimental type. A total of 29 controls with a mean age of 22.2±2.5 years (control group [CG]) and 30 pronated feet (PF) individuals with a mean age of 22.2±1.9 years (intervention group [IG]) participated in this study. In both pre and post-test phases, participants run barefoot on an 18-m runway at a constant velocity of 3.3±5% m/s while EMG activity was recorded using an EMG system. The sand training includes barefoot running for 3 sessions per week for 8 weeks. The frequency of lower limb muscle activities was used as a dependent variable. Repeated-measures analysis of variance (ANOVA) test was used for statistical analysis.

Results: The results demonstrated a significant group×time interaction for gluteus medius (gluteus-M) frequency content at the mid-stance phase ($P<0.001$; $\eta^2=0.670$). The results demonstrated an increase of frequency content for gluteus-M in CG (but not in IG) at post-test compared to the pre-test. The results demonstrated a significant group×time interaction for medial gastrocnemius (Gas-M) frequency content at push-off phase ($P=0.049$; $\eta^2=0.298$). Post-hoc analysis demonstrated an increase of Gas-M frequency content in IG (but not in the CG) at the post-test compared to the pre-test.

Conclusion: As mentioned in a previous study, the reduction of gluteus-M frequency content in IG may be associated with reduced foot pronation after sand training. A higher Gas-M frequency content in the IG after training may lead to improved force generation during the push-off phase.

*** Corresponding Author:**
Amirali Jafarnezhadgero, Associate Professor.
Address: *Department of Sport Biomechanics, Faculty of Educational Sciences and Psychology, University of Mohaghegh Ardabili, Ardabil, Iran.*
Phone: *+98 (910) 5146214*
E-mail: *amiralijafarnezhad@gmail.com*

Highlights

• The results demonstrated a significant group×time interaction for gluteus medius (gluteus-M) frequency content at the mid-stance.

• The results demonstrated an increase in frequency content for gluteus-M in the control group (CG) (but not in the intervention group [IG]) at the post-test than the pre-test.

• The results demonstrated a significant group×time interaction for medial gastrocnemius (Gas-M) frequency content at the push-off phase.

• The results demonstrated an increase in Gas-M frequency content in the IG (but not in the CG) at the post-test.

Plain Language Summary

Sand training can be a suitable treatment method for individuals with over-pronated feet. This study aimed to investigate the effect of long-term exercises on the sand on the frequency of lower limb muscles during running in runners with over-pronated feet. The results demonstrated an increase in frequency content for gluteus-M in the control group (CG) (but not in the intervention group [IG]) at the post-test compared to the pre-test. As mentioned in a previous study, reduced gluteus-M frequency content in the IG may be associated with reduced foot pronation after sand training. A higher Gas-M frequency content in the IG after training may lead to better force generation at the push-off phase. Sand training can lead to improved muscular performance in runners with overpronated feet during running.

1. Introduction

Pronated feet (PF) means reduced medial longitudinal arch at weight-bearing conditions. PF prevalence rates ranged from 48% to 78% in youth [1] and about 2%–23% in adults [2].

Individuals with over-pronated feet (OPF) demonstrate higher amplitude of tibialis posterior, tibialis anterior, toe flexors, medial gastrocnemius, and gluteus medius activities and lower amplitude of evertor activities compared to healthy individuals [3-5]. Electromyography (EMG) is a method to record the electrical activity of muscles [6]. The frequency content of EMG has been associated with muscle fatigue [7]. The frequency shift is associated with alterations in conduction velocity and changes in the recruitment of the motor units [7]. The median frequency during an isometric contraction is also related to the onset of muscle fatigue [8]. Accordingly, previous studies [3, 4] recommended that muscular activities should be regarded during the rehabilitation of OPF individuals.

Different procedures have been used in the rehabilitation of OPF [e.g. foot orthoses [9, 10] taping [11-13], and motion control shoes [14, 15]. Jafarnezhadgero et al., demonstrated that long-term running on sand led to reduced foot pronation and an increment in medial gastrocnemius amplitudes along with improved frontal plane pelvic stability due to higher gluteus medius amplitude [16]. However, these authors [16] did not evaluate the frequency content of muscles in their study. Sand has the potential to use as a suitable surface for rehabilitation sessions [17]. This study was conducted to assess the effect of long-term sand training on the muscular frequency content during running in runners with over-pronated feet.

2. Materials and Methods

G*Power software, version 3.1.9.4 was used to estimate the sample size (P=0.05, type error II=0.20, statistical power=80%, effect size=0.80) [18]. As a result, at least 30 samples are required to achieve large group×time interactions. Sixty male recreational runners with OPF participated in this randomized controlled trial study (Figure 1). The eligibility criteria include a navicular drop >10 mm [19] a foot posture index >10 [20], a right foot dominant, a rearfoot striker, and physically active individuals. The exclusion criteria include limb length discrepancies of >5 mm, muscle spasms, neuromuscular or orthopedic-related disorders, or a history of surgery. Finally, sixty recreational OPF runners were randomly allocated to the IG and CG groups (Table 1).

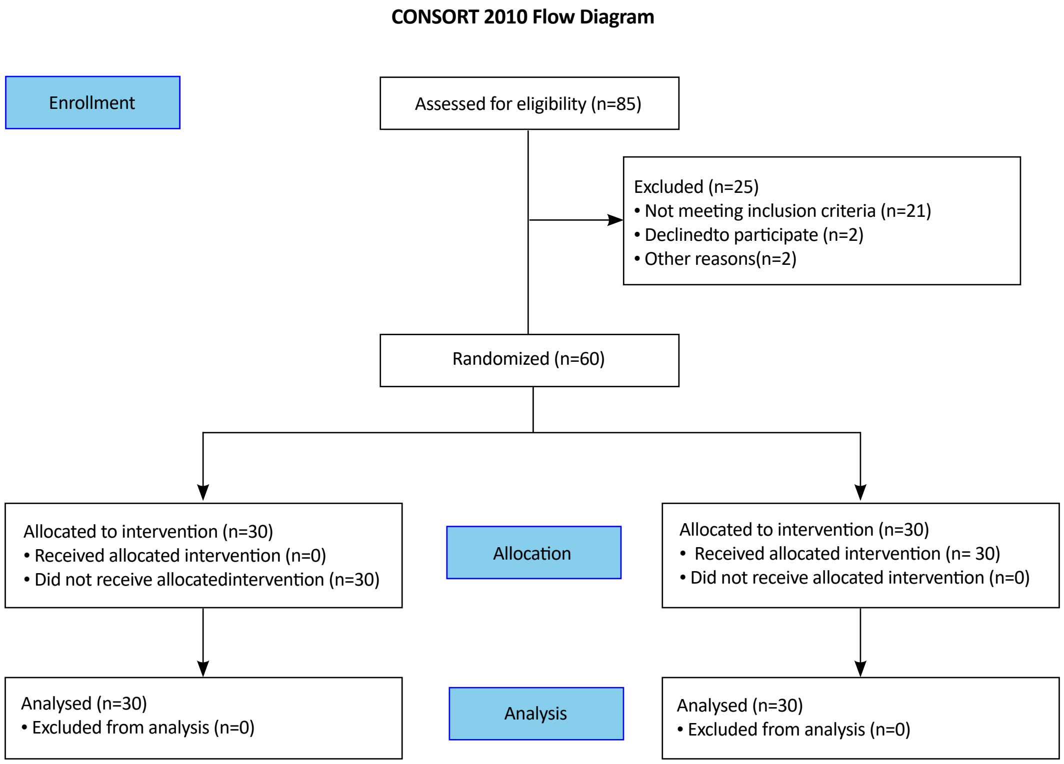

Figure 1. Flow diagram of the study

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Experimental procedures

At first, a warm-up protocol (5 minutes) was performed [21]. Then, all participants ran barefoot on an 18-m runway at a speed of 3.3±5% m/s [22]. Five running trials during both pre-test and post-test were used for further data analysis [23]. All data collection process was done by a nave individual.

Experimental setup and data processing

A force plate (Bertec Corporation, Columbus, OH, USA) was used to record ground reaction force (GRF) data (sampling rate of 1000 Hz). The GRF data was filtered through a cut-off frequency of 20 Hz [24]. Stance phase is defined as the period between ground contact (vertical GRF >10 N) to toe-off (GRF <10 N). Eight pairs of Ag/AgCl surface electrodes were used to record the muscle activities of tibialis anterior (TA), gastrocnemius medialis (GasM), biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), and gluteus medius (Gluteus-M) of dominant [8]. The EMG data were sampled at 1000 Hz using an EMG system (Biometrics Ltd, Nine Mile Point Ind. Est., New port, UK). First, the skin was cleaned with alcohol [25]. The stance phase was divided into loading (0%–20% stance), mid-stance (20%–50% stance), and push-of (50%–100% stance) phases [26-28]. EMG data were high-pass and low-pass filtered with a cut-off frequency of 10 and 500 Hz, respectively. The median frequency of EMG data was then extracted for further analysis.

Sand running training protocol

The sand running training program includes continuous barefoot jogging, striding, bounding, galloping, and short sprints for three sessions per week for 8 weeks [21, 29]. Each session included a 5-minute warm-up and stretching session, a 50-minute main training duration, and a 5-minute warm-down session [21]. For bounding, a straight-leg bound exercise was performed for a distance of 30 m [16]. For galloping, one foot was located in front of the opposite foot. The front foot took a large step forward, while the second foot remained in place. The 25 m sprints started with the subjects in a forward lunge status [16]. The IG was assessed after 6 days of the final training session [30]. Participants in the CG did not perform additional exercises during the study period.

Statistical analyses

The normal distribution of data was affirmed using the Shapiro-Wilk test. A separate 2 (time: Pre vs post-test)×2 (groups: CG vs IG) analysis of variance (ANOVA) with

Table 1. Demographic characteristics for all groups

Variables	CG	IG	P
Age (y)	22.2±1.9	22.2±2.5	0.955
Heigh (cm)	177.9±5.7	178.0±6.6	0.869
Mass (kg)	75.40±7.9	75.0±8.2	0.612
Foot posture index	11.0±0.7	11.2±0.7	0.401

CG: Control group; IG: Intervention group.

repeated measures was computed. Effect sizes were determined using eta-squared (η^2 p) [31]. The significance level was $P<0.05$. Statistical analyses were performed using SPSS software, version 24.

3. Results

Demographic variables were similar in both groups (Table 1).

The results demonstrated a significant group×time interaction for gluteus-M frequency content at the loading phase ($P=0.012$; $\eta^2=0.406$) (Table 2). Post-hoc analysis demonstrated an increase in frequency content for gluteus-M in the CG and decreases in the IG at the post-test than the pre-test.

The results demonstrated a significant group×time interaction for gluteus-M frequency content at the mid-stance phase ($P<0.001$; $\eta^2=0.670$) (Table 3). Post-hoc analysis demonstrated an increase in frequency content for gluteus-M in the CG (but not in the IG) at the post-test than the pre-test.

The results demonstrated a significant group×time interaction for Gas-M frequency content at the push-off phase ($P=0.049$; $\eta^2=0.298$) (Table 4). Post-hoc analysis demonstrated an increase in Gas-M frequency content in the IG (but not in the CG) at the post-test than the pre-test.

4. Discussion

This study was conducted to evaluate the effect of long-term exercises on the sand on the muscular frequency content during running in runners with over-pronated feet.

Table 2. Group-specific values in electromyography outcome variables during the loading response phase

Muscles	Mean±SD				Group-by-time Interactions Sig. (η^2)
	Control		Intervention		
	Pre	Post	Pre	Post	
TA	87.44±20.9	88.81±21.03	110.95±15.27	100.99±16.93	0.314 (0.128)
Gas-M	90.68±18.35	92.61±17.88	91.41±17.35	88.08±20.44	0.171 (0.187)
VL	65.56±23.27	63.08±17.22	78.51±16.98	65.30±13.45	0.587 (0.061)
VM	63.41±18.25	68.62±33.23	61.53±21.63	64.85±17.07	0.387 (0.106)
RF	59.62±18.44	62.46±18.72	64.51±12.61	72.52±20.45	0.783 (0.028)
BF	72.92±18.06	71.80±14.28	71.98±24.52	75.71±12.66	0.900 (0.012)
ST	75.97±14.93	82.00±22.19	75.45±12.70	74.23±17.01	0.561 (0.066)
Gluteus-M	59.57±24.73	78.29±44.14	74.93±16.21	69.08±36.79	0.012 (0.406)*

Abbreviations: TA: Transverse abdominal; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris; BF: Biceps femoris; ST: Semitendinosus; Gluteus-M: Gluteus medius; Gas-M: Gastrocnemius medialis.

*Significant difference, $P<0.05$.

Table 3. Group-specific values in electromyography outcome variables during the mid-stance phase

Muscles	Mean±SD				Group-by-time Interactions Sig. (η^2)
	Control		Intervention		
	Pre	Post	Pre	Post	
TA	97.34±12.7	101.18±17.27	121.88±20.13	118.62±21.28	0.430 (0.095)
Gas-M	95.39±10.05	94.95±10.88	95.00±15.89	92.22±21.440	0.369 (0.111)
VL	69.74±11.86	64.32±9.02	67.06±14.24	73.47±13.02	0.108 (0.231)
VM	69.08±13.04	64.54±14.64	75.38±19.72	80.53±15.05	0.370 (0.321)
RF	71.29±7.89	69.13±7.89	77.41±16.80	77.38±13.47	0.218 (0.068)
BF	89.13±28.33	85.93±22.10	88.94±23.50	9.34±16.71	0.322 (0.125)
ST	78.19±17.58	78.39±18.54	94.08±27.06	89.81±21.19	0.817 (0.023)
Gluteus-M	69.99±15.53	83.11±38.35	61.79±13.07	66.41±11.83	0.000 (0.670)*

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Abbreviations: TA: Transverse abdominal; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris; BF: Biceps femoris; ST: Semitendinosus; Gluteus-M: Gluteus medius; Gas-M: Gastrocnemius medialis.

*Significant difference, P<0.05.

The results demonstrated an increase in frequency content for gluteus-M in the CG and a decrease in the IG at the post-test compared to the pre-test. Foot pronation leads to internal tibia rotation and an anterolateral pelvic tilt. This may then lead to increased strain on pelvic muscles and a rotation of the lumbar vertebra during walking [32-34]. Decrease this strain via active contraction of erector spinae, theoretically, can lead to muscular fatigue [35]. As mentioned in a previous study, the reduced amount of gluteus-M frequency content in the intervention group may be associated with reduced foot pronation after sand training [16].

Table 4. Group-specific values in electromyography outcome variables during the push-off phase

Muscles	Mean±SD				Group-by-time Interactions Sig. (η^2)
	Control		Intervention		
	Pre	Post	Pre	Post	
TA	88.93±11.00	84.56±10.45	96.36±24.99	108.21±29.55	0.360 (0.113)
Gas-M	88.74±12.38	90.33±12.66	90.57±23.82	109.45±26.08	0.049 (0.298)*
VL	66.67±5.92	74.77±21.77	74.42±16.54	82.24±23.67	0.058 (0.286)
VM	72.59±10.50	67.94±12.96	74.15±19.44	80.92±22.97	0.443 (0.091)
RF	67.51±7.97	72.49±13.44	81.64±15.14	81.32±21.92	0.758 (0.032)
BF	83.60±21.73	82.23±21.77	103.58±24.49	109.45±24.65	0.269 (0.143)
ST	78.84±20.38	72.42±10.58	89.00±18.62	86.07±23.99	0.526 (0.073)
Gluteus-M	66.63±16.50	67.67±11.28	76.17±16.14	79.50±20.06	0.343 (0.118)

PHYSICAL TREATMENTS

Abbreviations: TA: Transverse abdominal; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris; BF: Biceps femoris; ST: Semitendinosus; Gluteus-M: Gluteus medius; Gas-M: Gastrocnemius medialis.

*Significant difference, P<0.05.

The results showed an increase in frequency content for gluteus-M in the CG (but not in the IG) at the post-test compared to the pre-test. Gluteus-M is a major muscle in motion of the pelvic hip complex in the frontal plane. During walking, gluteus-M provides the majority of support in the mid-stance phase [36]. It also works with the gluteus maximus to maintain the pelvis in the frontal plane [36]. Consequently, gluteus-M has a major role in daily activities, such as climbing [37], and running [38]. Weight-bearing exercises have been shown to generate higher gluteus-M activity than non-weight-bearing exercises [39, 40]. However, our results showed no changes in the gluteus-M activity after sand training in IG.

The results showed an increase in Gas-M frequency content in the IG (but not in the CG) at the post-test compared to the pre-test at the push-off phase. According to the literature [41], the relationship between the fascicles and tendons is crucial. In gait, the elastic energy cannot be provided directly from the impact due to the low Achilles force [42]. In running and jumping, the Achilles force increases during the loading phase [42]. In the running task, the Gas-M fascicles contracted together with high muscle activation during the loading phases [43]. A higher Gas-M frequency content in IG after training may lead to better force generation at the push-off phase.

This study has limitations that should be regarded. First, only male elite runners were used in this study. Therefore, our results cannot be applied to women. Second, we did not record kinematic data in this study.

5. Conclusion

As mentioned in a previous study, the reduced amount of gluteus-M frequency content in the intervention group may be associated with reduced foot pronation after sand training. A higher Gas-M frequency content in the IG after training may lead to better force generation at the push-off phase.

Ethical Considerations

Compliance with ethical guidelines

The present study was approved by the Ethical Committee of Ardabil University of Medical Sciences (Code: R.ARUMS.REC.1397.091), and registered at Iranian Registry of Clinical Trials (No.: IRCT20191211045704N1).

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Authors' contributions

Conceptualization, Visualization methodology, software, validation, formal analysis, investigation, resources, supervision, project administration, funding acquisition and review & editing: Amirali Jafarnezhadgero; Data curation, writing original draft: Kosar Gadehri and Ehsan Fakhri Mirzanag.

Conflict of interest

The authors declared no conflict of interest.

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