Research Paper

The Effect of Sand Exercise Program on Knee Muscle Co-contraction in Runners With Over-pronated Feet During Running

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ABSTRACT

Purpose: Over-pronated foot (OPF) is a common abnormality of the foot. Sand can change lower limb muscle activities. Therefore, the aim of this study was to evaluate the effect of a sand exercise program on knee muscle co-contraction in runners with OPF.

Methods: Thirty individuals (age range: 18–26 years) with OPF were randomly allocated to the equally sized control and experimental groups. The experimental group performed a sand running exercise protocol for eight weeks. Muscle activities were recorded using an electromyography system. Two variables, including directed co-contraction and general co-contraction, were calculated before and after training programs.

Results: In the experimental group, lower directed vastus lateralis/vastus medialis co-contraction, greater general knee co-contraction, and directed medial/lateral knee co-contraction during the mid-stance and push-off phases were found at the post-test compared to the pre-test (P<0.017). Irrespective of the time, greater directed medial/lateral knee co-contraction during the push-off phase was observed in the experimental group (P=0.043).

Conclusion: Sand can be used as a suitable surface for training, as increased muscle co-activation is required to make postural adjustments during running.

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Highlights

- The results demonstrated increases of directed medial/lateral knee muscle co-contraction in the push-off phase.

- The findings showed a decrease in co-contraction of the vastus lateralis/vastus medialis knee muscles in the mid-stance phase.

- The results demonstrated increases in general knee muscle co-contraction in the push-off phase.

- Findings demonstrated increases in directed medial/lateral knee muscle co-contraction in the push-off phase.

Plain Language Summary

Sand is a surface that is suitable to be used for individuals with overpronated feet because it is rather easy to access worldwide. The goal of this study was to investigate the effect of a sand exercise program on knee muscle co-contraction in runners with overpronated feet. The results demonstrated increases in directed medial/lateral knee co-contraction during the push-off phase in the intervention group. Training programs may have positive effects for individuals with overpronated feet to reduce knee injuries during running by the greater directed medial/lateral co-contraction of knee muscles.

1. Introduction

Running is the most popular form of recreational physical activity in the world [1]. Running-related injuries may be associated with the type of sport and lower limb abnormality [2]. Over the past decades, over-pronated foot (OPF) has been discussed as a potential risk factor for injuries or as the mechanism behind impact damping [3].

People with OPF demonstrate pain in the knee joint [4]. OPF deformity can lead to lower extremity dysfunction [5]. OPF alters lower extremity mechanics during daily activities [6]. Also, OPF is recognized as a running-related injury risk factor [5]. However, it is not clear whether the knee muscles are activated synchronously to modulate joint functions [7, 8].

The association between the agonist/antagonist muscular activations is assessed using surface electromyography [9]. Muscular co-contraction is the contraction of agonist and antagonist muscles at a joint simultaneously. Muscle co-contraction could be regarded as a main factor during training protocols [10, 11]. The increased levels of medial muscle co-contraction and lateral muscle co-contraction were reported in the osteoarthritis patients [12].

Training on sand produced higher muscle activities of the lower limbs with lower ground reaction forces during running and walking in individuals with OPF [13, 14]. An exercise program on an unstable surface, such as sand could be useful [15]. As such, a greater understanding of the sand exercise program is necessary to fully gauge the extent of its application to training methods in individuals with OPF. There is limited investigation on the effects of a sand exercise program on knee muscular co-contraction in OPF individuals.

2. Materials and Methods

The study type was a randomized controlled trial. The G*Power software, version 3.1 for the F-test family (repeated-measures ANOVA for within-between interaction) was used for a priori power analysis (type I error=0.05, type II error rate=0.20 (80% statistical power), and effect size=0.80). The G*Power software showed that at least 30 participants would be sufficient. Participants (age range: 18–26 years) were recruited from local clinics in Ardabil City. Thirty runners with OPF were considered for the control group and 30 runners with OPF for the experimental group (Table 1). For both groups, participants were recruited if they showed a navicular drop >10 mm [16] and a foot posture index >10 [16]. Exclusion criteria included musculoskeletal surgery history, orthopedic disorders (except for OPF), and limb length differences >5 mm.

An electromyography (EMG) system (Biometrics Ltd, Newport, UK) with Ag/AgCl electrodes were used to record the activity of the medial gastrocnemius (Gas-M), biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) muscles of the right limb [17]. The raw EMG signals were sampled at 1000 Hz. According to the SENIAM protocol, the skin surface of the selected muscles was cleaned and shaved with alcohol. The running was divided into the loading (0%-20% gait cycle), mid-stance (20%-47% gait cycle), push-off (47%-70% gait cycle), and swing (70%-100% gait cycle) phases. Maximum voluntary isometric contraction (MVIC) was used for the normalization process of EMG data during running.

Two types of co-contraction were calculated as follows: 1) Directed co-contraction (DCC) and 2) General co-contraction (GCC). DCC ratios were used for the medial (ST, VM, Gas-M)/lateral (BF, VL) direction (DCC-ML), medial (ST)/lateral (BF) hamstrings (DCCMLH), medial (VM)/lateral (VL) quadriceps (DCCMLQ), and the knee flexors (ST, BF, Gas-M)/extensors (VL, VM, RF) (DCCFE). The DCC ratios were assessed as Equation 1 [18]:

1. If agonist amplitude > antagonist amplitude;

DCC=1-Antagonist amplitude/Agonist amplitude

DCC=Agonist amplitude/Antagonist amplitude-1

Maximum directed co-contraction would be equal to zero and minimum directed co-contraction would be numbers approached to ratio 1 or -1 [18]. For GCC values, muscular activities were calculated from the normalized EMG data during each stance sub-phase and swing phase of running.

The intervention group performed training on sand consisting of walking and continuous running tasks for eight weeks (three sessions per week) [19]. Every session was done with a warm-up and stretching session for 5 minutes and ended with a cool-down session for 5 minutes [19]. The total training period was 50 minutes per session [19] (Table 2).

Participants conducted a 5-minute warm-up protocol. For the running trials, participants were familiarized with the laboratory situation and ran across runway three times. After the running trials, MVIC exercises were performed for each muscle. Five successful running trials were recorded and used for further data analysis. This process was performed for the groups in two steps "pre-test and post-test".

The normal distribution of data was examined and confirmed using the Shapiro-Wilk test, and an independent samples t-test was used to determine baseline between-group differences. For this purpose, the repeated-measures two-way ANOVA was used. Post hoc analyses were done using the Bonferroni test and paired sample t-test. The significance level was 0.05. All analyses were done using SPSS software, version 20.0.

3. Results

Participants' outcome variables at baseline are illustrated in Table 3.

The results did not show the significant effect of "time", "group", and group×time interaction for knee joint co-contraction in the loading phase (P>0.05) (Table 4). Significant effects of "time" were found for directed lateral/medial knee co-contraction during the mid-stance phase (P<0.043; d=0.544) (Table 4). The results revealed significantly lower directed lateral/medial knee co-contraction (P=0.043; d=0.602) in the post-test than the pre-test (Table 4). Group×time interactions were significant for directed lateral/medial knee co-contraction at the mid-stance (P<0.044; d=0.540) (Table 4). In the intervention group, significantly lower directed lateral/medial knee co-contraction (P=0.044, d=651) was found in the post-test compared to the pre-test (Table 4).

Of note, significant effects of "time" were observed for general and medial/lateral knee co-contraction in the push-off phase (P<0.033; d=0.574-0.648) (Table 5). Pair-wise comparisons revealed significantly greater general (P=0.033; d=0.445) and directed medial/lateral co-contraction of the knee muscles (P=0.017; d=0.506) in the post-test (Table 5).

Also, the findings demonstrated significant main effects of "group" for directed medial/lateral co-contraction of the knee muscles in the push-off phase (P<0.043; d=0.544) (Table 5). The results showed significantly greater directed medial/lateral co-contraction (P=0.043; d=0.527) of knee muscles in the experimental group compared to the control group (Table 5).

Finally, we found the significant effect of group×time interaction for general co-contraction and directed medial/lateral co-contraction of knee muscles during the push-off phase (P<0.045; d=0.540-617) (Table 5). In the experimental group but not the control group, significantly greater general co-contraction (P=0.045, d=611) and directed medial/lateral co-contraction (P=0.022, d=707) of knee muscles were found in the post-test compared to the pre-test (Table 5).

Table 1. Demographic information of the patients

Variables	Mean±SD		P
	Control	Experimental	
Age (y)	22.36±2.34	22.86±2.12	0.390
Haigh (cm)	172.76±8.37	174.76±7.12	0.323
Weight (kg)	72.40±11.18	73.90±11.61	0.612
Body mass index (kg/m²)	24.38±4.29	24.27±3.97	0.919

PHYSICAL TREATMENTS

Table 2. Training protocol of the experimental group

Session	Exercise Name	Duration (min)	Repetition	Distance (m)	Recovery Period (min)
1	Walking and continuous jogging	20	-	50	-
2	Striding	3	2-3	50	1
3	Bounding	3	2-3	30	1
4	Galloping	3	2-3	30	1
5	Short sprints	6	3-5	25	2

PHYSICAL TREATMENTS

No statistically significant main effects of "time" were found for the co-contraction of knee muscles during the swing phase (P>0.05; d=0.000-0.127) (Table 5). Also, the statistical analyses did not demonstrate any significant main effects of "group" for co-contraction of knee muscles during the swing phase (P>0.05; d=0.021-0.339) (Table 5). Finally, we found no significant effect of group×time interaction for co-contraction of knee muscles during the swing phase (P>0.05; d=0.002-0.271) (Table 5).

4. Discussion

This study aimed to evaluate the effect of a sand exercise program on knee muscle co-contraction in runners with OPF. Main results included: I) Lower directed co-contraction lateral/medial quadriceps of knee muscles during the mid-stance phase were observed in the intervention group at the post-test; significantly greater general co-contraction and directed medial/lateral co-contraction of knee muscles were observed in the intervention group at the post-test during push-off phase; II) Irrespective of the group, greater general co-contraction and directed medial/lateral co-contraction of knee muscles during the push-off phase were observed at the post-test; III) Irrespective of the time, greater directed medial/lateral co-contraction of knee muscles during the push-off phase were observed in the intervention group during sand exercise program.

Co-contraction values could be associated with internal force values and may be important for injury prevention. The neuro-muscular system adjusts mechanical joint stiffness through muscle activation level [20]. Moreover, reduced range of motion has also been associated with reduced limb stability [20]. The individuals with OPF demonstrated poor knee joint stability following external perturbation [21]. Underpinning the pathomechanisms of knee joint instability associated with OPF structural alignment may provide a better understanding of the prevention and treatment of knee joint injuries [21]. The regulatory role of the co-contraction between flexor and extensor muscles provides knee joint stability [22]. Higher ankle co-contraction is associated with better ankle stability but could increase quadriceps to hamstrings co-contraction [23]. Greater general and directed medial/lateral co-contraction of knee muscles were found at the post-test during push-off. Relevant training programs may help runners with OPF to reduce atypical knee loading during the loading phase and improve knee stability.

Reduction of range of motion has been linked to an increase in ankle and knee hardness [24, 25]. It has been shown that lower vertical leg motion resulted in an increase in stiffness on softer surfaces [26]. Although the sand exercise program was used in this study, it may produce some instability, which is controlled through increasing stiffness levels [27]. The individuals with OPF demonstrated poor knee joint stability following external

Table 3. Group-specific baseline values of all reported muscular co-contraction outcome variables

Electromyography (EMG)		Mean±SD		P
		Control	Experimental	
Loading phase	GCC	107.48±34.22	112.36±35.82	0.591
	DCCML	0.27±0.26	0.17±0.32	0.195
	DCCMLH	-0.22±0.34	-0.32±0.25	0.194
	DCCFE	-0.02±0.39	-0.08±0.32	0.524
	DCCLMQ	0.04±0.59	0.05±0.70	0.969
Mid-stance phase	GCC	233.95±48.74	235.92±53.08	0.881
	DCCML	0.43±0.17	0.42±0.18	0.906
	DCCMLH	0.02±0.54	0.01±0.51	0.882
	DCCFE	0.22±0.36	0.23±0.30	0.949
	DCCLMQ	0.05±0.37	0.01±0.49	0.675
Push-off	GCC	151.59±25.39	153.67±24.79	0.749
	DCCML	0.45±0.18	0.43±0.19	0.706
	DCCMLH	-0.25±0.57	-0.29±0.49	0.782
	DCCFE	-0.18±0.26	-0.17±0.29	0.864
	DCCLMQ	-0.11±0.48	-0.12±0.49	0.962
Swing phase	GCC	104.22±26.30	102.70±24.03	0.816
	DCCML	0.22±0.32	0.28±0.26	0.486
	DCCMLH	-0.17±0.63	-0.09±0.62	0.627
	DCCFE	0.32±0.30	0.36±0.23	0.540
	DCCLMQ	-0.01±0.62	0.06±0.35	0.551

PHYSICAL TREATMENTS

Note: GCC: General co-contraction; DCCML: Directed co-contraction medial/lateral muscles; DCCMLH: Directed co-contraction medial/lateral hamstrings muscles; DCCFE: Directed co-contraction flexor/extensors muscles; DCCLMQ: Directed co-contraction lateral /medial quadriceps muscles. The P were obtained from the independent samples t-test.

perturbation [21]. Underpinning the pathomechanisms of knee joint instability associated with OPF structural alignment may provide a better understanding of anterior cruciate ligament (ACL) injuries and a theoretical basis for more accurate clinical diagnosis, prevention, and treatment of knee joint injuries [21]. In the training group, both the general co-contraction and directed medial/lateral co-contraction of knee muscles were significantly greater in the post-test during the push-off phase. Relevant training programs may help runners with OPF to reduce atypical knee loading during the loading phase and improve knee stability.

Higher medial-lateral knee muscular co-contraction could lead to knee osteoarthritis [28]. Muscular activities could increase or decrease the rate of injury occurrences [28]. Previous studies have provided conflicting findings regarding muscular activity levels in OA patients [29, 30]. For example, it has been reported that lateral muscle co-activity in moderate OA is greater than in healthy ones [31]. The increased co-contraction of agonist and antagonist muscles may be interpreted as an attempt to increase lower-limb joint stability [32]. Muscle co-contraction around the knee joint is an important part of normal neuromuscular control [33]. Co-contraction could support joint ligaments in order to maintain joint stability and be used for injury prevention [33]. Training programs may have positive effects for individuals with PF to reduce knee injuries during running by the greater directed medial/lateral co-contraction of knee muscles.

Table 4. Mean values of muscle co-contraction during loading and mid-stance phases (% MVIC) while training on sand in individuals with PF

Variables		Control				Experimental			
		Mean±SD		95% CI	Δ%	Mean±SD		95% CI	Δ%
		Pre-test	Post-test			Pre-test	Post-test		
Loading phase	GCC	107.48±34.22	106.09±30.04	-5.09, 7.84	-1.29	112.36±35.82	115.39±32.57	-13.39, 7.34	2.69
	DCCML	0.27±0.26	0.25±0.25	-0.07, 0.10	-7.40	0.17±0.32	0.21±0.25	-0.14, 0.05	23.52
	DCCMLH	-0.22±0.34	-0.25±0.40	-0.17,0.25	13.63	-0.32±0.25	-0.24±0.43	-0.26, 0.09	-25
	DCCFE	-0.02±0.39	0.02±0.34	-0.17, 0.08	-200	-0.08±0.32	-0.09±0.51	-0.17, 0.17	12.5
	DCCLMQ	0.04±0.59	0.06±0.47	-0.20, 0.16	50	0.05±0.70	0.17±0.32	-0.38, 0.12	240
Mid-stance phase	GCC	233.95±48.74	231.72±52.23	-14.52, 18.97	-0.95	235.92±53.08	245.17±58.41	-27.82, 9.33	3.92
	DCCML	0.43±0.17	0.43±0.15	-0.07, 0.08	0.23	0.42±0.18	0.42±0.27	-0.09, 0.10	0.23
	DCCMLH	0.02±0.54	-0.09±0.31	-0.09, 0.34	-550	0.01±0.51	0.04±0.52	-0.26, 0.18	300
	DCCFE	0.22±0.36	0.26±0.31	-0.18, 0.11	18.18	0.23±0.30	0.26±0.30	-0.16, 0.09	13.04
	DCCLMQ	0.05±0.37	0.05±0.36	-0.17, 0.17	2	0.01±0.49	0.27±0.37	-0.46, -0.06	2600

Variables		Sig. (Effect Size)		
		Time	Group	GroupxTime
Loading phase	GCC	0.783(0.063)	0.382(0.230)	0.464(0.191)
	DCCML	0.671(0.110)	0.274(0.220)	0.357(0.247)
	DCCMLH	0.743(0.090)	0.517(0.168)	0.381(0.230)
	DCCFE	0.685(0.110)	0.346(0.247)	0.677(0.110)
	DCCLMQ	0.330(0.255)	0.613(0.127)	0.497(0.180)
Mid-stance phase	GCC	0.568(0.155)	0.534(0.168)	0.352(0.247)
	DCCML	0.909(0.000)	0.895(0.000)	0.995(0.000)
	DCCMLH	0.589(0.142)	0.543(0.155)	0.298(0.278)
	DCCFE	0.463(0.191)	0.959(0.000)	0.965(0.000)
	DCCLMQ	0.043(0.544)	0.314(0.263)	0.044(0.540)

PHYSICAL TREATMENTS

Legends: PF: Pronated feet; GCC: General co-contraction; DCCML: Directed co-contraction medial/lateral muscles; DCC-MLH: Directed co-contraction medial/lateral hamstrings muscles; DCCFE: Directed co-contraction flexion/extension muscles; DCCLMQ: Directed co-contraction lateral/medial quadriceps muscles; CI: Confidence interval.

Table 5. Mean values of muscle co-contraction during push-off and swing phases (% MVIC) while training on sand in individuals with PF

Variables		Control				Experimental			
		Mean±SD		95% CI	Δ%	Mean±SD		95% CI	Δ%
		Pre-test	Post-test			Pre-test	Post-test		
Push-off phase	GCC	151.59±25.39	152.09±30.55	-11.76,10.75	0.32	153.67±24.79	170.16±26.62	-27.77,-5.20	10.73
	DCCML	0.45±0.18	0.44±0.22	-0.06,0.07	-2.22	0.43±0.19	0.29±0.17	0.04,0.23	-32.55
	DCCMLH	-0.25±0.57	-0.27±0.53	-0.20,0.24	8	-0.29±0.49	-0.25±0.50	-0.28,0.20	-13.79
	DCCFE	-0.18±0.26	-0.16±0.36	-0.15,0.12	-11.11	-0.17±0.29	-0.25±0.22	-0.04,0.21	47.05
	DCCLMQ	-0.11±0.48	-0.12±0.35	-0.19,0.20	9.09	-0.12±0.49	-0.15±0.36	-0.19,0.24	25
Swing phase	GCC	104.22±26.30	101.37±22.62	-5.52,11.21	-2.73	102.70±24.03	104.83±26.87	-12.08,7.83	2.07
	DCCML	0.22±0.32	0.24±0.23	-0.15,0.12	9.09	0.28±0.26	0.31±0.19	-0.16,0.09	10.71
	DCCMLH	-0.17±0.63	-0.06±0.54	-0.41,0.18	-64.70	-0.09±0.62	-0.23±0.97	-0.26,0.54	155.55
	DCCFE	0.32±0.30	0.34±0.27	-0.14,0.10	6.25	0.36±0.23	0.32±0.24	-0.03,0.12	-11.11
	DCCLMQ	-0.01±0.62	-0.08±0.59	-0.23,0.36	-700	0.06±0.35	0.05±0.48	-0.23,0.24	-16.66

Variables		Sig. (Effect size)		
		Time	Group	GroupxTime
Push-off phase	GCC	0.033(0.574)	0.086(0.459)	0.045(0.540)
	DCCML	0.017(0.648)	0.043(0.544)	0.022(0.617)
	DCCMLH	0.889(0.000)	0.950(0.000)	0.701(0.110)
	DCCFE	0.438(0.201)	0.519(0.168)	0.281(0.286)
	DCCLMQ	0.820(0.063)	0.852(0.063)	0.885(0.000)
Swing phase	GCC	0.910(0.000)	0.864(0.063)	0.438(0.201)
	DCCML	0.627(0.127)	0.197(0.339)	0.848(0.063)
	DCCMLH	0.909(0.000)	0.731(0.090)	0.309(0.271)
	DCCFE	0.779(0.063)	0.837(0.063)	0.388(0.230)
	DCCLMQ	0.734(0.002)	0.272(0.021)	0.745(0.002)

PHYSICAL TREATMENTS

Legends: PF: Pronated feet; GCC: General co-contraction; DCCML: Directed co-contraction medial/lateral muscles; DCCMLH: Directed co-contraction medial/lateral hamstrings muscles; DCCFE: Directed co-contraction flexion/extension muscles; DCCLMQ: Directed co-contraction lateral/medial quadriceps muscles; CI: Confidence interval.

Limitations in the current study are acknowledged. The first limitation of the present data is the lack of temporal muscle activation values. Second, we did not record kinematic data in this study. Third, we only tested males, and therefore, our results may not be applicable to females.

5. Conclusions

This study identified co-contraction organizations of the knee muscles that contribute to stability in the OPF during running. Runners with OPF demonstrated poor knee joint stability. We observed greater co-contraction of knee muscles during a sand exercise program. Therefore, training on sand may help runners with OPF improve knee stability and reduce atypical knee loading and injuries while running.

Ethical Considerations

Compliance with ethical guidelines

Informed consent was obtained from the participants in accordance with the Declaration of Helsinki. The right foot was the dominant limb for all participants. This study was approved by the local Ethics Committee of Ardabil University of Medical Sciences (Code: IR.ARUMS.REC.1398.484).

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Authors' contributions

Conceptualization and methodology: Amir Fatollahi and Amir Ali Jafarnezhadgero; Data collection, data analysis and original draft preparation: Amir Fatollahi and Hamed Sheikhalizade; Review and editing: All authors.

Conflict of interest

The authors declared no conflict of interests.

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