Research Paper

Effect of Sand Training on Walking Mechanics in Men With Anterior Cruciate Ligament Reconstruction and Pronated Feet

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ABSTRACT

Purpose: People with both pronated feet and anterior cruciate ligament repair may benefit from walking on sand as a therapeutic option. The consequences of walking on sand on the muscular activity and gait biomechanics of these people are not well understood. This study aims to determine how sand training affects gait mechanics in individuals with both anterior cruciate ligament repair and pronated foot.

Methods: The intervention and control groups included 28 adult males with pronated feet, where anterior cruciate ligament repair was randomly performed. The walking task was done on an 18-meter walkway at a consistent velocity. Muscle activities and ground reaction forces (GRF) were recorded using an electromyography system and a Bertec force plate, respectively.

Results: Group-by-time interactions were significant for anterior and posterior reaction forces ($P<0.019$; $d=0.49-0.66$). Post hoc analysis demonstrated a significant increase for anterior and posterior reaction forces in control but not in the intervention groups. Also, group-by-time interactions were significant for vastus activities during heel contact ($P=0.033$; $d=0.88$).

Conclusion: The results showed that vastus lateralis activity was higher in the intervention group during the heel contact than those of the control group.

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Highlights

• Sand training increased vastus lateralis activities during the loading phase.

• Sand training did not change walking ground reaction forces (GRF).

• For the research, no injuries were reported.

Plain Language Summary

The effect of training on the sand on muscular activities of the lower limb in people with over-pronated foot (OPF) and anterior cruciate ligament reconstruction (ACLR) was examined in this study. The results demonstrated greater vastus lateralis activities during heel contact in the intervention group. Sand training did not alter ground reaction force components. Greater activities in the rectus remoris and biceps femoris muscles were found in the intervention group at the post-test. The study had limitations in terms of not including healthy control individuals and focusing on male individuals with OPF, limiting the generalization of the results to females.

Introduction

The occurrence of anterior cruciate ligament (ACL) injuries in male athletes ranged from 0.6% to 8.5% [1]. The prevalence rate of the pronated foot is about 14% in the population [2, 3]. During walking, the lateral pivot-shift phenomenon in the ACL-deficient knee is further compounded clinically by hyperpronation [4]. Following an initial injury, ACL reconstruction (ACLR) is a frequent procedure to restore stability of the knee joint and get patients back to their sports training programs. About 130000 ACLR operations and 250000 ACL injuries happen in the US each year [5].

ACLRs are associated with changes in walking and running mechanics that may affect cartilage injuries [6-9]. ACLR individuals experience greater vertical ground reaction force and loading rates (LR) [6], along with lower knee flexion moments [7, 9]. Walking following ACLR showed different knee kinematics and kinetics in the sagittal plane [10]. ACLR individuals demonstrated lower first and second vertical forces during walking [11] and these changes altered joint loading [11]. ACLR individiuals demonstrated had lower biceps femoris and vastus lateralis activities after fatigue protocol [6]. Moreover, increased activation of the vastus lateralis, biceps femoris, and gluteus maximus in ACLR individuals was observed during the landing phase after the fatigue protocol [7].

Over-pronated feet (OPF) lead to tibia malalignment [12], femur internal rotation [13], pelvis anterior tilt [14], and lumbar spine misalignment [15, 16] during walking [17]. Tibia and femur internal rotation caused by excessive pronation can lead to an anterior pelvis tilt [14, 18], abnormal lower limb kinematics [19, 20], changes in ground reaction forces (GRF) [21], altered muscle activities, such as erector spinae and gluteal muscles' activity [22-24] and free moments [25, 26] during walking. Additionally, a strong correlation is observed between excessive foot pronation and meniscus tears, knee ligament sprains, ankle sprains, tibial stress fractures, and patella-femoral pain syndrome [27-29]. Also, the elevated GRF characteristics lead to greater load on the other above-mentioned joints [30-32].

Sand walking has received great attention from athletes and coaches as a successful adjunct to firm surface training protocols [33]. Walking on the sand produces more net knee extensor activity than walking on level, solid ground from a biomechanics standpoint [34]. A previous study showed that sand walking results in a lower positive peak of free moments (FM) and impact load compared with walking on stable ground [35]. Also, sand walking demonstrated a major impact on kinematic and kinetic variables in healthy and multiple sclerosis individuals [34, 36]. Therefore, it is possible that sand walking may alter biomechanical elements and impact how ACLR individuals walk [34]. Thus, this study was conducted to evaluate how sand training affects the gait patterns of those who had both ACL repair and pronated foot.

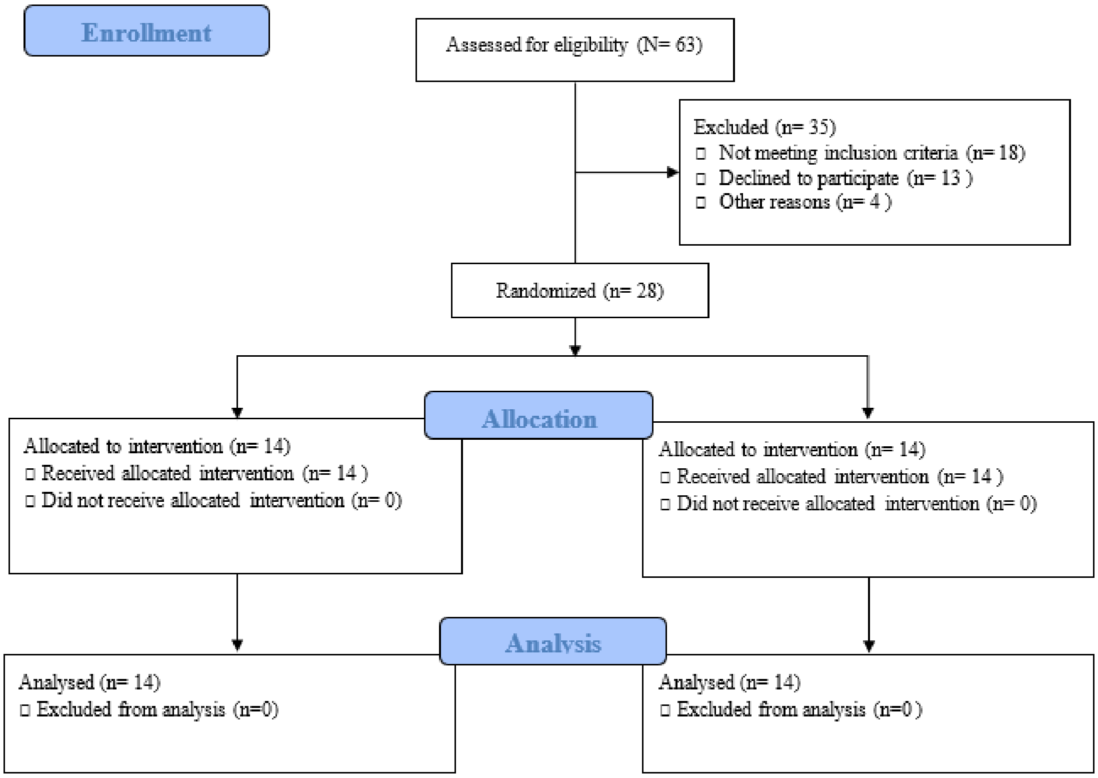

Figure 1. Flow diagram of this study

PHYSICAL TREATMENTS

Materials and Methods

The present study was a quasi-experimental type. The G*Power software, version 3.1, was used to estimate the sample size [37]. In this software, the type I error was 0.05, the statistical power was 0.8, and the effect size value was 0.80. The software showed that at least 14 samples would be needed in each group. Twenty-eight males aged 22 to 25 with a history of pronated foot and ACLR volunteered to take part in the study. This study includes intervention group (IG, n=14) and control (n=14) groups. Both participants and examiners were blinded by group allocation [38, 39].

This study was conducted as a randomized, double-blind, controlled experiment (Figure 1).

The following conditions are excluded, a history of regular exercise during the previous six months, and an inability to walk independently without pain. This study was conducted as a randomized, double-blind, controlled experiment.

Walking kinetics assessment

Walking GRF data was recorded at 1000 Hz using a force plate (Bertec Corporation, USA). The task required the participants to walk an 18-meter distance at a consistent pace of about 1.2 m/s. Five walking trials with a 5-minute rest between each one were performed at both pre-test and post-test.

GRFs data were analysed as mentioned by Jafarnezhadgero [35]. GRFs data was low pass filtered at 20 Hz. A 10 N vertical force threshold was used to determine the walking stance phase. The following dependent variables were extracted from walking data [35]. The vertical and anterior-posterior force curves yielded the initial impact vertical peak (Fz_{HC}), braking (Fy_{HC}), and propulsive forces (Fy_{PO}), respectively. The positive (lateral) peak (Fx_{HC}) and negative peak (Fx_{PO}) were computed using the medial-lateral curve. GRF amplitudes were expressed in percentage of body weight (BW). The interval between the first heel contact and the matching peak of GRF components was designated as the time to peak. The slope on the vertical force curve between heel contact and FzHC was used to define the loading rate. Additionally, the foot's free moment (FM) was calculated. Five trials were used to average each walking variable [17].

Table 1. Demographic, anthropometric, physiological, and biomechanical (kinetics, muscle activity) baseline data in both groups

Characteristics	Variables	Component	Mean±SD		95% CI	P
			CG	IG		
Demographics	Age (y)	-	24.21±1.05	24.28±1.06	3.4, 5.4	0.642
	Height (cm)	-	178.14±5.92	175.71±4.56	1.7, 6.5	0.235
	Weight (kg)	-	72.57±6.64	71.57±4.36	0.9, 0.8	0.860
Kinetics	Vertical ground reaction force (%BW)	Fx_{HC}	5.18±2.88	5.14±2.51	2.0, 2.1	0.968
		Fx_{PO}	6.19±1.39	6.48±1.71	0.9, 1.5	0.619
		Fy_{HC}	13.07±4.88	15.60±5.63	1.5, 6.6	0.216
		Fy_{PO}	12.59±3.62	14.53±3.29	1.9, 1.3	0.149
		Fz_{HC}	113.24±17.18	102.19±17.32	2.3, 24.4	0.102
		Fz_{PO}	112.72±17.33	103.58±22.23	6.3, 24.6	0.236
	Time to peak force (ms)	Fx_{HC}	25.47±5.79	23.14±6.34	2.3, 7.0	0.316
		Fx_{PO}	333.59±139.06	295.47±150.03	75.2, 150.4	0.492
		Fy_{HC}	74.00±59.20	85.76±38.38	50.5, 26.9	0.538
		Fy_{PO}	589.78±39.42	607.52±42.57	49.61, 14.14	0.263
		Fz_{HC}	151.28±42.84	166.26±34.96	45.3, 15.4	0.321
		Fz_{PO}	520.16±51.33	525.92±44.15	42.9, 31.4	0.753
	Free moment (% BW × height)	Negative FM × 10^{-3}	0.25±0.11	0.26±0.13	0.09, 0.1	0.901
		Positive FM × 10^{-3}	0.41±0.13	0.36±0.16	0.06, 0.1	0.404
Muscle activities	TA (%MVIC)	LR	55.24±17.23	66.81±27.11	29.2, 6.0	0.189
		MS	63.67±13.58	57.76±5.42	7.5, 34.2	0.143
		PO	75.92±23.47	93.90±66.24	56.5, 20.6	0.347
	GasM (%MVIC)	LR	57.59±15.20	69.21±19.26	116, 6.5	0.088
		MS	69.29±16.18	61.92±15.97	5.1, 19.9	0.235
		PO	57.08±21.30	57.90±45.98	28.6, 27.0	0.952
	VL (%MVIC)	LR	31.91±25.68	43.07±24.60	30.7, 8.3	0.251
		MS	53.63±14.50	56.26±6.55	1.0, 46.5	0.542
		PO	61.88±14.57	55.16±10.58	4.8, 3.1	0.175
	VM (%MVIC)	LR	63.89±16.49	58.11±8.81	5.7, 4.9	0.251
		MS	80.92±40.42	53.53±22.31	34.7, 28.1	0.830
		PO	64.39±16.53	57.41±10.95	5.2, 3.9	0.199

Characteristics	Variables	Component	Mean±SD		95% CI	P
			CG	IG		
Muscle activities	RF (%MVIC)	LR	25.12±7.39	23.95±6.11	4.1, 6.4	0.661
		MS	72.35±46.33	75.67±33.69	8.3, 3.6	0.430
		PO	68.77±16.36	65.10±4.59	4.5, 5.6	0.427
	BF (%MVIC)	LR	55.39±10.98	56.53±11.44	4.2, 9.8	0.790
		MS	21.77±9.92	24.10±4.41	42.7, 12.3	0.266
		PO	58.29±29.52	38.38±26.21	1.7, 41.6	0.071
	ST (%MVIC)	LR	42.31±21.57	39.57±23.38	14.7, 20.2	0.750
		MS	42.81±23.14	58.01±44.43	44.5, 20.8	0.464
		PO	95.66±52.52	69.98±18.52	14.8, 4.9	0.096
	Glut-M (%MVIC)	LR	36.10±19.07	36.53±20.62	15.8, 15.0	0.955
		MS	61.34±30.25	73.19±51.35	24.0, 53.2	0.444
		PO	70.24±46.77	77.47±22.23	2.6, 54.2	0.074

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Abbreviations: BW: Body weight; FM: Free moment; TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; BF: Iceps femoris; ST: Semitendinosus; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris; Glut-M: Gluteus medius; MVIC: Maximum voluntary isometric contraction; IG: Intervention group; CG: Control group; CI: Confidence interval; Fz_{HC}: Initial impact vertical peak; Fy_{HC}: Braking; Fy_{PO}: Propulsive forces; Fx_{HC}: Positive (lateral) peak; Fx_{PO}: Negative peak; LR: Loading rates, Ligament reconstruction.

Muscle activities assessment

The right limb's tibialis anterior (TA), gastrocnemius medialis (Gas-M), biceps femoris (BF), semitendinosus (ST), vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), and gluteus medius (Glut-M) muscles were recorded using an EMG system (Biometrics Ltd., UK) with 8 pairs of Ag/AgCl electrodes [23]. The skin surface of the chosen muscles was cleaned with alcohol and shaved in compliance with the SENIAM technique [23]. The walking stance phase was split into three parts for EMG analyses, the loading phase (the first 0%–20%), mid-stance (20%–50%), and push-off (50%–100% of the stance) [37, 40-42]. To normalize EMG during walking, maximum voluntary isometric contraction (MVIC) was employed [43]. The identical protocols used during the pre-test were used to reevaluate the IG samples after 8 weeks of the intervention treatment. The post-tests were taken six days following the final training session [44].

Sand walking training protocol

The sand walking training protocol was performed for 8 weeks (three sessions each week). The protocol includes running, striding, leaping, and galloping in the barefoot condition on the sand surface [45]. A five-minute warm-up was conducted before each session [45]. Each training session lasted for fifty minutes [45], under the guidance of a seasoned physical therapist. After eight weeks, the control group (CG) underwent the same training as the IG but on a stable platform.

Statistical analyses

Using the Shapiro-Wilk test, the normal distribution of the data was confirmed. A mixed analysis of variance (ANOVA) test was employed to compare the results between the groups across time. Bonferroni tests were used for post-hoc analysis. Partial eta-squared (η^2_p) was converted to Cohen's d to estimate the effect sizes (d<0.50 indicates modest effects, 0.50≤ d <0.80 indicates medium effects, and d ≥0.80 indicates big impacts). SPSS software, version 26, was used for all tests (significance threshold of 0.05).

Results

Table 1 presents the characteristics of the participants. Regarding the demographic and biomechanical data, no differences were observed between the groups at pre-test (P>0.05).

Table 2. Ground reaction force components during pre and post-test in both groups

Parameter		CG		Δ (%)	95% CI	IG		Δ (%)	95% CI	P (Effect Size Cohen's d)		
		Pre-test	Post-test			Pre-test	Post-test			Main Effect: Time	Main Effect: Group	Interaction: Group × Time
Vertical ground reaction force (%BW)	Fx_{HC}	5.18±2.88	6.07±2.7	17	-0.9, 0.4	5.14±2.51	5.11±1.19	1	-1.5, -0.1	0.503 (0.13)	0.456 (0.15)	0.473 (0.14)
	Fx_{PO}	6.19±1.39	6.69±1.92	8	-3.3, 0.4	6.48±1.71	6.56±2.35	1	-0.3, 2.1	0.553 (0.12)	0.873 (0.03)	0.660 (0.09)
	Fy_{HC}	13.07±4.88	18.65±5.70	43	-5.7, 1.3	15.60±5.63	15.06±5.47	3	-3.4, 2	0.050 (0.40)	0.751 (0.06)	0.019* (0.49)
	Fy_{PO}	10.44±3.16	17.40±4.44	67	-4.8, -1.5	14.53±3.29	15.62±4.56	8	-30.1, 20.7	0.000* (0.90)	0.344 (0.19)	0.002* (0.66)
	Fz_{HC}	113.24±17.18	102.19±17.32	10	1.1, 5.4	102.19±17.32	101.15±26.95	1	-4.4, 0.2	0.474 (0.14)	0.189 (0.26)	0.632 (0.10)
	Fz_{PO}	112.72±17.33	103.58±22.23	8	-18, 5.5	103.58±22.23	100.44±29.22	3	1.2, 5.4	0.251 (0.23)	0.345 (0.19)	0.615 (0.10)
Time to peak force (ms)	Fx_{HC}	25.47±5.79	21.02±7.36	17	-36.4, 36.3	23.14±6.34	19.92±5.30	14	-17.8, -1.6	0.057 (0.39)	0.222 (0.25)	0.750 (0.06)
	Fx_{PO}	333.59±139.06	347.97±156.89	4	30.8, 76.7	295.47±150.03	265.95±151.73	10	-3.8, 22.4	0.871 (0.03)	0.078 (0.36)	0.638 (0.10)
	Fy^{HC}	74.00±59.20	87.19±19.34	18	-13.5, 0.3	85.76±38.38	76.62±19.34	11	-11.7, 15.1	0.831 (0.04)	0.955 (0.00)	0.250 (0.23)
	Fy_{PO}	539.78±58.77	607.90±73.89	13	-0.7, 0.5	614.66±52.96	559.38±112.13	9	-4, 9.1	0.804 (0.04)	0.375 (0.18)	0.023 (0.47)
	Fz_{HC}	151.28±42.84	162.90±51.52	8	-0.1, 0.3	166.26±34.96	146.59±32.27	12	-0.5, 0.3	0.765 (0.05)	0.934 (0.00)	0.252 (0.23)
	Fz_{PO}	520.16±51.33	528.47±66.89	2	-1.3, 1.1	525.92±44.15	485.88±97.22	8	-0.6, 0.4	0.457 (0.021)	0.225 (0.24)	0.261 (0.22)
Vertical	Loading rate	8.08±2.80	7.34±2.61	9	-3, 1.3	6.34±1.76	6.90±1.05	9	-1.3, 1.3	0.830 (0.15)	0.065 (0.125)	0.335 (0.036)
Free moment (% BW × height)	Negative FM × 10^{-3}	0.25±0.11	0.30±0.13	20	-39.6, 4.3	0.26±0.13	0.25±0.11	4	-27.8, 12.9	0.701 (0.04)	0.472 (0.38)	0.456 (0.19)
	Positive FM × 10^{-3}	0.41±0.13	0.35±0.14	15	-14, 7.3	0.36±0.16	0.39±0.13	8	-46.9, 0.5	0.688 (0.08)	0.914 (0.14)	0.234 (0.15)

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Abbreviations: BW: Body weight; FM: Free moment; IG: Intervention group; CG: Control group; CI: Confidance interval; Fz_{HC}: Initial impact vertical peak; Fy_{HC}: Braking; Fy_{PO}: Propulsive forces; Fx_{HC}: Positive (lateral) peak; Fx_{PO}: Negative peak.

*P<0.05

Table 3. Electromyography data during pre and post-test in both groups

Parameter		CG Pre-test	CG Post-test	Δ (%)	95% CI	IG Pre-test	IG Post-test	Δ (%)	95% CI	P (Effect Sze Cohen's d) Main Effect: Time	Main Effect: Group	Interaction: Group × Time
TA (%MVIC)	LR	55.24±17.23	50.57±17.72	8	-13.4, 5	66.81±27.11	69.48±20.07	4	-25.1, 18.4	0.865 (0.08)	0.008* (1.12)	0.535 (0.24)
	MS	63.67±13.53	55.70±25.54	13	-25.5, 44.5	57.76±5.42	55.18±25.02	4	-51.1, 13.3	0.329 (0.03)	0.527 (0.56)	0.616 (0.12)
	PO	75.92±23.47	67.34±21.49	11	15.9, 65.4	93.90±66.24	65.54±33.18	30	34.9, 100.7	0.123 (0.20)	0.421 (0.13)	0.401 (0.10)
GasM (%MVIC)	LR	57.59±15.20	40.57±20.10	30	-18.6, 12.7	69.21±20.10	65.86±34.84	5	-15.1, 5.8	0.193 (0.31)	0.017* (0.66)	0.378 (0.17)
	MS	69.29±16.51	84.81±52.12	22	-42.4, 18.7	61.95±15.97	48.08±32.54	22	-11, 46.9	0.926 (0.26)	0.008* (0.50)	0.111 (0.18)
	PO	57.08±21.30	61.72±30.11	8	-25.8, 46.3	57.90±45.98	54.28±23.67	6	-13.7, 22.1	0.948 (0.00)	0.723 (0.56)	0.594 (0.32)
VL (%MVIC)	LR	31.91±25.68	28.83±24.23	10	-20.7, 13.6	43.07±24.60	68.67±34.22	85	-30.5, 1.1	0.089 (0.03)	0.004* (1.23)	0.033* (0.88)
	MS	53.63±85.18	85.15±54.66	59	-24.6, 52.4	56.25±6.55	47.25±16.56	16	0.3, 106.1	0.424 (0.35)	0.227 (0.62)	0.156 (0.44)
	PO	61.88±14.57	45.30±35.87	27	-32.3, 163.3	55.16±10.58	28.05±18.45	49	-24.9, 98.3	0.001* (1.16)	0.079 (0.24)	0.319 (0.29)
VM (%MVIC)	LR	63.89±16.49	23.38±21.20	63	-6.2, 37.5	58.11±21.20	40.60±31.87	30	-30.8, 7.8	0.001* (0.83)	0.346 (0.36)	0.043* (0.70)
	MS	72. 35±46.33	20.66±7.96	71	-14.3, 14.7	75.67±33.69	30.37±9.84	60	-6.8, 15.8	0.001* (1.05)	0.431 (0.19)	0.675 (0.42)
	PO	64.39±16.53	25.32±16.68	61	-5.9, 1.2	25.32±16.67	32.22±20.48	27	-2.2, 6.6	0.001* (1.26)	0.993 (0.16)	0.159 (0.08)
RF (%MVIC)	LR	25.12±7.39	24.84±3.87	1	-4.6, 8.2	23.95±6.11	45.15±31.72	89	-9.9, -0.6	0.015* (1.32)	0.059 (0.00)	0.013* (0.88)
	MS	21.77±4.47	22.11±4.42	2	-18.9, 11.6	24.10±9.92	27.60±6.59	15	2.2, 27.1	0.242 (0.51)	0.059 (0.39)	0.334 (0.52)
	PO	68.77±16.36	25.39±5.36	63	-53, 43.3	65.10±4.59	26.91±5.86	59	-12.6, 21	0.001* (1.23)	0.675 (0.39)	0.307 (0.19)
BF (%MVIC)	LR	55.39±10.98	49.44±30.29	11	-9.5, 25.9	56.53±11.44	28.54±17.82	50	-15.5, 20.1	0.004* (3.22)	0.053 (0.08)	0.052 (0.20)
	MS	42.81±23.14	30.98±16.10	28	-45.7, 46.4	58.01±44.43	30.52±10.72	47	-83, 43.4	0.005* (0.81)	0.354 (0.40)	0.237 (0.40)
	PO	58.57±20.90	40.77±29.15	40	-15.6, 20.4	40.77±29.15	19.30±9.28	53	-6, 29.4	0.001* (1.31)	0.043* (0.89)	0.072 (0.24)

Parameter		CG		Δ (%)	95% CI	IG		Δ (%)	95% CI	P (Effect Sze Cohen's d)		
		Pre-test	Post-test			Pre-test	Post-test			Main Effect: Time	Main Effect: Group	Interaction: Group × Time
ST (%MVIC)	LR	42.31±21.57	44.15±27.32	4	-11.9, 12.9	39.57±23.38	23.49±10.98	41	1.5, 93.2	0.156 (1.56)	0.087 (0.42)	0.078 (0.37)
	MS	61.34±30.25	28.25±16.74	54	-4.5, 95.9	73.19±51.35	32.82±13.98	55	15.3, 66.1	0.001* (0.91)	0.371 (0.18)	0.649 (0.09)
	PO	92.80±52.16	38.34±28.45	60	-15.9, 142.5	52.98±29.52	37.11±14.48	47	-7.9, 56.8	0.001* (1.71)	0.196 (0.26)	0.018 (0.99)
GlutM (%MVIC)	LR	36.10±19.07	46.71±27.99	29	-19.7, 69	36.53±20.62	52.91±32.62	45	-0.5, 58.8	0.045* (0.61)	0.653 (0.09)	0.656 (0.09)
	MS	80.09±43.84	30.20±13.07	62	5.7, 0.5	65.50±44.95	31.96±24.74	51	-7.9, 8.5	0.002* (1.27)	0.404 (0.17)	0.509 (0.13)
	PO	70.24±46.77	51.64±31.63	26	-19.7, 6.9	44.47±22.23	24.17±12.20	69	-0.5, 58.8	0.031* (0.89)	0.643 (0.47)	0.921 (0.03)

PHYSICAL TREATMENTS

Abbreviations: TA: Tibialis anterior; Gas-M: Gastrocnemius medialis; BF: Iceps femoris; ST: Semitendinosus; VL: Vastus lateralis; VM: Vastus medialis; RF: Rectus femoris; Glut-M: Gluteus medius; IG: Intervention group; CG: Control group; CI: Confidance interval; LR: Ligament reconstruction.

*P<0.05.

The results showed that time had a significant main influence on Fy_{PO} (P<0.001; d=0.90). A pairwise comparison showed that the post-test Fy_{PO} was significantly lower than the pre-test. Furthermore, Fy_{PO} and Fy_{HC} showed significant group-by-time interactions (P<0.019; d=0.49-0.66) (Table 2). Fy_{HC} and Fy_{PO} significantly increased in the CG but not in the IG, according to posthoc analysis.

For VM during loading, mid-stance, and push-off, RF during loading, BF during loading, mid-stance, and push-off phases, ST during mid-stance and push-off, and Glut-M during loading, mid-stance, and push-off phases, the results showed a substantial main effect of time (P<0.045; d=0.61-3.22). When comparing the pre-test and post-test data, it was evident that more VM activity was significantly observed during the loading,mid-stance, and push-off phases. Additionally, a paired-wise comparison showed that more RF activity was significantly observed throughout the loading and push-off phases in the pre-test than in the post-test. When comparing the pre-test and post-test pairwise, it was evident that the BF activity throughout the loading, mid-stance, and push-off phases had significantly increased. Additionally, a paired-wise comparison showed significantly greater ST activity throughout the push-off phase and mid-stance in the pre-test than in the post-test. Additionally, a paired-wise comparison showed that the pre-test and post-test Glut-M activity significantly increased throughout the loading, mid-stance, and push-off phases.

Group-by-time interactions were significant for VL, VM, and RF activities during the loading phase (P<0.043; d=0.50-1.23) (Table 3). Greater Gas-M activities were shown in the post-test in the IG during the loading and mid-stance stages, but not in the CG. Moreover, a paired-wise comparison showed higher VL activity during the loading stages in IG but not in the CG. Also, post-hoc analysis showed greater RF and BF activities during the push-off phase at IG but not in the CG. Significant group-by-time interactions were observed for VL, VM, and RF activities during the loading phase (P<0.043; d=0.70-0.88). In IG, but not CG, post-hoc analysis revealed higher VL activity at the post-test than at the pre-test. Additionally, post-hoc analysis revealed that VM activity at post-test was lower in CG than in IG. Additionally, post-hoc analysis revealed that RF had higher activities in IG at the post-test compared to the pre-test.

Discussion

This study was conducted to assess the long-term effects of sand training on certain lower limb muscle activities in OPF patients.

Our results demonstrated a significant increase for Fy_{HC} and Fy_{PO} in CG but not in the IG. To the authors' knowledge, no research has examined how long-term sand training affects walking kinematics in people with both ACLR and OPF. Our results demonstrated that sand training maintained GRF components after 8 weeks of training, while Fy_{HC} and Fy_{PO} changed in CG after 8 weeks of training on a stable surface. However, further study is warranted to better establish this issue. Research suggests that walking barefoot activates plantar cutaneous mechanoreceptors, especially on uneven ground like sand [42]. Better pronation control and a potential decrease in GRFs can result from the increased afferent input [43]. However, this is conjectural and requires confirmation in additional research. Our results showed that, in people with ACLR and pronated feet, exercise on sand may reduce the peak impact of Fy_{HC} and Fy_{PO} during walking on stable ground. As a result, the exercise regimen in place may help to prevent injuries. Future research should examine whether exercising regularly on sand lowers the risk of injury.

The results showed decreased activities for VM during the loading phase at the post-test compared to the pre-test in CG but not in IG. To the authors' knowledge, no research has examined how long-term sand training affects muscle activity in people with both ACLR and OPF. A previous study showed higher VM and VL amplitudes in subjects with patellofemoral pain syndrome from patella instability and concluded that greater EMG activity reflected knee extensor weakness [46]. Therefore, lower VM during the loading phase at the post-test than in the pre-test in CG may be due to an increase in VM muscle strength and a stable surface. Also, the results showed greater RF and BF activities during the push-off phase at IG but not in the CG. Compared to healthy persons, prior research found that ACLR individuals had higher co-contraction ratios of the hamstrings-quadriceps and lower peak anterior–posterior shear force during a drop jump [47]. The biceps femoris is a major synergist of the ACL which operates to increase joint stability at the loading phase to decrease tibial translation [49, 50]. In ACLR individuals, the two quadriceps muscles have greater activity and the biceps femoris have less activity than normal subjects [51].

Conclusion

For example, in fully grown guys with repaired ACLs and pronated feet when walking, sand training enhanced the activation of the vastus lateralis muscle.

It is essential to recognize some of the current study's shortcomings. First off, since we did not evaluate healthy control subjects, we cannot conclude that the non-OPF walking should follow the same methods. Second, we did not evaluate kinematic data.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Baqiyatallah University of Medical Sciences (Code: IR.BMSU.BAQ.REQ.1399.050) and the study's protocol was registered by the Iranian Registry of Clinical Trials (IRCT) (Code: IRCT20200912048696N1). Before the study, each subject confirmed a written consent form.

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Authors' contributions

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

Conflict of interest

The authors declared no conflict of interest.

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