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Title: The Effect of Sand Surface Training on Knee and Ankle Co-Contraction in Individuals with Pronated Feet and Anterior Cruciate Ligament Reconstruction During Gait Analysis: A Randomized Controlled Trial

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Abstract

Background: The human skeletal-muscular system operates as an interconnected framework, meaning changes in one part can influence other areas and potentially disrupt fundamental motor skills like walking .The purpose of this study was to assess the impact of sand surface training on the co-contraction of knee and ankle muscles in individuals with pronated feet and anterior cruciate ligament reconstruction (ACLR) during walking.

Methods: Twenty-eight adult males with pronated feet and ACLR were divided into two equal groups (intervention and active control groups). Participants were instructed to maintain a steady pace of approximately 1.2 m/s along an 18 m pathway. Muscle activities were monitored through a surface bipolar electromyography system before and after the test. The intervention cohort participated in an eight-week sand-based walking training regimen, incorporating consistent jogging, long-stride walking, bounding movements, galloping, and brief sprints, conducted three times weekly. Conversely, the control cohort completed a comparable training protocol on a stable surface.

Findings: Results revealed significantly greater directed knee flexor/extensor co-contraction during the loading phase (p=0.010) in the intervention group (but not in the control group). Furthermore, findings revealed a substantial decrease in directed knee mediolateral muscle concomitance during the propulsion phase in the IG (but not in the CG) (p=0.001).

Conclusion: In accordance with our results, it could be concluded that sand training may knee joint co-contraction pattern in adult males with pronated feet and ACLR.

Keywords: EMG, Motion correction, contraction, walking

Highlights

This research utilized biomechanical analysis to evaluate how sand surface training affects knee and ankle co-contraction in individuals with pronated feet and those recovering from anterior cruciate ligament reconstruction.

Findings indicate that participants experienced significant changes in muscle activation patterns, suggesting improved joint stability during walking.

Sand training demonstrated a notable enhancement in proprioception and coordination, potentially aiding rehabilitation in individuals post-ACL reconstruction.

The results highlight the effectiveness of sand surface training as a rehabilitation method, encouraging its incorporation into therapeutic protocols for those with pronated feet and ACL injuries.

Plain Language Summary

This research explores how training on sand affects the muscles around the knee and ankle in people with flat feet and those recovering from knee surgery. The study found that this type of training can improve muscle coordination and stability when walking, which may help in recovery after surgery. The findings suggest that using sand for exercise could be beneficial for rehabilitation and should be considered in recovery programs for these individuals.

Introduction

Anterior cruciate ligament (ACL) tear is very prevalent (1). The human skeletal-muscular system operates as an interconnected framework, meaning changes in one part can influence other areas and potentially disrupt fundamental motor skills like walking (2, 3). Walking is a primary function of the lower body, involving tasks such as absorbing the impact forces from foot strikes, maintaining stability, and generating forward propulsion. These actions are crucial for forming a coordinated and efficient walking pattern (3, 4).

Research indicates that natural walking relies on neural control, muscle force production, and an adequate range of motion. Disruptions in any of these factors can lead to abnormal gait patterns (5). Abnormal gait, in turn, can cause various issues in the lower limbs, with foot pronation being one potential factor that increases the risk of walking-related injuries. Anterior Cruciate Ligament Reconstruction (ACLR) surgeries are commonly required for ACL injuries, with over 175,000 procedures performed annually in the U.S. The incidence of ACLR has increased from 32.94 per 100,000 person-years in 1994 to 43.48 per 100,000 by 2006. Similarly, annual rates of ACLR from 2004 to 2007 in Scandinavian countries were 32, 34, and 38 per 100,000 person-years for Sweden, Norway, and Denmark, respectively. Despite advancements in surgical techniques that effectively restore knee function, ACLR patients face an elevated risk of developing early-onset knee osteoarthritis (OA) (6, 7).

The precise mechanisms contributing to the elevated susceptibility to OA in individuals who have undergone ACLR remain uncertain. Nevertheless, the augmented risk of knee OA in this particular group could potentially be attributed to the abnormal elevation in joint compressive force induced by altered neuromuscular strategies. Studies have documented specific adaptations in gait mechanics following ACLR, including reductions in internal knee extensor moments(8, 9) and increased internal hip extensor moments (4, 10). These biomechanical modifications may represent compensatory movement strategies employed to safeguard the reconstructed knee joint. Concomitantly, these adaptations may be accompanied by alterations in neuromuscular activity patterns. Individuals who underwent ACLR demonstrated increased hamstring activity and concurrent activation of both quadriceps and hamstring muscles during various functional movements, including running, jumping, and walking (11-13). The augmentation of muscle co-contraction has been shown to elevate the tibiofemoral compressive force within a simulated knee model with ACL deficiency (14). This muscle recruitment pattern—frequently observed in people who have undergone ACL reconstruction (ACLR)—is thought to enhance joint stability and lessen anterior shear forces on the knee by creating a posterior shear force through the hamstrings (۱۵). Thus, one possible explanation for the improved compressive pressures at the tibiofemoral joint is the greater co-contraction of muscles seen in ACLR patients (۱۵).

Overpronation of the foot is considered a risk factor for ACL injuries, and it is common in the general population (16, 17). Beckett et al. (2018) established a direct correlation between ACL tears and excessive pronation of the subtalar joint (18). There is clear evidence suggesting that the combination of excessive internal rotation of the tibia and overpronation of the feet can generate twisting forces, resulting in more forces on the knee (19).

According to a recent comprehensive review and meta-analysis, gait retraining shows promise as a treatment for decreasing foot pronation (20). Research suggests that walking barefoot activates plantar cutaneous mechanoreceptors, especially on uneven ground like sand (21). Our results showed that, in people with ACLR and pronated feet, exercise (22). The current study's researchers did not encounter any existing research exploring the impact of exercise on a sand surface on muscle co-contraction in individuals with pronated feet and ACLR during walking. Therefore, it's important to find efficient therapy modalities to enhance muscular co-contraction in people with ACLR and pronated feet. Therefore, it's important to find efficient therapy modalities to enhance muscular co-contraction in people with ACLR and pronated feet. Therefore, the purpose of this study was to evaluate how sand surface training affects the co-contraction of the knee and ankle muscles in people who have pronated feet and ACLR while they walk. We hypothesize that sand training could decrease directed ankle and knee joint co-contraction at the loading phase in both sagittal and frontal planes.

Methods

Study design and participants

A randomized controlled trial was used in this investigation (Fig 1). A one-tailed preliminary power analysis was performed with the free G*Power software. For the power analysis, the F-test family—particularly the ANOVA repeated measures within/between interactions—was employed. The foundation of this analysis was a related study (23). The power analysis demonstrated at least 28 samples were needed for this study design. Due to difference in walking biomechanical characteristics in accordance with the gender, only males were used in the present study. A total of 28 male individuals aged 22-25 with a history of ACLR volunteered to participate. A random assignment was employed to distribute the participants into two groups:

An intervention group (N=14), and a control group (N=14), and a control group (CG) also consisting of 14 individuals. The study participants were divided into these experimental groups using the block randomization approach with a block size of 4. The participants were blinded to their respective group allocation, and the examiners responsible for data collection remained unaware of the group assignments.

The study received ethical approval from the local ethics committee (IR.BMSU.BAQ.REC.1399.050) prior to its commencement. Moreover, IRCT20200912048696N1, the Iranian Clinical Trial Organization, has the study registered. Before they participated in the trial, all subjects provided written informed consent. The research followed the guidelines of the CONSORT Statement, as outlined in the Supplementary Document (Appendix 1).

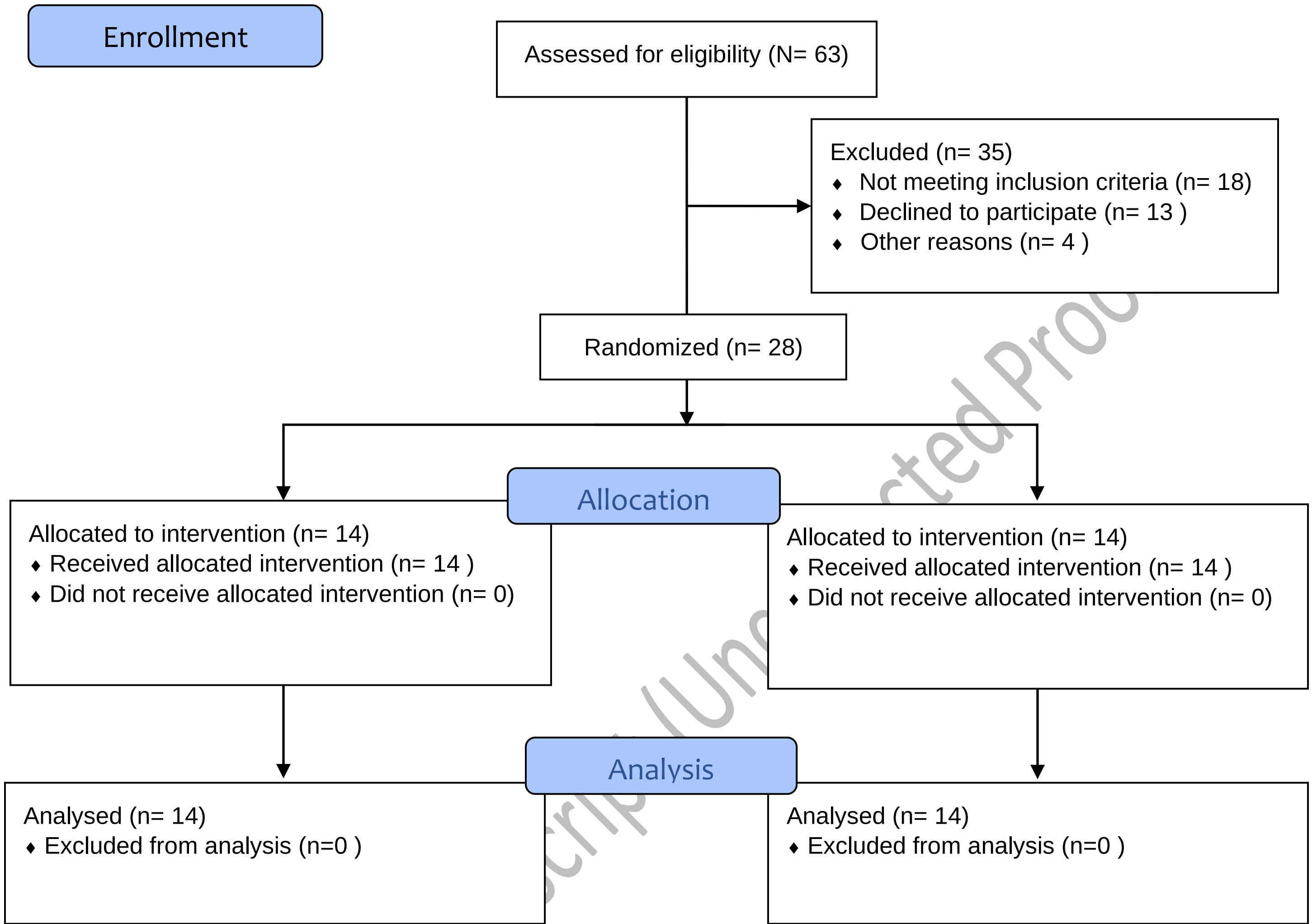

Fig 1. Flowchart of the double-masked, randomized controlled study

Inclusion and Exclusion criteria

The inclusion criteria were: a foot posture index score ranging from 6 to 12, prior ACLR, absence of ankle injury within the preceding six-month period, absence of ankle pain at the time of the study, and capacity to provide informed written consent. A total of sixty-three individuals met these criteria and were enrolled in the study after providing their informed written consent. The rights and well-being of all participants were duly protected throughout the duration of the study.

The exclusion criteria included the ability to walk independently without pain or assistive devices, as well as the presence of cardiac conditions, unstable hypertension, musculoskeletal disorders, or Disabilities resulting from stroke, cerebral palsy, polio, rheumatoid arthritis, the use of prosthetic devices, or moderate to advanced osteoarthritis. Additionally, people who had exercised regularly within the previous six months were not eligible.

Assessment of muscle activities

A wireless electromyography (EMG) system was used to quantify the amount of muscle activity in the right leg, specifically in the rectus femoris (RF), biceps femoris (BF), vastus lateralis (VL), vastus medial (VM), and tibialis anterior (TA). These muscles were selected because they have a critical role in lower limb joints stability and mobility. This system used seven pairs of bipolar Ag/AgCl surface electrodes with a center-to-center distance of 25 mm, an input impedance of 100 MΩ, and a common-mode rejection ratio greater than 110 dB (EMG Preamplifier, Biometrics Ltd., Nine Mile Point Industrial Estate, Newport, UK) (24). The electrodes were securely attached to the patient's muscular bellies using a double-sided adhesive tape that included die-cutting and was appropriate for medical use. After being digitally transformed at a frequency of 1000 Hz, the original EMG signals were Bluetooth-enabled and wirelessly sent to a computer for additional analysis. Following the recommendations of the European Society of Biomechanics for surface electromyography (SENIAM), the skin covering the affected muscles was carefully cleaned and shaved with a 70% ethanol (C2H5OH) solution (25). According to Dugan et al. (2005), Jafarnezhadgero et al., 2019a, 2021a, and Jafarnezhadgero et al., 2021, the walking stance phase has been divided into three separate sub-phases for EMG analyses: The loading response occurs from 0–20% of the gait cycle, followed by the mid-stance phase from 20–47%, and the push-off phase, which spans from 47–70% of the gait cycle (23, 26-29). To standardize the EMG results, the Maximum Voluntary Isometric Contraction (MVIC) of each muscle recorded during walking was measured using a handheld dynamometer. It was recommended that the participants give the tests their all (30). Three test trials were performed, with rest intervals of 1-2 minutes between each trial. An isometric belt set at zero velocity and guaranteed to immobilize joints was used to test MVIC. For normalization, the test's highest recorded MVIC value was used (31).

Biometrics DataLITE software was used to treat the electromyography data, adding a low-pass filter set at 10-500 Hz. The RMS value for each muscle was divided by the corresponding maximum voluntary isometric contraction (MVIC) measurement, and this quotient was then multiplied by 100 to standardize the EMG signals. The following formulas were used to determine general and directed co-contraction values during different walking phases (32).

To determine directed co-contraction, if the mean EMG value of the agonist muscle is greater than that of the antagonist, then directed co-contraction is calculated as:

$$Directed\ muscle\ concomitance = 1 - \frac{antagonist\ mean\ EMG}{agonist\ mean\ EMG}$$

Else

$$Directed\ muscle\ concomitance = 1 - \frac{agonist\ mean\ EMG}{antagonist\ mean\ EMG}$$

$$General\ muscle\ concomitance = The\ sum\ of\ the\ mean\ activity\ of\ all\ muscles$$

In directed muscle concomitance, as the numerical value approaches zero, the level of co-contraction intensifies. Conversely, when the value approaches either 1 or -1, the degree of co-contraction diminishes (32).

Sand walking training protocol

The training regimen included a variety of barefoot workouts, including running nonstop, walking, running in place, galloping, and sprinting short distances. A fifty-minute training session began with a five-minute warm-up and stretching routine, and each session ended with a five-minute warm-down (33). Throughout the sessions, a physiotherapist supervised to ensure proper technique execution and made necessary adjustments to meet the program requirements. The program was the same for both groups, yet the IG group executed it on sand, whereas the CG group performed the task on stable ground surface. Six days following the last training session, post-tests were given to participants to make sure they had fully recovered (34). Throughout the intervention period, participants in both the intervention group (IG) and control group (CG) were instructed not to engage in any other forms of exercise. The training activities that were recommended for both groups included specific exercises aimed at improving their fitness and performance levels, ensuring that they adhered strictly to the prescribed regimen during the study (35).

- Walking, jogging, striding, leaping, galloping, and brief sprints are among the workouts. Each exercise has training characteristics such as duration, intensity, number of repetitions, distance traveled, and rest intervals.
- Walking is performed for 5 minutes. During the first 4 weeks, the intensity is 1.2 m/s, which increases to 1.4 m/s for weeks 5 to 8. The distance covered is 50 meters, and no repetitions or rest periods are specified.
- Jogging lasts for 20 minutes with an intensity of 2.0 m/s during the first 4 weeks, rising to 2.5 m/s in weeks 5 to 8. Similar to walking, the distance is 50 meters, and no repetitions or rest periods are specified.

- Striding is done for 3 minutes, with an intensity of 3.5 m/s in the first 4 weeks and 4.5 m/s for the following 4 weeks. The exercise includes 2 repetitions for the first 4 weeks and 3 repetitions for weeks 5 to 8, with a 1-minute rest after each repetition. The distance covered per repetition is 50 meters.
- Bounding is also a 3-minute exercise with the same intensity progression as striding (3.5 m/s to 4.5 m/s). Similarly, it includes 2 repetitions for the first 4 weeks and 3 for weeks 5 to 8, with 1 minute of rest after each. The distance covered is 30 meters per repetition.
- Galloping follows the same structure as bounding, with a duration of 3 minutes, intensities increasing from 3.5 m/s to 4.5 m/s, 2 repetitions for the first 4 weeks, and 3 for weeks 5 to 8. The distance covered per repetition is 30 meters, with a 1-minute rest period.
- Short sprints last 6 minutes, with the participants running as fast as possible throughout both phases of the program. The first 4 weeks involve 3 repetitions, increasing to 4-5 repetitions for weeks 5 to 8. Each sprint covers 25 meters, with a 2-minute rest between repetitions.

The descriptions of the MVIC tests for TA, Gas-M, BF, ST, VL, VM, and RF muscles were as follows. Throughout the intervention period, participants in both the intervention group (IG) and the control group (CG) were instructed not to engage in any additional exercises. The test protocols for the muscle evaluations are as follows:

- TA: Participants sat in a chair with a backrest, maintaining a 90-degree flexion in the hip, knee, and ankle joints. They were instructed to exert maximal effort in activating the transversus abdominis (TA) against resistance.
- Gas-M: Subjects exerted maximal activation of their plantar flexor muscles against resistance while positioned seated on the examination table, with the hip flexed to a 90-degree angle and both the knee and ankle in a neutral alignment.
- BF: The participants used their hamstring muscles at maximum effort against resistance while sitting on a chair with their knee and hip extended to a 90-degree angle.
- ST: Participants maximally engaged their knee flexors against resistance while sitting with their hips and knees flexed to a 90-degree angle.
- VL, VM, and RF: Participants maximally engaged their knee extensors against resistance while sitting on a chair with their hips and knees flexed to a 90-degree angle.

Statistical analyses

We conducted a within-between repeated measures ANOVA to examine the effects of time (pre vs. post) and group (CG vs. IG) on outcomes. The Bonferroni test was used in post-hoc analysis. Partial eta-squared (η^2p) was transformed into Cohen's d to estimate effect sizes; values less than 0.50, 0.50–0.80, and $d \geq 0.80$ indicate minor effects, medium effects, and large effects, respectively. All analyses were conducted using SPSS version 26.0, with a significance threshold of $p<0.05$.

Results

The general ankle co-contraction during the loading response (p=0.019) and mid-stance phases (p=0.034) at baseline showed significant variations, according to the results (Table 1).

Table 1. Baseline co-contraction data in both groups

Co-contraction	Phase	CG	IG	Sig.
General ankle	LR	112.84 ± 23.23	136.03 ± 25.83	**0.019**
	MS	132.97 ± 11.1	119.69 ± 19.28	**0.034**
	PO	133.01 ± 27.79	151.81 ± 57.43	0.280
Directed ankle	LR	-0.18 ± 0.6	-0.29 ± 0.83	0.692
	MS	-0.19 ± 0.54	-0.07 ± 0.24	0.459
	PO	0.13 ± 0.54	-0.45 ± 2.58	0.419
General knee	LR	276.24 ± 35.12	290.51 ± 26.16	0.234
	MS	321.21 ± 86.32	349.17 ± 111.72	0.465
	PO	415.38 ± 79.18	368.26 ± 63.79	0.095
Knee flexor/extensor	LR	-0.36 ± 0.41	-0.39 ± 0.4	0.830
	MS	-0.3 ± 0.47	-0.24 ± 0.42	0.735
	PO	-0.13 ± 0.25	-0.08 ± 0.3	0.610
Directed knee medio-lateral	LR	-0.29 ± 0.4	-0.04 ± 0.42	0.120
	MS	-0.4 ± 0.53	-0.41 ± 0.74	0.966
	PO	-0.25 ± 0.4	-0.1 ± 0.2	0.215

Notes: CG, control group; IG, intervention group; LR, loading response; MS, mid-stance; PO, push-off.

The findings showed that "Time" had a substantial major impact on the overall muscle concomitance of the knee muscles throughout the loading (p=0.003; η2=0.298), mid-stance (p=0.002; η2=0.305), and push-off (p<0.001; η2=0.840) phases. Additionally, results indicated that "Time" had a significant main influence on directed knee flexor/extensor muscle concomitance during the propulsion phase (p=0.003, η2=0.288) as well as directed knee mediolateral co-contraction during the loading ($p=0.003$, $\eta2=0.285$) and mid-stance ($p<0.001$, $\eta2=0.460$) phases (Table 2).

The results showed that "Group" had a significant main influence on overall knee muscle concomitance during the loading phase ($p=0.012$; $\eta2=0.217$). Furthermore, directed knee flexor/extensor muscle concomitance during the loading phase ($p=0.016$; $\eta2=0.204$) and directed knee medio-lateral muscle concomitance during push-off ($p=0.017$; $\eta2=0.201$) showed significant main effects of "Group" (Table 2).

Directed knee flexor/extensor muscle concomitance during the loading phase ($p=0.010$; $\eta2=0.230$) and directed knee mediolateral muscle concomitance during the propulsion phase ($p=0.001$; $\eta2=0.326$) both showed significant group-by-time interaction (Table 2). Post-hoc analysis revealed significantly greater directed knee flexor/extensor co-contraction during the loading period in the IG (but not in the CG). Furthermore, post-hoc analysis revealed a substantial decrease in directed knee mediolateral muscle concomitance during the propulsion phase in the IG (but not in the CG).

Table 2. Co-contraction data during pre and post-test in both groups.

Co-contraction	Phase	CG		IG		P-value (Eta square)		
		Pre-test	Post-test	Pre-test	Post-test	Main effect: Time	Main effect: Group	Interaction: Group × Time
General ankle co-contraction	PO	133.00 ± 27.79	129.07 ± 40.82	151.81 ± 57.42	119.83 ± 35.75	0.071 (0.120)	0.708 (0.005)	0.154 (0.077)
Directed ankle co-contraction	LR	-0.18 ± 0.60	-0.29 ± 0.83	0.04 ± 0.61	-0.93 ± 0.94	0.327 (0.037)	0.515 (0.017)	0.938 (0.000)
	MS	-0.18 ± 0.53	-0.71 ± 1.18	-0.06 ± 0.24	-0.13 ± 1.34	0.260 (0.049)	0.161 (0.074)	0.382 (0.029)
	PO	0.13 ± 0.53	-0.44 ± 2.5	0.02 ± 0.50	0.001 ± 0.62	0.651 (0.008)	0.412 (0.026)	0.466 (0.021)
General knee co-contraction	LR	276.23 ± 35.11	211.22 ± 55.73	290.51 ± 26.16	272.64 ± 69.88	**0.003 (0.298)**	**0.012 (0.217)**	0.070 (0.121)
	MS	321.20 ± 86.31	272.01 ± 138.90	349.17 ± 111.72	216.67 ± 45.82	**0.002 (0.305)**	0.622 (0.009)	0.134 (0.084)
	PO	415.38 ± 79.18	236.86 ± 101.56	368.26 ± 63.79	197.89 ± 46.39	**P<0.001 (0.840)**	0.089 (0.107	0.787 (0.003)
Directed knee flexor/extensor	LR	-0.35 ± 0.41	-0.20 ± 0.30	-0.38 ± 0.40	0.00 ± 0.88	0.315 (0.039)	**0.016 (0.204)**	**0.010 (0.230)**
	MS	-0.29 ± 0.47	-0.51 ± 0.72	-0.23 ± 0.42	-0.10 ± 0.47	0.776 (0.003)	0.088 (0.108)	0.249 (0.051)
	PO	-0.13 ± 0.25	-0.71 ± 0.65	-0.07 ± 0.30	-0.48 ± 0.82	**0.003 (0.288)**	0.340 (0.340)	0.565 (0.013)
Directed knee medio-lateral	LR	-0.28 ± 0.40	-0.00 ± 0.51	-0.03 ± 0.42	0.27 ± 0.35	**0.003 (0.285)**	0.055 (0.134)	0.894 (0.001)
	MS	-0.39 ± 0.52	0.24 ± 0.45	-0.40 ± 0.73	0.15 ± 0.26	**P<0.001 (0.460)**	0.741 (0.004)	0.760 (0.004)

	PO	-0.24 ± 0.40	0.17 ± 0.34	-0.09 ± 0.18	-0.92 ± 1.22	0.253 (0.050)	**0.017 (0.201)**	**0.001 (0.326)**

Notes: CG, control group; IG, intervention group; LR, loading response; MS, mid-stance; PO, push-off.

Covariate analysis showed greater general ankle co-contraction at post-test during loading phase in IG than that CG (p=0.012) (Table 3).

Table 3. Results of Covariate test

Co-contraction	Phase	CG	IG	sig
General ankle	LR	91.15 ± 22.29	135.53 ± 46.57	**0.012**
	MS	140.51 ± 64.79	103.26 ± 40.79	0.708

Notes: CG, control group; IG, intervention group; LR, loading response; MS, mid-stance.

Discussion

This study aimed to assess the effects of sand surface training on the co-contraction of the knee and ankle muscles in individuals with pronated foot and ACLR during gait. Overall, the findings demonstrated that: I) directed knee flexor/extensor co-contraction increased significantly during the loading phase in the IG; II) directed knee mediolateral co-contraction significantly decreased during the push-off phase in the IG; and III) The overall activation of ankle muscles during the loading phase was higher in the intervention group than in the control group after the post-test.

Our research results indicated that training on sand had no significant impact on overall knee co-contraction while walking. Knee muscle co-contraction serves as a mechanism to modify joint stability and articular loading (36). There are two primary forms of knee muscle co-contraction: generalized and directed co-contraction (37). In generalized co-contraction both agonist and antagonist muscles of the knee are activated equally, potentially impacting articular loading. (38, 39). Notably, our research demonstrated a significant increase in directed knee flexor/extensor co-contraction during the loading phase in the IG, while such increase was not observed in the CG.

The results show a significant reduction in mediolateral knee muscle co-contraction during the propulsion phase in the exposure group compared to the control group. This specific form of co-contraction involves the simultaneous activation of both medial agonist and antagonist muscles to assist the lateral muscles in generating adduction moments. It is believed that purposeful co-contraction aids in maintaining the external moment, thereby preventing condylar lift-off and reducing the load concentration on the medial knee compartment (40). Our findings indicate that training in sand may help decrease articular stress in the medial knee region. In line with our results, other researchers have suggested that exercises aimed at lowering co-contraction could be beneficial in reducing joint load, due to its potential adverse effects on knee stress and disease progression (41, 42).

Muscle co-contraction increases the stiffness of the joint(s) around which the muscles act (43). During novel situations in which the postural control system is challenged, increased co-contraction may be employed as a strategy to reduce the degrees of freedom that the postural control system is responsible for organizing (44), thereby stabilizing the body's centre of mass movement and increasing postural stability (45). However, high levels of co-contraction require greater energy expenditure (46), reducing the efficiency of the movement (47) and contributing to fatigue and potentially injury (48). In addition, the increased joint rigidity resulting from co-contraction may hinder the execution of accurate balance reactions, and/or the ability to update movement strategies quickly (49).

The findings revealed a greater general ankle co-contraction during the loading response in the post-test in the IG compared to the CG. TA and GL are key muscles involved in lifting and lowering the foot during the gait cycle(50, 51). In line with previous studies, TA and GL exhibited significant variability in activation patterns while walking, including the frequency of each activation mode. Both TA and GL were observed to use different activation modalities from one stride to the next. During mid-stance, the ankle's antagonistic pair does not function in their usual opposing manner; rather than acting solely as an ankle dorsiflexor, research indicates that TA behaves more like an inverter of the foot (52). The TA and GL muscles collaborate synergistically to regulate the movement of the tibia over the talus bone in the ankle joint. During walking when the contralateral limb is swinging forward, the TA and GL help decelerate the lower limb's displacement and maintain balance (53). Our findings demonstrated that running sand training increased general ankle co-contraction during loading response at post-test due to training induced adaptation. Our study results are consistent with earlier research, which found that the short foot exercise—functioning through similar mechanisms as sand training for activating foot muscles—was more effective than traditional methods (54). The intrinsic muscles of the lower limb play an important role in energy transfer and force production during dynamic activities. These small but powerful muscles act across the joints of the foot and ankle to provide stabilization and precise movement. Thus, sand training, which strengthens the intrinsic muscles, not only boosts the medial longitudinal arch and stability but also enhances energy transfer throughout the lower limb (55).

The study has certain limitations that warrant attention. We examined the long-term effects of walking on sand for males with pronated feet and patients who have undergone ACL reconstruction (ACLR). Therefore, it is not possible to extrapolate our findings to females.

Future research is required to determine whether sand walking is a preventive or therapeutic strategy for females with pronated feet. The current study did not look at walking kinematics. Consequently, it is recommended that upcoming studies investigate how sand-based training influences lower limb movement patterns while walking.

Conclusions

Based on our findings, we can conclude that sand training may influence the knee joint co-contraction pattern in adult males with pronated feet and those who have undergone. Overall, this study highlights the potential benefits of sand surface training in modulating muscle co-contraction in individuals with pronated feet and ACL reconstruction during gait. The findings demonstrate that sand training significantly increased directed knee flexor/extensor co-contraction during the loading phase and reduced mediolateral knee co-contraction during the push-off phase, potentially decreasing medial knee compartment stress. Additionally, sand training enhanced general ankle muscle co-contraction during the loading response, suggesting improved stability and energy transfer within the lower limb. These outcomes emphasize the role of sand training in strengthening intrinsic foot and ankle muscles, thereby contributing to joint stability and dynamic movement efficiency.

Competing interests

None.

Declarations of interest

None.

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