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Article

Impact of various training programs on lower limb biomechanics in adolescent Latin dancers

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Abstract: Latin dance attracts many young dancers globally. While these adolescents exhibit flexibility and imitation skills, their muscular strength and neuromuscular control often fall short, making complex movements challenging. Thus, incorporating functional training methods is essential for enhancing performance and reducing injury risk. This study, a total of 30 adolescent female Latin dancers aged 12–14 years with at least one year of training and competition experience were recruited for this study and randomly divided into two groups: One group of 15 students (average height 154.37 ± 3.82 cm, average weight 45.31 ± 5.29 kg) received traditional Latin dance training, and the other group of 15 students (15 students average height 154.73 ± 4.28 cm, average weight 44.63 ± 4.37 kg) received traditional Latin dance training and based on traditional Latin dance training, functional exercise was carried out for 12 weeks. A Vicon motion capture system, force platform, and electromyography were used to collect biomechanical data. Paired samples *t*-tests assessed significant differences between groups pre- and post-intervention. The experimental group showed significant improvements post-intervention: in the sagittal plane, ankle joint angles improved by 14.01% to 52.21% ($p < 0.001$); in the coronal plane, knee joint angles increased by 0% to 31.21% ($p < 0.001$) and 66.67% to 100% ($p < 0.001$); in the horizontal plane, hip joint angles improved by 4.99% to 76.00% ($p < 0.001$). Muscle activation showed significant increases in gastrocnemius lateral ($p = 0.016$), gluteus maximus ($p = 0.001$), tibialis anterior ($p = 0.014$), and rectus femoris ($p < 0.001$). Functional training enhances joint flexibility, muscle activation, balance, and overall performance in adolescent Latin dancers. Integrating functional training into regular routines can improve athletic performance and lower injury risk, informing the development of targeted training programs.

Keywords: functional training; adolescent Latin dancers; lower limb biomechanics; muscle activation; injury prevention

1. Introduction

As a highly captivating and visually compelling performance art, Latin dance has garnered a vast following of enthusiasts from around the globe [1]. It encompasses five distinct styles: Rumba, Cha-cha, Samba, Paso Doble, and Jive, each characterized not only by its unique rhythm but also by its distinctive style and flair [2–4]. Through precise movements, dancers embody the beats and rhythms of the music, conveying a rich spectrum of emotions with a passionate and compelling intensity [5]. Latin dance emphasizes the seamless fusion of movement and music, where each gesture is meticulously crafted to amplify the musical expression, offering the audience a dual sensory experience of both sight and sound.

Adolescents constitute a pivotal segment within the dancer community [6–8].

Their high plasticity, learning ability, and remarkable capacity for imitation enable them to swiftly master the fundamental techniques of Latin dance and demonstrate significant progress in a short period. For adolescents, who are in a critical phase of physical development, their bones, muscles, and joints exhibit heightened flexibility and adaptability during this period of rapid growth [9]. Thus, they are well-positioned to grasp and master the intricate movements of Latin dance. However, despite their considerable flexibility, adolescents' muscle strength and neuromuscular control are not yet fully developed. Consequently, certain complex techniques requiring substantial core strength and high stability may present significant challenges for them.

From a biomechanical perspective, Latin dance places significant physical demands on dancers, particularly in terms of balance, flexibility, coordination, core strength, and lower limb control [10,11]. In Latin dance training, a dancer's balance, coordination, and core control are crucial factors that determine the execution and quality of their movements [12]. Since adolescents are still developing their sense of balance and stability, they may experience instability when performing complex movements, such as the high-speed rotations in Paso Doble or the rapid step transitions in Samba. These deficiencies represent key challenges for young dancers and are a primary cause of lower limb injuries. Therefore, scientifically structured training methods are essential in addressing these issues.

Functional training has been widely adopted across various sports disciplines as an effective method for enhancing athletic performance and preventing injuries [13–15]. Through targeted training regimens, athletes can improve their physical attributes, strengthening lower limb stability, coordination, and power, thereby extending their athletic careers [16]. Considering the unique physical characteristics of adolescent dancers, functional training can significantly improve their core strength, balance, and stability. This training not only supports youth dancers in executing the complex movements inherent to Latin dance but also reduces the risk of injuries associated with inadequate muscle strength or unstable movements. In the context of youth dance training, systematic biomechanical assessments are essential for ensuring the effectiveness and safety of training protocols. By monitoring the biomechanical parameters of dancers' lower limbs, coaches can gain valuable insights into muscle activation levels and joint conditions, allowing them to tailor training programs accordingly [7,17,18]. For instance, Latin dance frequently requires substantial trunk rotation and hip twisting. Through biomechanical monitoring, coaches can develop specialized training plans to enhance adolescent performance in these specific areas. Furthermore, ongoing assessments enable coaches to evaluate training progress, optimize programs, and ensure continuous improvement in dancers' technical abilities.

Relying exclusively on specialized training may be insufficient for effectively preventing sports injuries and achieving significant performance improvements. This study posits that the integration of functional training is likely to yield superior outcomes. To test this hypothesis, adolescent dancers will be divided into two groups: one will engage exclusively in Latin dance training, while the other will incorporate physical conditioning into their regimen over a 12-week intervention period. By monitoring biomechanical indicators of the lower limbs in both groups, this study aims to elucidate performance differences. The results are expected to provide coaches with personalized training recommendations that enhance dance skills. This comprehensive approach not only equips adolescents with both theoretical knowledge and practical experience but also establishes a robust foundation for their future careers in dance. As training methodologies evolve, the interplay between biomechanics and functional training is likely to create new opportunities and perspectives for the future development of Latin dance.

2. Methods

2.1. Population and sample group

Before recruiting subjects, this study used G*Power 3.1 software to calculate the appropriate sample size for the experiment. Based on the calculation results and previous related research, a total of 30 subjects were recruited for this experiment. According to the results, this study recruited a total of 30 adolescent female Latin dance students from Chunhui Latin Dance Training School in Ningbo and randomly divided them into two groups: an experimental group with 15 students and a control group with 15 students. The inclusion criteria were: (1) girls aged 12–14; (2) at least one year of professional Latin dance training; (3) at least one competition experience; (4) healthy with no upper or lower limb injuries in the past six months. The experimental group had an average height of 154.37 ± 3.82 cm and an average weight of 45.31 ± 5.29 kg, while the control group had an average height of 154.73 ± 4.28 cm and an average weight of 44.63 ± 4.37 kg. Data showed normal distribution, and independent sample *T*-test analysis revealed no significant differences in height, weight, or BMI between the experimental and control groups ($P < 0.05$). Participants' basic information is summarized in **Table 1**. The study received approval from the Ethics Committee of Ningbo University (Protocol Code: RAGH20230901).

Table 1. Basic information of subjects (Mean ± SD).

	N	**Height (cm)**	**Weight (kg)**	**BMI**
Experimental group	15	154.37 ± 3.82	45.31 ± 5.29	19.02 ± 2.14
Control group	15	154.73 ± 4.28	44.63 ± 4.37	18.61 ± 1.21
T		−0.247	0.380	0.639
P		0.806	0.707	0.528

2.2. Training program

2.2.1. Basic Latin dance training program (control group)

Through field research in several representative Latin dance training institutions in Ningbo, the study identified the traditional training methods commonly used. This led to the establishment of a basic Latin dance training program for adolescents. (**Tables 2–4**).

1) Phase One

Table 2. Dance training stage training content (Weeks 1–4).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Warm-up	Jogging	None	1	5 min	60
Stretching Exercises	Reverse Shoulder Stretch Trunk Side Bend Trunk Rotation Forward Bend in Lunge (Great Stretch) Side Lunge Squat Single Leg Standing Leg External Rotation	None	1	5 min	60
Learning Latin dance skills	Forward walk Back walk Forward Triple Step Forward walk, backward walk, forward triple step combination	None	2 2 2 4	45 min	60

2) Phase Two

Table 3. Training content for advanced stage (Weeks 5–8).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Warm-up	Jogging		1	5 min	60
Stretching Exercises	Reverse Shoulder StretchTrunk Side Bend Trunk Rotation (Left and Right) Forward Bend in Lunge Position (Great Stretch) Side Lunge Squat Single Leg Standing Leg Outward Rotation		1	5 min	60
Learning Latin dance skills	Backward Three-Step Cuban Rock Combination of Backward Three-Step and Cuban Rock	None	2 2 4	45 min	60

3) Phase Three

Table 4. Consolidation training phase (Weeks 9–12).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Warm-up	Jogging			5 min	60
Stretching Exercises	Reverse Shoulder Stretch Trunk Side Bend Trunk Rotation (Left and Right) Forward Bend in Lunge Position (Great Stretch) Side Lunge Squat Single Leg Standing Leg Outward Rotation			5 min	60
Learning Latin dance skills	Forward walk Backward walk Forward triple step Backward triple step Cucaracha Combination of forward walk, backward walk, forward triple step, backward triple step, and Cucaracha	None	1 1 1 1 1 4	45 min	60

2.2.2. Functional Latin dance training program (experimental group)

Developed through expert consultations, this program is divided into three phases over 12 weeks: basic training, improvement training, and consolidation training. The training progresses from simple to complex, small to large, and easy to difficult, with each phase built upon the previous one.

First Phase (weeks 1–4): Basic Training Phase. This phase focuses on foundational learning and adaptation. Comprehensive body training is emphasized, developing both large muscle groups' strength and smaller muscle groups' strength and endurance. Based on the teaching focus of the basic phase of Latin dances such as Rumba walks, speed and strength in competitions, and balance, rotation, and turning requirements in scoring standards—appropriate training content was designed. The selected training activities include stretching exercises, core stability training, lower limb stability training, and basic strength training. Specific details are provided in **Tables 5–7**.

1) Phase One

Table 5. Dance training stage training content (Weeks 1–4).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Warm-up	Jogging	None	1	5 min	60
Stretching Exercises	Reverse Shoulder Stretch Trunk Side Bend Trunk Rotation (Left and Right) Forward Bend in Lunge Position (Great Stretch) Side Lunge Squat Single Leg Standing Leg Outward Rotation	None	1	5 min	60
Learning Latin dance skills	Forward walk	None	2	45 min	60
	Backward walk		2		
	Forward triple step		2		
	Forward walk, backward walk, forward triple step combination		4		
Core stability functional training	quadruped position	None	2	30 s	45
	side plank holds on both sides		2	20 s	45
Lower limb stability functional training	Mini resistance band lateral movements	Resistance band	2	2 × 6 times	45
	Single-leg stance	None	2	30 s	45
Basic strength training	Dumbbell squats	5 kg dumbbell	2	10 times	60
	Medicine ball side toss exercise	2.5 kg medicine ball	2	2 × 6 times	60

2) Phase Two

Table 6. Advanced training stage (Weeks 5–8).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Warm-up	Jogging		1	5 min	60
Stretching Exercises	Reverse Shoulder Stretch Trunk Side Bend Trunk Rotation (Left and Right) Forward Bend in Lunge Position (Great Stretch) Side Lunge Squat Single Leg Standing Leg Outward Rotation		1	5 min	60

Table 6. (*Continued*).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Learning Latin dance skills	Backward Three-Step	None	2	45 min	60
	Cucaracha		2		
	Combination of Backward Three-Step and Cucaracha		4		
Core stability functional training	plank	None	2	20 s	60
	supine leg raise	None	2	2 × 6 times	45
Lower limb stability functional training	Lunge	None	2	2 × 6 times	60
	Straight-leg deadlift	5 kg dumbbell	2	8 times	90
Basic strength training	Rapid arm extension squat with weighted medicine ball	2.5 kg medicine ball	2	10 times	90
	Rapid arm extension squat with weighted medicine ball		2	2 × 6 times	90

3) Phase Three

Table 7. Consolidation training phase (Weeks 9–12).

Training Module	Training Content	Load	Sets	Reps or Time	Rest Between Sets (s)
Warm-up	Jogging			5min	60
Stretching Exercises	Reverse Shoulder Stretch Trunk Side Bend Trunk Rotation (Left and Right) Forward Bend in Lunge Position (Great Stretch) Side Lunge Squat Single Leg Standing Leg Outward Rotation			5 min	60
Learning Latin dance skills	Forward walk	None	1	45 min	60
	Backward walk		1		
	Forward triple step		1		
	Backward triple step		1		
	Cucaracha		1		
	Combination of forward walk, backward walk, forward triple step, backward triple step, and cucaracha		4		
Core stability functional training	Side standing rotation and lateral medicine ball throw exercise	2.5 kg medicine ball	2	2 × 6 times	60
	Forward and backward lunge with 90-degree rotation	None	2	2 × 6 times	60
Lower limb stability functional training	Resisted knee lift	Resistance band	3	2 × 6 times	60
	Resisted knee lift	2 × 2.5 kg	3	2 × 6 times	60
Basic strength training	Dumbbell rotational exercise	2 × 2.5 kg	3	2 × 6 times	60
	Resistance band hip rotation exercise	Resistance band	3	2 × 6 times	60
	Rotational exercise in place	None	3	10 times	60

2.3. Kinesiology, kinetics and muscle activity data collection

All tests were performed in the sports biomechanics lab at the University of Ningbo, Research Academy of Grand Health. The motion capture system used was the Vicon system (Oxford Metrics Ltd., Oxford, UK), equipped with 8 cameras, which were utilized to capture kinematic data of participants during the stop-jumping task. The sampling frequency was set to 200 Hz [19,20]. During the Latin gait task, the force platform (AMTI, Watertown, Massachusetts, USA) was set to a sampling frequency of 1000 Hz to collect kinetic data. Both experimental setups were synchronized. The vertical surface reaction force exceeding 10 N was set as the initial contact [21]. All participants wore tight-fitting shorts and shirts. Consistent with previous research, 38 spherical reflective markers with a diameter of 12.5 millimeters were affixed to each participant to identify movement patterns during each trial [22]. SENIAM guidelines were followed when placing the EMG sensors [23]. Eight electromyography (EMG) sensors (Delsys, Boston, MA, USA) were attached to the muscle bellies of the peroneous longus, medial and lateral gastrocnemius, tibialis anterior, rectus femoris, vastus lateralis, vastus medialis, and biceps femoris to measure muscle activation. Reflective markers were placed at specific anatomical landmarks and EMG on the body, as shown in **Figure 1A**.

Figure 1. (A) Iillustration of placing reflex markers on human skeletal markers and EMG electrodes on human lower limbs; **(B)** illustration of the Rumba Walk test procedure.

Before the formal experiment, subjects were required to wear specialized Latin dance shoes with a heel height of 5.5 cm and tight-fitting clothing, then perform a

10-minute warm-up jog at 8 km/h. The 5.5 cm heel height was chosen because it aligns with the standard heel height used in Latin dance training and competitions. This height is commonly adopted in practice to maintain consistency between training conditions and actual performance scenarios, ensuring that dancers develop proper technique and stability while adapting to the specific posture and biomechanics associated with this type of footwear. Subsequently, subjects need to familiarize themselves with the experimental environment and procedures. In the formal experiment, subjects were required to provide a set of static data. Subjects stood in the anatomical position, stepped onto the force plate upon hearing the command, and prepared to collect data. Following the rhythm of the music, with their hands on their waists, subjects performed the rumba walk from one end of the force plate to the other to collect data. Subjects were specifically instructed to coordinate the contact of their right foot with the force plate on the "two" beats. When collecting surface EMG, excess hair in the test area was removed to reduce impedance at the skin-electrode interface. Throughout the experiment, researchers closely monitored the participants' performance. If participants deviated from the music rhythm or failed to fully place their foot on the force plate, the trial was considered invalid, and repeated measurements were required to ensure data accuracy and reliability (**Figure 1B**).

The kinematics and kinetics data collected from Vicon were exported to C3D file format and then converted to coordinate system, low pass filtered, data extraction, and formatted for kinematic and GRF data using MATLAB (MathWorks, Massachusetts, USA). The C3D files were converted to trc file format and mot file format using MATLAB and imported into OpenSim to calculate biomechanical parameters [24]. OpenSim is an open-source software platform developed by Stanford University for modeling, simulating, and analyzing the musculoskeletal system and movement dynamics. It is widely used in biomechanics research to understand how muscles, bones, and joints interact during different physical activities. Models were scaled based on body measurements to obtain subject-specific models, and a musculoskeletal model with 23 degrees of freedom and 92 muscle actuators were used for all musculoskeletal simulations, comparing distances between two markers on segments measured in the static standing test to distances on the generic model [25]. Subsequently, these scaling factors were applied to adjust segment length, segment inertia properties, and muscle attachment points. Measurements of muscle initiation and insertion points and muscle moment arms were aligned with the participant's limb length. Surface EMG signals were initially band-pass filtered using a fourth-order Butterworth filter over the 10-400 Hz frequency range. This was followed by full-wave rectification and low-pass filtering at a cutoff frequency of 6 Hz [26]. In addition, the EMG signals were normalized by dividing the EMG amplitude by the maximum root-mean-square amplitude and further normalized by MVC to obtain the activation level of each muscle.

2.4. Statistics analysis

Before conducting statistical analysis, the Shapiro-Wilk normality test (IBM SPSS Statistics 26, SPSS Inc., Chicago, IL, USA) was performed on the dataset to assess whether the data conformed to a normal distribution. If the data followed a normal distribution, an independent samples t-test was used to examine whether there were significant differences between the two groups before the intervention. Subsequently, after each group's intervention period, the Shapiro-Wilk normality test was again used to assess the data's normality. Paired samples *t*-tests were then used to analyze whether there were significant differences within each group before and after the intervention. Descriptive statistics were reported as mean ± standard deviation, with statistical significance defined as $\alpha < 0.05$.

3. Result

3.1. Kinematics and kinetics

3.1.1. Comparison of the biomechanics between the experimental and control groups before the intervention experiment

The analysis revealed in the kinematics and kinetics that there was no significant difference between the experimental and control groups during the stance phase before the intervention experiment (**Tables 8** and **9**).

Table 8. Comparison of kinematics (means ± standard) between experimental group and control group during the stance phase.

Parameters	Peak Value	Experimental group Mean ± SD	Control group Mean ± SD	*P*-Value
Ankle Angle (°)	Dorisiflexion	12.34 ± 2.14	11.26 ± 2.50	0.258
	Plantarflexion	−39.01 ± 11.88	−37.50 ± 10.73	0.096
	Inversion	12.05 ± 10.24	15.51 ± 11.09	0.529
	Eversion	−19.13 ± 2.80	−18.24 ± 2.61	0.627
	Ext Rot	12.61 ± 4.56	14.19 ± 5.31	0.475
	Int Rot	−10.07 ± 8.52	−10.80 ± 8.50	0.756
Hip Angle (°)	Extension	31.48 ± 5.76	31.22 ± 5.06	0.561
	Flexion	−18.18 ± 4.31	−18.35 ± 4.70	0.641
	Inversion	18.56 ± 2.37	18.96 ± 1.95	0.095
	Eversion	−14.22 ± 2.56	−12.72 ± 2.41	0.641
	Int Rot	12.05 ± 4.02	10.80 ± 3.97	0.089
	Ext Rot	−24.48 ± 2.68	−24.08 ± 2.99	0.496
Knee Angle (°)	Flexion	1.80 ± 1.51	2.067 ± 1.11	0.443
	Extension	−27.98 ± 8.44	−23.04 ± 9.87	0.242
	Eversion	4.81 ± 2.27	4.25 ± 2.48	0.062
	Inversion	−0.68 ± 0.68	−0.30 ± 0.58	0.503
	Int Rot	9.29 ± 6.49	11.17 ± 3.70	0.523
	Ext Rot	−16.87 ± 6.52	−17.78 ± 2.34	0.377

Table 9. Comparison of kinetics (means ± standard) between experimental group and control group during the stance phase.

Parameters	Peak Value	Experimental group Mean ± SD	Control group Mean ± SD	*P*-Value
Ankle Moment (Nm/kg)	Dorisiflexion	0.13 ± 0.08	0.11 ± 0.09	0.680
	Plantarflexion	−1.40 ± 0.09	−1.38 ± 0.10	0.707
	Eversion	0.52 ± 1.40	0.27 ± 0.09	0.194
	Inversion	−0.20 ± 0.01	−0.02 ± 0.01	0.731
	Ext Rot	0.04 ± 0.03	0.03 ± 0.02	0.488
	Int Rot	−0.29 ± 0.05	−0.29 ± 0.05	0.818
Hip Moment (Nm/kg)	Extension	1.04 ± 0.09	1.04 ± 0.10	0.659
	Flexion	−0.62 ± 0.08	−0.60 ± 0.83	0.809
	Eversion	0.39 ± 0.11	0.38 ± 0.10	0.802
	Inversion	−1.16 ± 0.08	−1.14 ± 0.09	0.453
	Ext Rot	0.13 ± 0.05	0.14 ± 0.05	0.645
	Int Rot	−0.54 ± 0.03	−0.54 ± 0.05	0.899
Knee Moment (Nm/kg)	Extension	0.29 ± 0.03	0.23 ± 0.07	0.113
	Flexion	−0.22 ± 0.04	−0.16 ± 0.10	0.053
	Inversion	0.30 ± 0.05	0.32 ± 0.04	0.550
	Eversion	−0.61 ± 0.07	−0.59 ± 0.66	0.366
	Int Rot	0.02 ± 0.06	0.03 ± 0.02	0.905
	Ext Rot	−0.16 ± 0.03	−0.16 ± 0.34	0.874

3.1.2. Comparison of the control group between pre-intervention and post-intervention

Differences were found between pre-intervention and post-intervention. **Figure 2** shows the difference in ankle joint angle, joint moment between pre-intervention and post-intervention during the stance phase. **Figure 3** shows the difference in knee joint angle and joint moment between pre-intervention and post-intervention during the stance phase. **Figure 4** shows the difference in hip joint angle and joint moment between pre-intervention and post-intervention during descending phase. **Table 10** displays significant differences in ankle Inversion angle ($p < 0.001$), ankle int rot angle ($p = 0.001$); hip inversion angle ($p < 0.001$), hip int rot angle ($p = 0.006$); knee eversion angle ($p < 0.001$). **Table 11** displays significant differences in hip ext rot moment ($p < 0.001$), hip int rot moment ($p = 0.030$).

Ankle angle, moment

The SPM analysis revealed the results of ankle joint kinematics and kinetics during the stance phase, comparing pre-intervention with post-intervention. For the results of the ankle joint in the sagittal plane: In the coronal plane: ankle joint angle (0%–27.23%, $p < 0.001$; 90.57%–100%, $p = 0.007$).

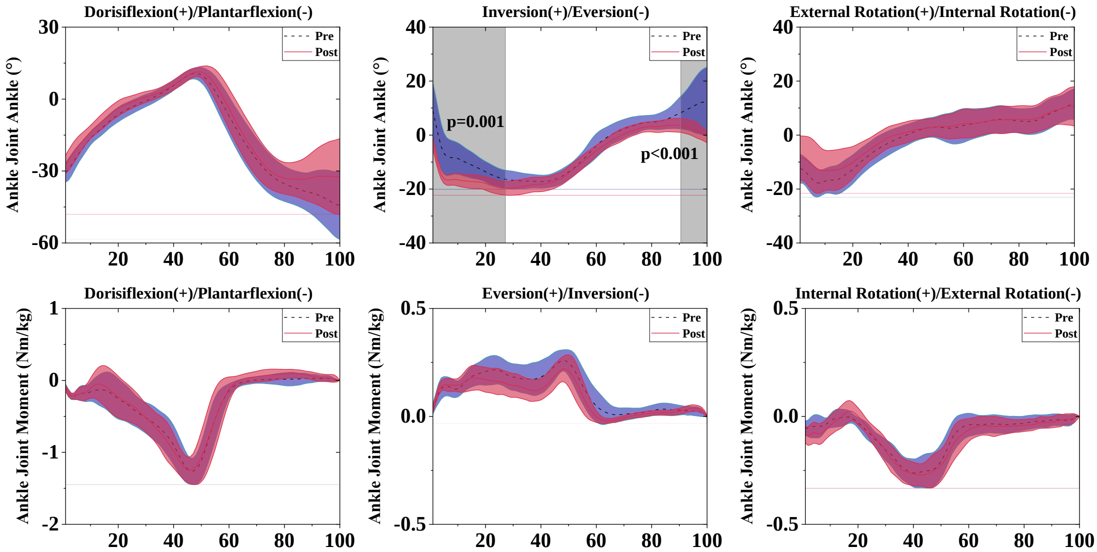

Figure 2. Illustration of the results between the pre-intervention and post-intervention lower limb showing the statistical parametric mapping outputs for the ankle angle, moment during the stance phase.

Knee angle, moment

The SPM analysis revealed the results of knee joint kinematics and kinetics during the stance phase, comparing pre-intervention with post-intervention. For the results of the knee joint in the sagittal plane: In the coronal plane: knee joint angle (0%–3.08%, p = 0.038; 62.99%–66.56%, p = 0.035; 98.63%–100%, p = 0.047); knee joint moment (0.41%–5.48%, p = 0.002; 36.44%–55.99%, p < 0.001; 67.62%–97.36%, p < 0.001). In the Horizontal plane: knee joint angle (83.40%–100%, p < 0.001).

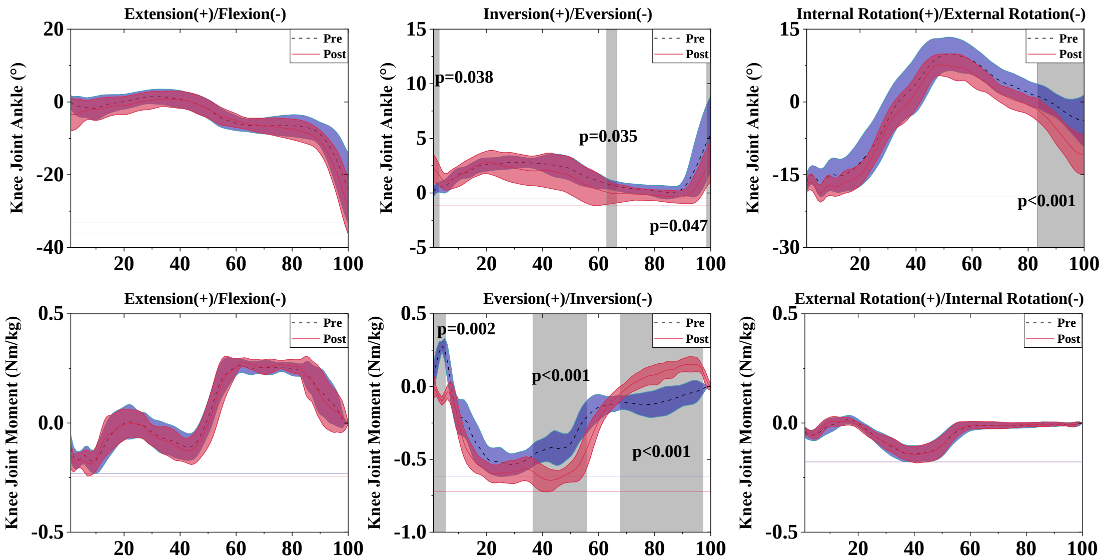

Figure 3. Illustration of the results between the pre-intervention and post-intervention lower limb showing the statistical parametric mapping outputs for the knee angle, moment during the stance phase.

Hip angle, moment

The SPM analysis revealed the results of hip joint kinematics and kinetics during the stance phase, comparing pre-intervention with post-intervention. For the results of the hip joint in the sagittal plane: hip joint angle (0%–18.77%, p = 0.001; 68.11%–97.52%, p < 0.001); hip joint moment (0%–10.57%, p < 0.001; 39.55%–41.44%, p = 0.027; 57.39%–98.73%, p < 0.00). In the Horizontal plane: hip joint moment (2.58%–4.52%, p = 0.032; 82.94%–97.44%, p < 0.001).

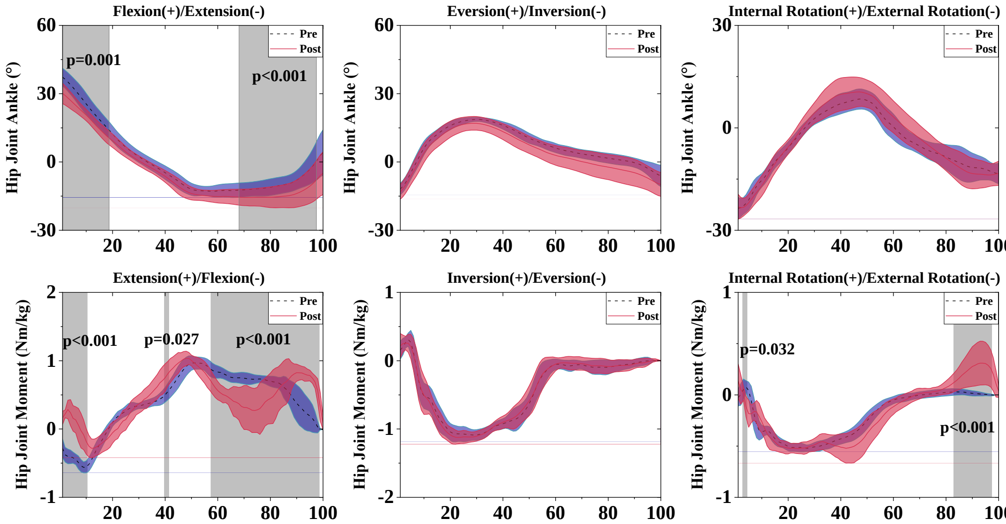

Figure 4. Illustration of the results between the pre-intervention and post-intervention lower limb showing the statistical parametric mapping outputs for the hip angle, moment during the stance phase.

Table 10. Comparison of kinematics (means ± standard) between pre-intervention and post-intervention during the stance phase in the control group.

Parameters	Peak Value	Pre-intervention Mean ± SD	Post-intervention Mean ± SD	*P*-Value
Ankle Angle (°)	Dorisiflexion	11.26 ± 2.50	12.33 ± 1.75	0.064
	Plantarflexion	−37.50 ± 10.73	−38.35 ± 12.36	0.147
	Inversion	15.51 ± 11.09	4.60 ± 2.48	<0.001*
	Eversion	−18.24 ± 2.61	−20.77 ± 2.08	0.241
	Ext Rot	14.19 ± 5.31	14.30 ± 5.89	0.659
	Int Rot	−10.80 ± 8.50	−15.17 ± 7.30	0.001*
Hip Angle (°)	Extension	31.22 ± 5.06	30.12 ± 4.55	0.419
	Flexion	−18.35 ± 4.70	−18.09 ± 3.12	0.209
	Inversion	18.96 ± 1.95	17.43 ± 2.84	<0.001*
	Eversion	−12.72 ± 2.41	−14.09 ± 3.12	0.174
	Int Rot	10.80 ± 3.97	11.28 ± 4.69	0.006*
	Ext Rot	−24.08 ± 2.99	−24.36 ± 2.83	0.712
Knee Angle (°)	Flexion	2.067 ± 1.11	1.84 ± 1.83	0.853
	Extension	−23.04 ± 9.87	−29.95 ± 8.13	0.143
	Eversion	4.25 ± 2.48	3.98 ± 1.39	<0.001*
	Inversion	−0.30 ± 0.58	−0.96 ± 0.60	0.973
	Int Rot	11.17 ± 3.70	8.83 ± 2.09	0.085
	Ext Rot	−17.78 ± 2.34	−19.27 ± 1.59	0.087

Note: "*" indicates a significant difference between pre-intervention and post-intervention in the stance phase (P < 0.05).

Table 11. Comparison of Kinetics (means ± standard) between pre-intervention and post-intervention during the stance phase in the control group.

Parameters	Peak Value	Pre-intervention Mean ± SD	Post-intervention Mean ± SD	*P* Value
Ankle Moment (Nm/kg)	Dorisiflexion	0.11 ± 0.09	0.26 ± 0.07	0.905
	Plantarflexion	−1.38 ± 0.10	−1.38 ± 0.94	0.838
	Eversion	0.27 ± 0.09	0.25 ± 0.58	0.050*
	Inversion	−0.02 ± 0.01	0.02 ± 0.09	0.023*
	Ext Rot	0.03 ± 0.02	0.05 ± 0.04	0.345
	Int Rot	−0.29 ± 0.05	−0.30 ± 0.05	0.878
Hip Moment (Nm/kg)	Extension	1.04 ± 0.10	1.09 ± 0.10	0.722
	Flexion	−0.60 ± 0.83	−0.37 ± 0.11	0.437
	Eversion	0.38 ± 0.10	0.41 ± 0.10	0.864
	Inversion	−1.14 ± 0.09	−1.18 ± 0.73	0.136
	Ext Rot	0.14 ± 0.05	0.33 ± 0.21	<0.001*
	Int Rot	−0.54 ± 0.05	−0.62 ± 0.08	0.030*
Knee Moment (Nm/kg)	Extension	0.23 ± 0.07	0.05 ± 0.01	0.162
	Flexion	−0.16 ± 0.10	−0.23 ± 0.04	0.285
	Inversion	0.32 ± 0.04	0.16 ± 0.05	0.992
	Eversion	−0.59 ± 0.66	−0.70 ± 0.05	0.511
	Int Rot	0.03 ± 0.02	0.02 ± 0.02	0.927
	Ext Rot	−0.16 ± 0.34	−0.16 ± 0.30	0.713

Note: "*" indicates a significant difference between pre-intervention and post-intervention in the stance phase ($P < 0.05$).

3.1.3. Comparison of the experimental group between pre-intervention and post-intervention

Differences were found between pre-intervention and post-intervention. **Figure 5** shows the difference in ankle joint angle, joint moment between pre-intervention and post-intervention during the stance phase. **Figure 6** shows the difference in knee joint angle and joint moment between pre-intervention and post-intervention during the stance phase. **Figure 7** shows the difference in hip joint angle and joint moment between pre-intervention and post-intervention during descending phase. **Table 12** displays significant differences in ankle plantarflexion angle ($p < 0.001$), angle inversion angle ($p < 0.001$), ankle eversion angle ($p = 0.007$), ankle ext rot angle ($p = 0.013$), ankle int rot angle ($p < 0.001$); hip extension angle ($p < 0.001$), hip flexion angle ($p < 0.001$), hip int rot angle ($p = 0.002$), hip ext rot angle ($p = 0.032$); knee extension angle ($p = 0.005$); knee eversion angle ($p < 0.001$). **Table 13** displays significant differences in ankle dorisiflexion moment ($p < 0.001$), angle inversion moment ($p < 0.001$); hip ext rot moment ($p < 0.001$); knee extension moment ($p = 0.039$); knee eversion moment ($p = 0.018$).

Ankle angle, moment

The SPM analysis revealed the results of ankle joint kinematics and kinetics during the stance phase, comparing pre-intervention with post-intervention. For the results of the ankle joint in the sagittal plane: ankle joint angle (14.01%–52.21%, $p <$

0.001). ankle joint moment (0%–3.56%, p = 0.024; 7.56%–15.12%, p < 0.001; 45.01%–58.11%, p < 0.001; 94.31%–100%, p = 0.044). In the coronal plane: ankle joint angle (0%–9.94%, p = 0.038; 64.11%–100%, p < 0.001). ankle joint moment (0%–3.78%, p = 0.012; 9.87%–48.81%, p < 0.001; 52.18%–69.16%, p < 0.001; 97.89%–98.12%, p = 0.048). In the Horizontal plane: ankle joint angle (0%–39.81%, p < 0.001; 53.88%–90.91%, p < 0.001); ankle joint moment (0%–15.11%, p < 0.001; 44.32%–48.38%, p = 0.005; 65.92%–98.47%, p <0.001).

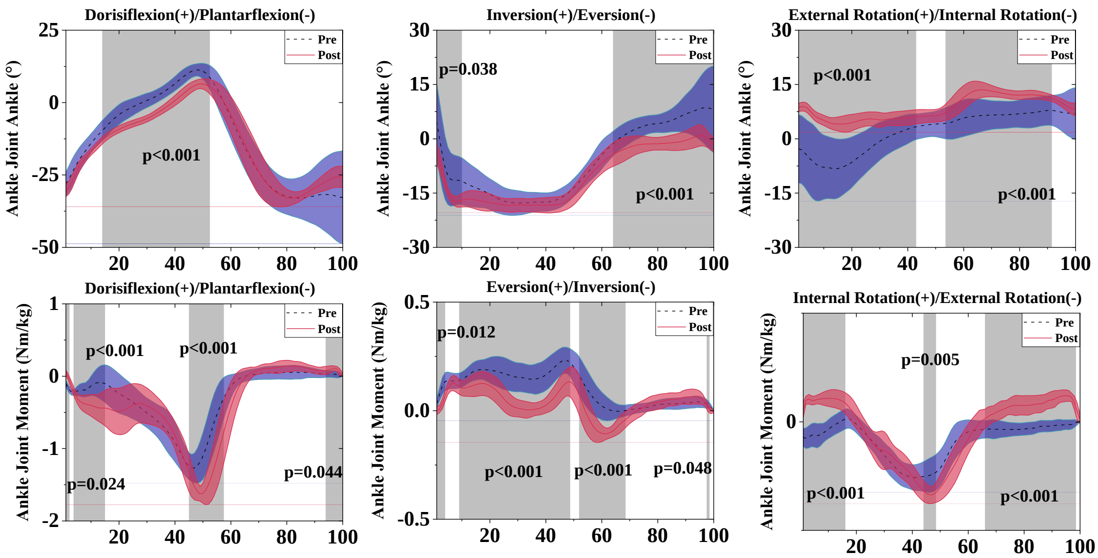

Figure 5. Illustration of the results between the pre-intervention and post-intervention lower limb showing the statistical parametric mapping outputs for the ankle angle, moment during the stance phase.

Knee angle, moment

The SPM analysis revealed the results of knee joint kinematics and kinetics during the stance phase, comparing pre-intervention with post-intervention. For the results of the knee joint in the sagittal plane: knee joint angle (0%–95.78%, p < 0.001); knee joint moment (0%–5.12%, p = 0.001; 10.67%–30.02%, p < 0.001; 41.77%–62.79%, p < 0.001; 87.11%–97.51%, p < 0.001; 99.10%–100%, p = 0.044). In the coronal plane: knee joint angle (0%–31.21%, p < 0.001; 66.67%–100%, p < 0.001); knee joint moment (0%–5.79%, p = 0.001; 10.56%–13.08%, p =0.028; 35.70%–59.26%, p < 0.001; 68.99%–97.47%, p < 0.001). In the Horizontal plane: knee joint angle (0%–20.98%, p < 0.001; 44.92%–90.26%, p < 0.001); knee joint moment (0%–7.93%, p < 0.001; 13.62%–58.94%, p < 0.001; 66.18%–98.82%, p <0.001).

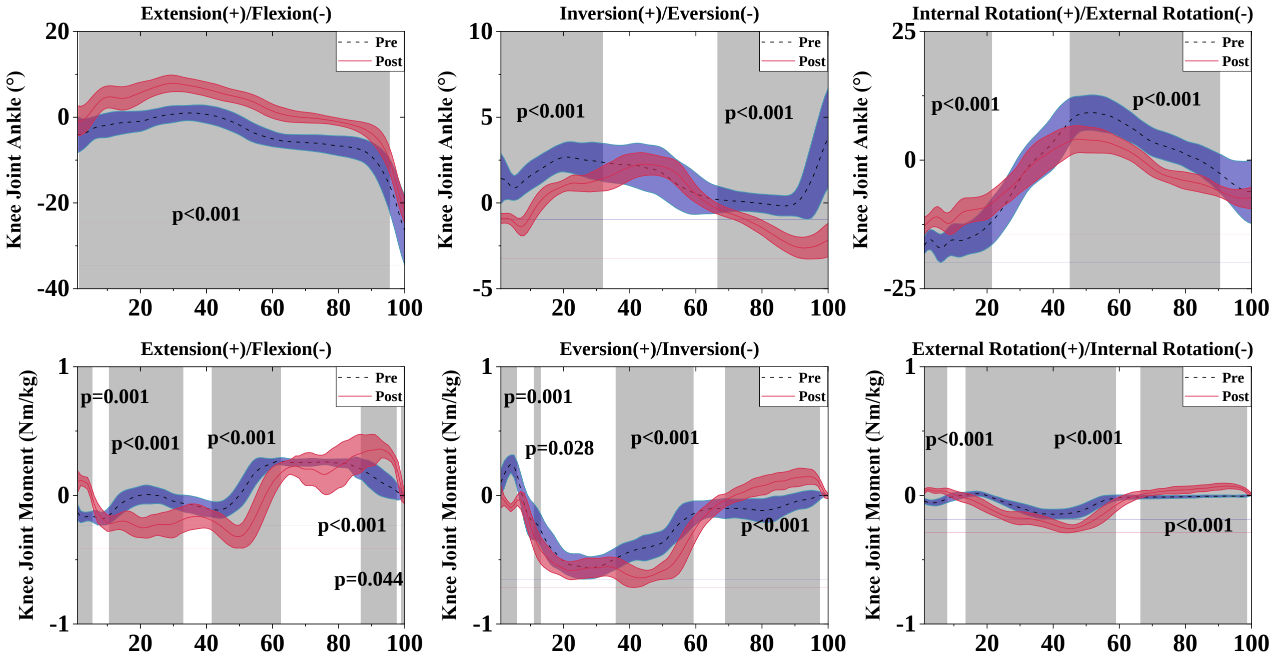

Figure 6. Illustration of the results between the pre-intervention and post-intervention lower limb showing the statistical parametric mapping outputs for the knee angle, moment during the stance phase.

Hip angle, moment

The SPM analysis revealed the results of hip joint kinematics and kinetics during the stance phase, comparing pre-intervention with post-intervention. For the results of the hip joint in the sagittal plane: hip joint angle (0%–100%, p < 0.001); hip joint moment (0%–10.15%, p < 0.001; 19.58%–21.17%, p = 0.033; 34.09%–46.02%, p < 0.001; 55.94%–77.91%, p < 0.001; 89.00%–98.61%, p < 0.001). In the coronal plane: hip joint angle (0%–12.10%, p = 0.015; 21.13%–39.10%, p = 0.005); hip joint moment (0%–5.85%, p < 0.001; 10.71%–65.18%, p < 0.001; 79.17%–96.16%, p < 0.001). In the Horizontal plane: hip joint angle (4.99%–76.00%, p < 0.00); hip joint moment (3.27%–4.93%, p = 0.019; 6.98%–8.21%, p = 0.039; 39.11%–58.22%, p <0.001; 81.02%–100%, p < 0.001).

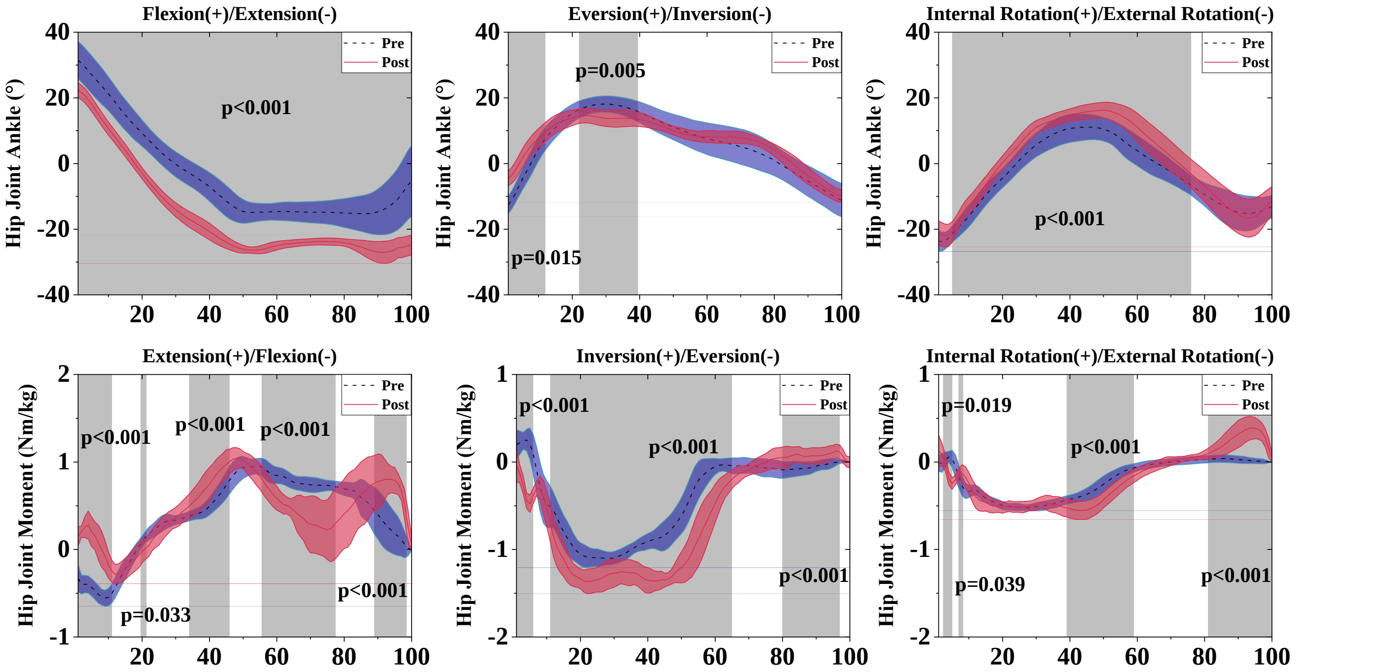

Figure 7. Illustration of the results between the pre-intervention and post-intervention lower limb showing the statistical parametric mapping outputs for the hip angle, moment during the stance phase.

Table 12. Comparison of kinematics (means ± standard) between pre-intervention and post-intervention during the stance phase in the experimental group.

Parameters	Peak Value	Pre-intervention Mean ± SD	Post-intervention Mean ± SD	*P*-Value
Ankle Angle (°)	Dorisiflexion	12.34 ± 2.14	6.92 ± 1.55	0.442
	Plantarflexion	−39.01 ± 11.88	−33.77 ± 2.28	<0.001*
	Inversion	12.05 ± 10.24	1.57 ± 2.43	<0.001*
	Eversion	−19.13 ± 2.80	−19.63 ± 1.69	0.007*
	Ext Rot	12.61 ± 4.56	14.19 ± 2.04	0.013*
	Int Rot	−10.07 ± 8.52	3.13 ± 2.02	<0.001*
Hip Angle (°)	Extension	31.48 ± 5.76	22.34 ± 2.33	<0.001*
	Flexion	−18.18 ± 4.31	−28.63 ± 1.77	<0.001*
	Inversion	18.56 ± 2.37	14.94 ± 2.32	0.758
	Eversion	−14.22 ± 2.56	−10.25 ± 1.88	0.085
	Int Rot	12.05 ± 4.02	16.95 ± 2.06	0.002*
	Ext Rot	−24.48 ± 2.68	−22.92 ± 3.90	0.032*
Knee Angle (°)	Flexion	1.80 ± 1.51	8.38 ± 1.80	0.631
	Extension	−27.98 ± 8.44	−23.59 ± 3.11	0.005*
	Eversion	4.81 ± 2.27	2.54 ± 0.53	<0.001*
	Inversion	−0.68 ± 0.68	−2.82 ± 0.61	0.641
	Int Rot	9.29 ± 6.49	4.46 ± 2.60	0.284
	Ext Rot	−16.87 ± 6.52	−13.28 ± 1.61	0.213

Note: "*" indicates a significant difference between pre-intervention and post-intervention in the stance phase ($P < 0.05$).

Table 13. Comparison of Kinetics (means ± standard) between pre-intervention and post-intervention during the stance phase in the experimental group.

Parameters	**Peak Value**	**Pre-intervention Mean ± SD**	**Post-intervention Mean ± SD**	***P*-Value**
Ankle Moment (Nm/kg)	Dorisiflexion	0.13 ± 0.08	0.19 ± 0.28	<0.001*
	Plantarflexion	−1.40 ± 0.09	−1.73 ± 0.06	0.451
	Eversion	0.52 ± 1.40	0.18 ± 0.43	0.165
	Inversion	−0.20 ± 0.01	−0.12 ± 0.03	<0.001*
	Ext Rot	0.04 ± 0.03	0.14 ± 0.02	0.818
	Int Rot	−0.29 ± 0.05	−0.35 ± 0.04	0.739
Hip Moment (Nm/kg)	Extension	1.04 ± 0.09	1.11 ± 0.12	0.372
	Flexion	−0.62 ± 0.08	−0.35 ± 0.09	0.795
	Eversion	0.39 ± 0.11	0.15 ± 0.14	0.998
	Inversion	−1.16 ± 0.08	−1.45 ± 0.29	0.247
	Ext Rot	0.13 ± 0.05	0.40 ± 0.13	<0.001*
	Int Rot	−0.54 ± 0.03	−0.62 ± 0.08	0.029*
Knee Moment (Nm/kg)	Extension	0.29 ± 0.03	0.39 ± 0.07	0.039*
	Flexion	−0.22 ± 0.04	−0.38 ± 0.07	0.053
	Inversion	0.30 ± 0.05	0.16 ± 0.06	0.641
	Eversion	−0.61 ± 0.07	−0.69 ± 0.04	0.018*
	Int Rot	0.02 ± 0.06	0.07 ± 0.03	0.414
	Ext Rot	−0.16 ± 0.03	−0.26 ± 0.04	0.932

Note: "*" indicates a significant difference between pre-intervention and post-intervention in the stance phase ($P < 0.05$).

3.2. Muscular data

3.2.1. Comparison of electromyographic (EMG) activity between the experimental group and the control group before intervention experiment

In the statistical analysis of electromyography (EMG) data, first, an independent samples *t*-test was conducted on the pre intervention EMG data collected from the control and experimental groups to determine if there were any significant statistical differences between the two groups. As shown in **Table 14**, there were no statistically significant differences in the average muscle activation levels of RF, VL, VM, BF, GM, GL, TA, and PL during the pre-test experiments ($p > 0.05$). This indicates that there was no significant difference between the experimental group and the control group before the intervention experiment. This meets the experimental requirements and further experiments can be conducted.

Table 14. Comparison of average muscle activation pre-test data between two groups.

	Control Group	**Experimental Group**	***p*-value**
GL	41.03% ± 3.35%	41.72% ± 3.36%	$P = 0.67$
GM	45.06% ± 4.48%	45.55% ± 4.21%	$P = 0.81$
TA	53.57% ± 4.53%	53.83% ± 4.56%	$P = 0.91$
PL	36.83% ± 4.00%	37.01% ± 3.49%	$P = 0.92$
VM	35.50% ± 4.12%	34.75% ± 3.85%	$P = 0.30$

Table 14. (*Continued*).

	Control Group	Experimental Group	*p*-value
VL	55.21% ± 4.96%	55.88% ± 4.54%	*P* = 0.42
BF	35.54% ± 3.65%	36.35% ± 3.58%	*P* = 0.43
RF	38.25% ± 3.91%	37.48% ± 3.56%	*P* = 0.67

Note. RF refers to Rectus Femoris, VL refers to Vastus Lateralis, VM refers to Vastus Medialis, BF refers to Biceps Femoris, GM refers to Gastrocnemius Medialis, GL refers to Gastrocnemius Lateralis, TA refers to Tibialis Anterior, PL refers to Peroneus Longus.

3.2.2. Data analysis of post-intervention control and experimental groups

After undergoing 12 weeks of two different training regimens, significant differences in muscle activation were observed between the control and experimental groups. Paired-sample t-tests were conducted to analyze pre- and post-test data for each group. **Figure 8** illustrates the comparison of average muscle activation levels before and after intervention with different training regimens over 12 weeks. **Figure 8a** shows the comparison in the control group after intervention with regimen 1, revealing a significant increase in gastrocnemius medial (GM) activity post-test compared to pre-test ($p = 0.034$), while other muscles showed no significant differences ($p > 0.05$). **Figure 8b** demonstrates the comparison in the experimental group after intervention with regimen 2, indicating significant increases in gastrocnemius lateral (GL) ($p = 0.016$), GM (p=0.001), tibialis anterior (TA) ($p = 0.014$), and rectus femoris (RF) ($p < 0.001$) post-test compared to pre-test, with no significant differences observed in other muscles.

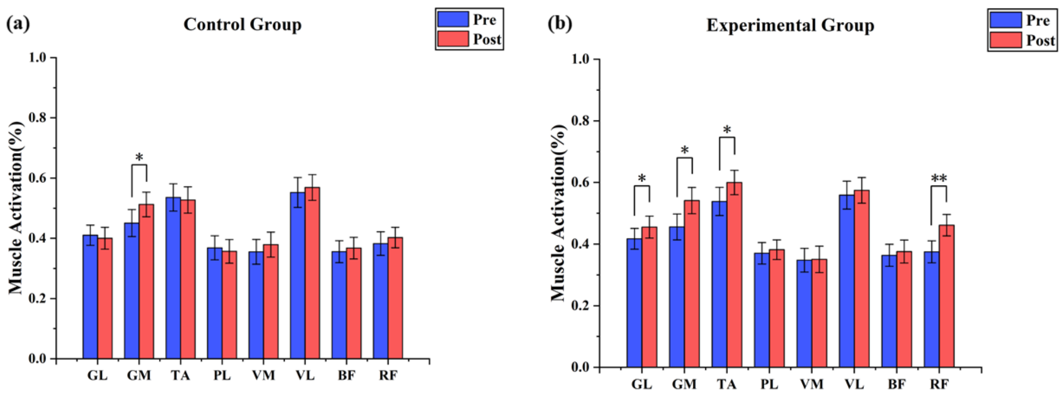

Figure 8. Compares the average muscle activation levels before and after 12 weeks of intervention for two groups of participants. **(a)** Shows the average muscle activation levels in the control group before and after intervention with regimen 1, while; **(b)** shows the average muscle activation levels in the experimental group before and after intervention with regimen 2.

The left scale ranges from 0 (no muscle activation) to 1 (full muscle activation). Blue indicates pre-intervention, and red indicates post-intervention. * indicates significant difference ($p < 0.05$), ** indicates highly significant difference ($p < 0.001$).

4. Discussion

This study aimed to examine the effects of integrating functional training with traditional Latin dance training on the biomechanical and neuromuscular performance of adolescent dancers. Specifically, the research sought to determine whether a combined training regimen could enhance joint range of motion, neuromuscular coordination, and overall dance proficiency while mitigating injury risk. The principal findings indicated that participants in the experimental group, who incorporated functional training alongside conventional dance practice, exhibited significant biomechanical and neuromuscular adaptations compared to the control group. These dancers demonstrated increased ankle dorsiflexion, improved knee extension, and greater hip internal rotation, suggesting enhanced joint mobility and flexibility. Muscle activation analysis revealed substantial increases in the activity of key lower limb muscles, with the lateral gastrocnemius, gluteus maximus, tibialis anterior, and rectus femoris exhibiting heightened activation levels post-intervention. These adaptations in joint kinematics and muscle activation patterns suggest that functional training can improve dancers' capacity for executing complex movement sequences, enhance dynamic stability and postural control, and potentially decrease the incidence of musculoskeletal injuries. This underscores the importance of incorporating functional training into standard dance training programs for adolescent dancers, offering a comprehensive approach to optimizing both performance and injury prevention.

4.1. Kinematics and kinetics

This study found that the control group who only received basic Latin dance training had an increase in ankle inversion angle after intervention. This change is speculated to be due to the dancers maintaining a certain inversion posture to enhance aesthetic movements during various dance actions. Prolonged practice may lead to an increase in ankle inversion angles. However, research indicates that ankle inversion alters the distribution of foot and ankle strength, making it more challenging to maintain stability and balance during movements. This deviation in center of gravity increases the risk of falls or errors [27], and places additional strain on surrounding ligaments and muscles. Ligament laxity around the ankle joint may result in joint instability, reducing control over balance and increasing the risk of ankle sprains [28]. The study also noted an increased hip extension angle in dancers, possibly as a compensatory response to increased ankle inversion angles for balance maintenance. Ankle inversion alters the distribution of strength in the foot and ankle, shifting the position of the center of gravity. Additionally, ankle inversion may predispose individuals to lateral ankle sprains, a common occurrence among adolescents and physically active individuals [29–31], which may recur and eventually lead to chronic ankle instability [31]. In this situation, the body needs to adjust through other joints to maintain overall balance. Hip extension can reduce the burden on the knee and ankle joints, helping to adjust and control the body's center of gravity. This assists in redistributing the center of gravity, bringing it closer to the base of support, thereby maintaining stability [32].

It can be clearly seen from the results that the experimental group receiving basic Latin dance training combined with functional training also showed an increase in ankle inversion angle compared to the pre intervention level. The difference between the experimental group and the control group is that after the cycle intervention, the dancers' ankle dorsiflexion angle also increased in the experimental group, which may be related to heel elevation exercises in functional training. On one hand, extensive heel raise exercises may condition the ligaments around the ankle joint to handle higher loads and tensions, thereby increasing their elasticity and promoting greater ankle joint mobility. On the other hand, the increased ankle inversion angle imposes significant pressure on maintaining body balance. To counterbalance this, dancers increase ankle dorsiflexion angles to reduce the load around the ankle joint. Research indicates that increasing ankle dorsiflexion angles can enhance stability during standing [33], positively influencing balance ability, enhancing movement efficiency, reducing the likelihood of imbalance, and thereby potentially decreasing the risk of ankle joint injuries to some extent.

In addition, this study found that post-intervention, the experimental group showed an increase in knee extension angles. In contrast, there were no significant differences in the sagittal plane knee angles in the control group between pre- and post-intervention phases. The study suggests that the increased knee extension angles in the experimental group may be related to resistance knee lifts. Increased knee extension angle plays a crucial role for Latin dancers. Firstly, Latin dance involves strong rhythm and large movements, emphasizing flexibility and smoothness of actions [1,34]. Therefore, having good knee extension angles positively impacts dancers' ability to perform complex and graceful dance movements. Knee extension enhances stride length and depth, allowing dancers to cover a larger stage area during performances and enhancing the overall visual appeal of the dance. Furthermore, increased knee extension enhances dancers' technical skills and performance ability. In Latin dance, many techniques require dancers to execute leg movements with flexibility, such as high leg lifts, quick turns, and jumps. Insufficient knee extension angles can restrict these movements, affecting the precision and expressiveness of the dance. By training and enhancing knee extension capability, dancers can perform complex movement sequences more freely, showcasing higher levels of technical proficiency and artistic expression. Additionally, increasing knee extension angles helps prevent and reduce sports injuries [35]. Latin dance movements often demand rapid leg transitions and shifts in center of gravity, posing challenges to knee joint stability and flexibility. Strengthening knee extension through training improves muscle flexibility and strength around the joint, minimizing discomfort and injuries during movement [35]. This is particularly crucial for dancers engaged in long-term dance activities, helping them maintain health and consistent dance performance. Increased knee extension also enhances dancers' stage presence and performance capability. Excellent knee extension allows dancers to perform more gracefully and smoothly in competitions or performances, enhancing their stage charisma and audience visual enjoyment. Good knee extension not only elevates the artistry of dance but also boosts dancers' confidence and stage presence. Therefore, enhancing knee extension through systematic knee lift training continually improves dance skills, reduces the risk of sports injuries, and enhances stage performance and audience visual impact.

It is worth noting that the flexibility and control of the hip joint are crucial for performing high-level Latin dance techniques and styles. From the results, it is observed that intervention in the experimental group led to an increase in dancers' hip joint internal rotation angles. Within the intervention program, exercises such as rotational movements and core stability training likely contributed to these changes in hip joint angles. Prolonged rotational movements enhance hip joint flexibility, allowing for greater range of motion, while core stability training strengthens the muscles around the hip joint to support its movements. Latin dance styles emphasize dynamism and rhythmic expression, and flexible hip movements contribute to graceful and expressive dance postures. Dancers use hip swings, rotations, and twists to convey rhythm and emotions. Therefore, this study suggests that compared to basic Latin dance training alone, combining basic training with functional training has a more significant positive impact on adolescent Latin dancers. It not only improves their technical skills but also enhances their body control and balance, reduces the risk of sports injuries, and boosts their overall stage performance.

4.2. Muscle activity

Under the intervention of 12-week basic Latin dance step training, adolescents showed a significant increase in activation levels of the GM during the forward progression of the rumba. The GM is categorized as a plantar flexor [36], primarily responsible for plantar flexion of the ankle joint in the sagittal plane. Increased activation of GM during forward steps contributes to enhanced plantar flexion force in the calf, thereby improving performance in activities such as jumping and kicking. Moreover, it helps to some extent in enhancing ankle stability in inversion [37,38]. Improved stability of the ankle joint in inversion can potentially reduce the risk of ankle injuries among adolescents during dance training and competitions [39]. Therefore, undergoing 12 weeks of basic Latin dance step training not only enhances the proficiency of movements among adolescents but also strengthens the control of the GM over the ankle joint, thereby improving athletic performance and reducing potential injury risks. This holds significant importance for adolescents because lowering the risk of injury not only promotes their healthy development but also prolongs their athletic careers [40]. Furthermore, in the experimental group undergoing 12 weeks of Latin dance steps combined with functional training, there was not only a significant increase in GM activation levels but also in the activation levels of the GL, TA, and RF muscles. This demonstrates that additional functional training has a notable impact on the activation of lower limb muscles. The roles of GL and GM during the forward progression of the rumba are similar, both responsible for sagittal plane plantar flexion. It’s important to note that sustained GM activation without changes in GL could lead to uneven distribution of load in the gastrocnemius muscle, resulting in asymmetrical use with the ankle joint, thereby increasing the risk of injury or altering gait patterns [41].

Therefore, this study suggests that compared to an increase in unilateral GM activation alone, a concurrent increase in GM and GL activation levels can distribute loads more evenly, providing greater balance and stability. This highlights that incorporating functional training alongside basic step training is likely to yield more beneficial effects. We believe that the significant increase in average activation levels of GM and GL is likely related to specific exercises in functional training, such as lunges and weighted calf raises [42]. Research indicates that ankle joint functional training helps enhance activation levels of muscles around the ankle joint, and exercises like lunges and calf raises effectively stimulate the plantar flexors of the ankle joint, including the gastrocnemius muscle [43,44]. The TA acts as both an invertor and dorsiflexor of the ankle joint, playing a crucial role in dorsiflexion movements in the sagittal plane and collaborating with the PL to determine ankle joint inversion and eversion control [45]. The increased activation of TA has multifaceted implications and impacts. Firstly, increased TA activation aids in fine motor control of foot and toe movements, crucial for maintaining balance and executing complex dance movements. It helps adolescent dancers better control foot position and angle, playing a crucial role in mitigating excessive lateral deviation of the ankle joint due to external forces or tendencies towards ankle inversion [46]. Secondly, by enhancing tibialis anterior activation, dancers can perform ankle dorsiflexion more flexibly, particularly important for movements requiring the lifting of the dorsum of the foot, such as turns and specific foot positions [27,47]. Finally, during movements that involve jumping and landing, activation of the tibialis anterior helps controls the force and posture of landing, making movements more agile and graceful while reducing impact on the ankles [48,49]. Latin dance involves intricate footwork, including internal and external rotations, quick changes in direction, and places high demands on ankle joint stability. The increased activation levels of the gastrocnemius and tibialis anterior muscles post-functional training represent a beneficial mechanism, crucial for preventing ankle injuries in Latin dance.

In addition, under the intervention of functional training, besides significant changes observed in some calf muscles, this study also noted a notable increase in activation levels of the RF in the thigh (**Figure 7b**). This could be closely related to lower limb stability exercises and basic strength training in functional training programs, as several studies indicate [50–52]. Squatting exercises, for instance, are known to significantly enhance the muscles of the anterior thigh. RF, located in the front of the thigh, not only participates in knee extension but also in hip flexion [53]. The increased activation of RF during forward steps can strengthen knee extension power, enabling adolescent dancers to achieve greater height and range in leg lifting movements [54]. Moreover, RF activation contributes to improving muscle balance, enhancing movement efficiency and safety, and reducing the risk of sports injuries due to muscle fatigue or inadequacy [55]. Therefore, incorporating scientific functional training alongside Latin dance basic step training is beneficial for enhancing the activation of important lower limb muscles, thereby enhancing joint stability, improving performance, and reducing the risk of injuries during physical activity. While these findings underscore the immediate benefits of functional training, it remains essential to determine whether these improvements are sustainable over the long term. We plan to conduct a follow-up study that will evaluate the same biomechanical and neuromuscular indicators at multiple intervals after the initial intervention period. This long-term follow-up will help ascertain the durability of the observed improvements and provide insights into whether ongoing functional training is necessary to maintain these benefits. By understanding the long-term effects, we can offer more comprehensive recommendations for training protocols, ensuring that the benefits of functional training can be sustained over an athlete's competitive career.

5. Conclusion

This study shows that incorporating functional training into basic Latin dance training has a more profound impact on adolescent Latin dancers compared to basic training alone. The combination of these two methods not only increases joint flexibility, such as ankle dorsiflexion, knee extension, and hip internal rotation, but also helps improve balance, body control, and overall stage performance. Additionally, functional training significantly enhances the activation of key lower limb muscles, including the medial and lateral gastrocnemius, tibialis anterior, and rectus femoris, with muscle activation potentially contributing to safer training. Therefore, integrating functional training into the regular training routines of adolescent Latin dancers can effectively improve their athletic performance and reduce the risk of injuries. This also provides recommendations for developing more targeted, scientifically based training programs to optimize the competitive performance of adolescent dancers.

Author contributions: Conceptualization, ML and EH; methodology, EK; software, JD; validation, YK, ML and YK; formal analysis, ML; investigation, ML; resources, ML; data curation, ML; writing—original draft preparation, ML; writing—review and editing, EK; visualization, JD; supervision, EK; funding acquisition, YY. All authors have read and agreed to the published version of the manuscript.

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Ethical approval: The study was conducted in accordance with the Declaration of Helsinki and approved by the ethics Committee of Ningbo University (Protocol Code: RAGH20230901; Approval Date: September 1, 2023).

Conflict of interest: The authors declare no conflict of interest.

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