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Plyometric Training Combined with or without Hamstring Strengthening in the Prevention of Anterior Cruciate Ligament Injuries in Female Amateur Athletes

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ABSTRACT

Anterior Cruciate Ligament (ACL) injuries are common among female athletes, especially in sports involving jumping and pivoting. **Objectives:** To study the plyometric training along with hamstring training on the prevention of ACL injuries among female amateur athletes. **Methods:** A total of 60 female amateur athletes aged 18 to 30 were selected as participants of this randomized controlled trial and randomly stratified into two groups (Group A: plyometric strengthening + hamstring strengthening; Group B: plyometric strengthening). The intervention took six weeks, and it was trained twice a week. At baseline, Week 3, and Week 6, the outcome measures were knee strength (flexion and extension), dynamic balance (Star Excursion Test), and functional mobility (KOOS). The data were analyzed in SPSS version 24.0, repeated measures ANOVA and independent t-tests were used ($p<0.05$). **Results:** Time-related within-group improvements were significant in both groups of all outcome measures ($p<0.001$). Group A became stronger (flexion: 24.06-29.89 kg; extension: 30.33-36.60 kg), more stable (SET: 15.59-19.59 cm), and KOOS (56.32-72.11). The same gains were observed with Group B (flexion: 24.39-30.91 kg; extension: 30.24-36.04 kg; SET: 14.12-21.37 cm; KOOS: 58.99-71.88). No statistically significant differences in any of the post-intervention points ($p>0.05$). **Conclusions:** Plyometric training is an effective intervention in enhancing lower limb strength, balance, and functional mobility of female amateur athletes. The inclusion of hamstring strengthening did not result in any extra benefits over 6 weeks and may indicate that plyometric-only programs can be useful and time-efficient in the context of ACL injury prevention in the chosen population.

INTRODUCTION

The Anterior Cruciate Ligament is a notable knee joint ligament, which assists the knee in being stable and mobile. In case of a strained or torn ACL, this can occur when you suddenly stop, shift gears, or when you strike your knee squarely on the ground [1]. Sudden halting, change of direction, or jumping or landing is another cause of ACL injury among athletes who place unnecessary stress on the ligament. Specifically, non-contact forces such as pivoting, cutting, slowing down, etc., may damage the ACL since they apply excessive rotational, anterior shear, and valgus force on the knee [2]. Scientific and physical factors are also many, as to why female athletes have higher chances of injuring their ACLs due to differences in their anatomy, hormone variations, and differences in muscle composition [3]. In addition to that, women also have a smaller intercondylar notch (the groove in the femur where the ACL is) and a more vertical femoral shaft of the femur and this increases the chances of the ACL becoming damaged. Such anatomy-related alterations may alter the normal functioning of the knee joint and increase the risk of ACL ruptures [4]. ACL injuries may be small and severe and result in pain, swelling, and

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instability. They undergo surgery and a lengthy restoration process. The mild and moderate ACL injuries that also involve partial rupture or sprain can be very painful and cause movement difficulty, although they may not require an operation immediately [5]. The type of injuries may result in pain, swelling, and stiffness in the knee, or the feeling of instability or discomfort when placing any weight on it or switching direction. Certain athletes can continue to perform some of the activities, and some cannot play sports and must undergo a rehabilitation program and strengthen the muscles surrounding the knee and improve its functioning [6]. When mild and moderate ACL injuries are treated and rehabilitated, they are usually self-limiting and, therefore, individuals manage to resume regular activities and sports. Nevertheless, in case the knee is not absolutely stable, there is a possibility of getting injured once more [7]. The complete rupture of the ACL may be rather painful, accompanied by swelling and rendering the knee joint unstable. This is highly detrimental, and it can cause difficulty in movement [8]. In case of a torn ACL, the knee gets a feeling that it is giving way or buckling, and it is difficult to support weight on it and perform even basic tasks [9]. ACL injuries that are severe might cause significant emotional impact besides the physical ones. They usually require surgery and a lengthy healing process, and this can make a player miss months or even years of playing their games and carrying out their activities [10]. Moreover, female and male athletes report identical rates of ACL in non-contact sports, such as swimming and distance running, 0.36/10,000 AEs and 0.21/10,000 AEs, respectively [11]. Physical therapy plays a very significant role in preventing and treating ACL injuries. An entire physical therapy program that prevents ACL injuries is a combination of exercises and strategies that increase the strength, power, agility, flexibility, and neuromuscular control. It involves neuromuscular training. It works on enhancing communication between the nerves and muscles so as to render the muscles stronger and easier to manage [12]. Plyometric exercises such as the jump squats and box jumps are also applicable in strength and power building. The example of agility activities that can make you run faster, quicker, and more able to change direction is cone exercises and shuttle runs. Activities such as squats, lunges, and leg presses are improved by strengthening the muscles and making them more effective in managing them. Planks and bridges are core stabilization exercises that strengthen the core and stabilize it [13]. Balance and proprioceptive activities, which include single-leg squats and balance boards, will also aid in making you more conscious of where your body is and also increase your balance. Functional movements such as squats, lunges, and step-ups can also be used to aid in muscular control and movement patterns [14]. Progressive resistance exercises, such as resistance band exercises, and flexibility and mobility exercises, such as foam rolling and stretching, are also covered in the program. Finally, it is highly crucial to teach people about ACL injuries, their prevention, and proper movement to provide athletes and other individuals with the instruments they should use to avoid being injured [15]. A physical therapist has the ability to tailor an exercise program to an individual based on his or her needs and goals. The list of activities that can be part of this plan is single-leg squats, lateral lunges, carioca exercises, box jumps, agility ladder exercises, exercises on a resistance band, and plyometric exercises [16]. Hamstring strengthening is a significant component in ACL preventive programs since it will reduce the load on the ACL, stabilize the knee, enhance landing and deceleration techniques, and reduce the chances of ACL injuries [17]. There are good exercises such as deadlifts, leg curls, glute-ham raise, Romanian deadlifts, single-leg deadlifts, hamstring bridges, and Nordic hamstring curls. It is advisable that you begin with low intensities and then increase [18]. Plyometric exercise is a significant component of the programs that can prevent ACL injury because it makes you stronger, nimbler, and in better command of your muscles, which reduces the risk of an ACL injury. Nonetheless, the question of whether plyometric training and hamstring strengthening can collaborate to prevent the occurrence of ACL problems in female amateur athletes remains to be clarified. The hamstring reinforcement is a significant aspect of preventing ACL injuries as it reduces the load on the ACL and renders the knee more stable, as well as enhances landing and deceleration techniques. Therefore, one should establish the effectiveness of plyometric training and hamstring strengthening to prevent the occurrence of ACL injuries in female amateur sportspeople. This will assist in developing evidence-based prevention measures that may be incorporated in training programs and reduce the incidence of ACL injuries, and will render sporting activities safe for all.

Limited evidence exists on whether adding hamstring strengthening to plyometric training provides additional preventive benefits against ACL injuries in healthy female amateur athletes, as most prior research has focused on elite or rehabilitative populations. Furthermore, few randomized trials have directly compared these training approaches to guide efficient injury prevention strategies in amateur sports settings. This creates uncertainty for clinicians and trainers regarding the most effective and time-efficient program. Therefore, the present study

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aimed to compare the effects of plyometric training alone versus plyometric training combined with hamstring strengthening on lower limb strength, dynamic balance, and functional mobility to determine the optimal approach for ACL injury prevention in female amateur athletes.

METHODS

This randomized controlled trial (NCT07047833) was done to see how plyometric training with strengthening exercises compared to plyometric training alone affected the strength, static balance, and functional mobility of female amateur athletes. Ethical approval was obtained from The University of Lahore Ethics Committee (REC-UOL-/287/24) to take place over nine months from 1 August 2024 to April 2025. The Sports Departments of the University of Lahore, the University of Central Punjab, and the University of Management and Technology, Lahore, were from where the data were collected. The study utilized a purposive sample method to recruit 60 participants. The study randomly assigned 30 athletes to each group. The sample size was calculated using Statulator software. The calculation was based on detecting a medium effect size (Cohen's d = 0.5) with a significance level (α) of 0.05 and a statistical power (1-β) of 80% for an independent t-test comparing two groups. This yielded a minimum required sample size of 25 participants per group. To account for a potential 20% dropout rate, the sample size was increased to 30 participants per group, resulting in a total sample of 60 participants. The formula used was: $n = 2(Z_{1-\alpha/2} + Z_{1-\beta})^2 \sigma^2/\Delta^2$. Where σ is the standard deviation, and delta is the expected difference between groups. To be included, female athletes had to be between the ages of 18 and 30, play sports that required leaping, turning, and cutting, and practice at least six times a week. Athletes had to show that they could leap and land safely. Some of the reasons for exclusion were athletes who only exercised for fun or weren't trained, those who only trained for less than five hours a week, those who had injuries or operations in the past that were treated in different ways, and those who were rehabilitating before surgery. Informed consent was taken. Participants signed a paper giving their written agreement, and they were told that their information would be kept private and that they may leave at any moment without consequence [19, 20]. Participants were randomly assigned to groups using a computer-generated sequence. Outcome assessors were blinded to group allocation. A random number generator was used to divide the eligible participants into two groups randomly. The study was single-blinded, which means that the person doing the assessment didn't know which group the participants were in. At the beginning, week 1, week 3, and week 6 after the intervention, outcome evaluations were done. Group A's workout plan lasted 60 minutes and included 15 minutes of warming up, 20 minutes of plyometric training, 20 minutes of strengthening, and 5 minutes of cooling down. Group B had a similar workout, except it didn't include the strengthening part; thus, it lasted 40 minutes. For all groups, the plyometric part included squat leaps, depth jumps, and lateral jumps. They did 2–3 sets of 6–12 reps, with 30–60 seconds of rest between sets. The study made the exercises harder by making the jumps higher or shortening the breaks. Group A's strength training regimen includes Nordic hamstring curls and machine or free-weight hamstring curls (2–3 sets of 8–12 repetitions), with controlled movement and enough rest between sets. There were 12 sessions in total, with each one taking place twice a week for six weeks [19, 21]. Standardized and proven measurement tools were used to measure outcomes such as muscle strength, static balance, and functional movement. Knee flexion and extension strength were assessed using an isokinetic dynamometer (Cybex Norm, Ronkonkoma, NY, USA), a tool with high test-retest reliability (ICC > 0.90) [22]. Dynamic balance was evaluated using the Star Excursion Balance Test (SET), which has demonstrated excellent intra-rater reliability (ICC = 0.84–0.92) [23]. Functional mobility related to the knee was measured using the Knee Injury and Osteoarthritis Outcome Score (KOOS), a valid and reliable patient-reported outcome measure with high internal consistency (Cronbach's alpha > 0.80) [24]. To control for the effects of recovery after exercise, both groups did the same tests and stretches during cooldown. The study was conducted in accordance with the ethical standards, which included ensuring that the participants were safe, that they wanted to participate in the study, that their data were to be preserved, and that the university regulations were observed. The study design ensured a strict approach to the methods by applying clear eligibility criteria, sufficient randomization, blinding, and uniformity in intervention procedures. This research was aimed at discovering whether the addition of plyometric training to strength training can result in superior changes in athletic performance and functional outcomes. The data were entered and analyzed using SPSS Version 24.0. The numerical data, like age, were presented as mean ± SD. Categorical Data, like gender groups, were presented in the form of frequency (Percentage). The normality of the data distribution was tested by the Kolmogorov-Smirnov test. The data were normally distributed, repeated measures of ANOVA and interdependent t-test were for between-group and within-group comparisons; p-value<0.05 was considered significant.

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RESULTS

The study showed that all measures (strength, balance, and functional mobility) improved significantly within each group over time, which proved that both therapies worked. But inferential statistics indicated that there were no significant differences between Group A (plyometric plus strengthening) and Group B (plyometric only) at Week 6 for any outcome measure (p>0.050). These results imply that plyometric exercise alone may be enough to help healthy female amateur athletes improve their performance in a short amount of time (Table 1).

Table 1: Average Hours of Standing and Walking per Shift

Variables	n	Mean ± SD	Minimum	Maximum
Age (Group A)	30	24.23 ± 3.53	18	30
Age (Group B)	30	24.63 ± 3.66	18	30
BMI (Group A)	30	22.18 ± 1.9	18	30
BMI (Group B)	30	22.13 ± 1.97	18	30

There were no statistically significant differences between Group A (plyometric + strengthening) and Group B (plyometric only) on any of the outcome measures—Strength Dynamometer Flexion (SDF), Strength Dynamometer Extension (SDE), Balance Star Excursion Test (SET), and Functional Mobility (KOOS)—at baseline, Week 3, and Week 6 (all p > 0.050). The between-group effect sizes at Week 6, calculated using Cohen's d, were small for all outcomes: Strength Dynamometer Flexion (d = 0.18), Extension (d = 0.10), Star Excursion Test (d = 0.26), and KOOS (d = 0.01), further supporting the lack of practical significance of the observed differences. Levene's test showed that the variances were the same, and the 95% confidence intervals for the mean differences contained zero. This further supports the idea that there were no differences between the groups. Even though both groups made significant progress over time, the lack of significant differences between the two groups suggests that plyometric training alone was just as effective as the combined intervention in improving lower limb strength, balance, and functional mobility in female amateur athletes during the 6-week intervention period (Table 2).

Table 2: Between-Group Comparison of Strength, Balance, and Functional Mobility

Variables	Levene's F	Levene's Sig.	t-value	df	Sig. (2-tailed)	Mean Difference ± SD Error	95% CI Lower	95% CI Upper
SDF Baseline	0.215	0.645	-0.283	58	0.778	-0.335 ± 1.182	-2.701	2.031
SDF Week 3	0.652	0.423	-0.204	58	0.839	-0.269 ± 1.314	-2.898	2.361
SDF Week 6	1.623	0.208	-0.679	58	0.5	-1.016 ± 1.497	-4.012	1.98
SDE Baseline	0.104	0.748	0.065	58	0.948	0.088 ± 1.349	-2.613	2.789
SDE Week 3	0.172	0.679	-0.303	58	0.763	-0.413 ± 1.363	-3.141	2.315
SDE Week 6	0.143	0.707	0.379	58	0.706	0.563 ± 1.486	-2.412	3.539
SET Baseline	1.658	0.203	1.089	58	0.281	1.471 ± 1.351	-1.234	4.175
SET Week 3	0.096	0.758	0.269	58	0.789	0.378 ± 1.403	-2.431	3.187
SET Week 6	1.642	0.205	-1.278	58	0.206	-1.781 ± 1.394	-4.571	1.008
KOOS Baseline	0.017	0.895	-0.636	58	0.527	-2.664 ± 4.187	-11.045	5.717
KOOS Week 3	0.892	0.349	-0.912	58	0.366	-3.471 ± 3.806	-11.09	4.149
KOOS Week 6	0.128	0.722	0.063	58	0.95	0.277 ± 4.424	-8.579	9.133

DISCUSSION

This research highlighted the significant enhancement of lower limb strength, balance, and functional mobility in female amateur athletes with plyometric training, and no further short-term advantages of isolated hamstring strengthening. These two interventions worked out, yet the fact that the significant differences were not found between groups implies the possibility that plyometric exercise alone can be effective in strengthening neuromuscular performance in healthy athletes. These results are found to be in line with the other studies that have suggested the effectiveness of plyometric training and neuromuscular training in preventing injuries. Equally, Olivares-Jabalera *et al.* achieved positive outcomes regarding functional performance under the exercise programs of plyometrics, agility, and strength training [25]. According to Al Attar et al. neuromuscular control and ACL injury prevention are achieved through plyometric training [22], and Schlick showed that the biomechanics of the lower limbs improved in adolescent female athletes after undergoing plyometric-based training [26]. Conversely, papers that promoted multi-component training or post-injury rehabilitation, including Monajati *et al.* and Kasmi *et al.* showed an added value of training that combined plyometric and hamstring-strengthening activities [17, 19]. These variations could be attributed to the fact that our participants were healthy amateurs with a normal neuromuscular baseline; other studies involved injured or deficient athletes who needed extra hamstring activation.

The study was limited to female amateur athletes over six weeks with no long-term follow-up; future research should include longer interventions, diverse athletes, and sport-specific assessments. Future studies should extend the

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intervention period beyond six weeks and include long-term follow-up to assess sustained benefits and injury incidence. Research should also explore these training protocols in diverse populations, including male athletes and different skill levels. Additionally, incorporating sport-specific drills and direct biomechanical or injury rate outcomes would strengthen the evidence for injury prevention programs.

CONCLUSIONS

The study showed that plyometric exercise, either by itself or with hamstring strengthening, made female amateur athletes stronger, better at balancing, and more able to move around. However, there were no large differences between the groups. This implies that plyometric training may be sufficient to prevent the occurrence of ACL injuries in the short term. It did not help to strengthen the hamstrings further. The results of these short-term studies, which are female-specific among amateur athletes, support the idea of basic and fast programming in an amateur sports environment. The short period of intervention does not allow for the assumption of conclusions regarding the long-term effectiveness, and further studies are necessary to investigate those interventions over a longer period of time and in a more extensive population.

Authors' Contribution

Conceptualization: FR
Methodology: FR, FM
Formal analysis: FR
Writing and Drafting: FR, FM, RY, MT
Review and Editing: FR, FM, RY, MT

All authors approved the final manuscript and take responsibility for the integrity of the work.

Conflicts of Interest

The authors declare no conflict of interest.

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