Improvement of Balance Performance by Plyometric Training: A Sustainable Strategy for Injury Prevention in Adolescent Volleyball Players

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Abstract. Volleyball is a sport that needs a range of physical skills including static and dynamic balance, which contribute to performance and injury prevention. Plyometric exercise may improve neuromuscular control and proprioception through the stretch–shortening cycle, which may affect athletes' balance. The purpose of this study was to investigate the effect of plyometric exercise on static and dynamic balance in volleyball players at PBV Rajawali using a quasi-experimental two-group pretest–posttest design with 30 athletes aged 13–15 years (intervention n=15, control n=15). The intervention group performed 6 weeks of plyometric training (3 sessions/week) in addition to their normal club training, whereas the control group continued with normal training. Static balance was measured with the Flamingo Test and dynamic balance with the Y Balance Test, analysed with Wilcoxon Signed-Rank and Mann-Whitney U tests. The intervention group showed a substantial improvement in the static balance ($p=0.014$ left, $p=0.026$ right) and the dynamic balance ($p<0.001$), while the control group improved significantly only in the dynamic balance. No statistically significant between-group differences were observed Both groups showed the better improvement of dynamic balance than static balance. Plyometric training could be a low-cost, sustained preventive exercise strategy for volleyball athletes and warrants further investigation with bigger samples.

Keywords: plyometric training, sustainable health care, injury prevention, balancing performance, adolescent athletes.

1 Introduction

The involvement of sports with the aim of becoming an athlete among children aged 10-15 years in Indonesia reaches 10.7%. The participation of volleyball alone reaches 14.2% or comparable to around 3 million children [1]. Children aged 13–15 years are in a crucial stage of growth and physical maturity, with rapid height increase, development of muscular mass, and hormonal changes that determine physical health in the long term [2]. Properly structured training is crucial for athletes of this age to optimise physical capacity and reduce injury risk.

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Volleyball is a team activity that needs sophisticated movement skills, and the essential physical traits required include balance, endurance, speed, power and strength [3]. In volleyball, balance is very important since it is the foundation for rapid changes of direction, jumps and for the maintenance of posture in offensive and defensive actions. During the reception and transmission, players must maintain body position during aerial phases such as spiking, blocking and serving for effective execution and postural stability for movement precision [4]. Reduced performance and an increased risk of injury are associated with impaired balance. Injury surveillance among the Indonesian national volleyball training team in 2019 showed 20.4 injuries per 1,000 playing hours with only 1 of 34 athletes staying injury-free. The most common sites of injury were the knee (36%), ankle (18%) and lower back (16%) while the most common kinds of injury were sprains (21%), tendinitis (21%) and low back discomfort (13%) [5]. Both dynamic balance (the capacity to maintain stability and body control during movement) and static balance (the ability to maintain a stable body position at rest to prepare for later movement) help to reduce this injury burden. Balance is controlled by the integration of three systems: the visual system that controls the position of the body in space, the vestibular system located in the inner ear (utricle, saccule, and semicircular canals) that detects linear and rotational movement of the head, and the proprioceptive system that detects information from the muscles, tendons, joints, and skin about the position and movement of the body [6]. Proprioceptive sensory input from joints and muscles delivers coordination information to the brain, represented via motor output; good proprioceptive function increases joint stability and lower injury risk by improved awareness of body position.

Plyometric training is a form of training characterised by short, rapid movements such as jumping and pushing, based on the stretch-shortening cycle (SSC) which involves an eccentric loading phase where muscle-tendon units lengthen and store elastic energy, followed by a concentric phase in which the stored energy is released to produce maximal force [7]. Plyometric exercise, paired with systematic strength training, can increase vertical jump performance, joint awareness, and proprioception. Plyometric training enhances neuromuscular control in healthy individuals by activating neurological receptors, including muscle spindles, Golgi tendon organs, and joint/ligament mechanoreceptors, which detect alterations in muscle length, thereby increasing the power and rapidity of muscle contraction [7]. Plyometric movements continually activate these proprioceptive pathways, therefore the training is directly related to balance, allowing the body to adapt more quickly to the complex movement demands that dynamic-balance-dependent sports require.

Previous studies support that association. Kanbak and Dağlıoğlu [8] evaluated 8 weeks of plyometric training (drop jump, box jump, squat jump, split squat jump, overhead slam, and plyometric push-up) in male volleyball players and reported significant increases in speed and dynamic balance. Akça and Baylan [9] showed significant improvements in female volleyball players' vertical jump and right-leg balance after 8 weeks of plyometric training, using Y Balance Test, Opto Jump test and long jump test.

Sitti and Köroğlu [10] observed increases in speed and balance with the most gain in agility following 6 weeks of plyometric exercise in adolescent volleyball players who were tested with sprint, agility, and Flamingo Balance tests.

Despite this data, few research have concurrently assessed the effect of plyometric training on both static and dynamic balance in Indonesian volleyball clubs. In addition, as far as we know, no study has compared the level of improvement of the two types of balance in the same cohort. In parallel, sustainable sports healthcare is increasingly focusing on preventive, low-cost interventions—rather than solely performance-driven ones—to lessen the long-term burden of sports injuries on healthcare resources, and contemporary athlete management is progressively integrating digital balance-assessment tools and wearable sensors to facilitate early, technology-enabled intervention. The present study therefore aimed to investigate the effect of plyometric training on static and dynamic balance and compare the extent of improvement of both types of balance in volleyball players at PBV Rajawali. The broader aim was to inform sustainable, evidence-based injury-prevention strategies for adolescent athletes.

2 Materials and Methods

2.1 Design of The Study

In this work, the quantitative technique was applied and the standard experimental model was adopted as a quasi-experimental two-group pretest–posttest design that is frequently used to evaluate change by comparing the outcomes pre and post intervention [11]. Participants were randomized to an intervention group who got plyometric training in addition to their regular club training and a control group who continued with regular club training only. Static and dynamic balance was tested twice, at baseline and at the end of the intervention period.

2.2 Time and Setting

The research was conducted at the PBV Rajawali volleyball pitch, Tuban Regency, East Java, Indonesia. This location was chosen since it is where the athletes regularly train and the club has a history of competing at the provincial level. The study duration was six months and included proposal seminar, ethical review, baseline data collection (week 3 of January), 6 weeks intervention (beginning week 4 of January to week 1 of March), end point data collection (week 2 of March) and final data analysis.

2.3 Population and Sample Size

The population comprised all 30 active PBV Rajawali members aged 13–15 years. A total sampling technique was used, enrolling the entire eligible population as the study

sample, appropriate given the relatively small population size [12]. Inclusion criteria were active club membership, age 13–15 years, and being free of injury or chronic disease affecting physical capacity; exclusion/drop-out criteria included sustaining an injury during the program, absence at pre- or post-testing, or attending fewer than 3 intervention sessions. All 30 athletes were retained through study completion and randomly allocated into an intervention group (n=15) and a control group (n=15).

2.4 Experimental Procedure

Following ethical approval, the research team contacted the club coach, and the eligible athletes provided informed parental/guardian consent as minors. The consent forms described the background, aims, procedures, duration, potential hazards and discomforts, benefits, data confidentiality and participant rights of the study. Group allocation was accomplished at the time of informed consent distribution. Anthropometric data (height, weight, leg length), vital signs (blood pressure, respiration rate, heart rate, SpO_2), and the Functional Movement Screen (FMS) were recorded at baseline before regular training, and the Flamingo Test and Y Balance Test were recorded after regular training. Prior to data collection, researcher demonstrated all test protocols to standardise technique.

Following baseline testing, the control group continued the club's regular training program and the intervention group completed the regular training followed by a plyometric program including drop jump, box jump, squat jump, split squat jump, overhead slam, and plyometric push-up, at a dosage of 10 repetitions × 3 sets per exercise (6 repetitions × 2 sets for plyometric push-up). The intervention was provided across 18 sessions in 6 weeks (3 sessions/week) with the researcher supervising technique throughout. At the end of the intervention period, the endpoint (post-test) measurements with the Flamingo Test and Y Balance Test were redone using the same protocol.

2.5 Outcome

Flamingo Test (static balance) Participants stood barefoot on one leg on a wooden beam (50 × 4 × 3 cm) with the other leg flexed backward for one minute and the number of balance losses (falls off the beam) was recorded. If the athlete fell 15 times in the first 30 seconds, they were given a score of zero.

Dynamic balance: Y Balance Test. A Y-shaped grid was marked on the floor (anterior line 90° from the two posterior lines, each posterior line 135°; each line 120 cm long). Participants stood barefoot with hands on hips reaching with one leg in the anterior, posteromedial and posterolateral direction while maintaining single-leg posture without weight-bearing on the reaching leg, switching legs. The composite score was computed as:

COMPOSITE SCORE = [(ANTERIOR + POSTEROMEDIAL + POSTEROLATERAL) / (3 X LEG LENGTH)] X 100

2.6 Analysis of Data

Data analysis was conducted in four phases: (1) descriptive statistics of the participants (age, sex, height, weight, leg length, vital signs, FMS score) and pre-/post-test balance scores; (2) the Shapiro–Wilk test for normality, appropriate considering the sample size (n=30); (3) the Wilcoxon Signed-Rank test for pre- and post-test within-group comparisons, used because the data were not normally distributed; and (4) the Mann-Whitney U test on delta (post-test minus pre-test) values for between-group comparisons.

2.7 Ethical Issues

This study was approved by the Research Ethics Committee of the Vocational Education Program, Universitas Indonesia (registration no. KES-52/01/2026). Parents/guardians provided informed consent prior to enrolment; data confidentiality was maintained throughout; participants had the right to withdraw at any time without consequence; vital-sign screening, standardised warm-up/cool-down, and adequate rest between sessions were used to minimise injury risk, with medical support and an emergency referral pathway (RSUD Dr. Koesma Tuban) available throughout the intervention.

3 Results

3.1 Characteristics of Participants

Thirty volleyball players (13-15 years) completed the trial (control n=15, intervention n=15). The control group was largely male (66.7%) and the intervention group predominantly female (53.3%) with comparable mean age (14.0 ± 0.85 vs. 14.2 ± 0.86 years). The mean height was 165.33 ± 5.83 cm (control) and 162.07 ± 6.60 cm (intervention), and the mean weight was 58.87 ± 11.71 kg (control) and 58.33 ± 9.88 kg (intervention) with a wide range (41–90 kg) and similarly substantial standard deviations in both groups. Mean leg length was comparable between groups (about 87–88 cm) but was more dispersed in the intervention group (75–99 cm). The FMS was used to screen for injury risk and all participants had normal vital signs and were found to be appropriate for the intervention.

Table 1. Descriptive characteristics of participants (N=30)

Variable	Control (n=15)	Intervention (n=15)
Sex, male/female (%)	66.7 / 33.3	46.7 / 53.3
Age (years), mean ± SD	14.0 ± 0.85	14.2 ± 0.86

Height (cm), mean ± SD	165.33 ± 5.83	162.07 ± 6.60
Weight (kg), mean ± SD	58.87 ± 11.71	58.33 ± 9.88
Leg length, left (cm), mean ± SD	87.93 ± 3.69	87.33 ± 5.67
Leg length, right (cm), mean ± SD	88.00 ± 3.51	87.33 ± 5.67

(source: primary data, 2026)

3.2 Static and Dynamic Balance Results

Descriptively, mean Flamingo Test (fall count) scores declined marginally in the control group (left: 2.672.27; right: 2.532.20), whereas the intervention group decreased more (left: 1.200.47; right: 1.330.60), with maximum scores similarly decreasing (left: 73; right: 52). Both groups demonstrated improvement in their Y Balance Test composite scores (control left: 90.95→94.24, right: 89.81→93.45; intervention left: 90.01→97.49, right: 91.09→96.46) but the intervention group achieved higher and more consistent post-test results.

Table 2. Within- and between-group balance outcomes following the 6-week program

Outcome	Control (pre→post)	Sig. (within)	Intervention (pre→post)	Sig. (within)	Sig. (between)*
Flamingo Sinistra (falls/min)	2.67 → 2.27	0.346	1.20 → 0.47	**0.014**	0.393
Flamingo Dextra (falls/min)	2.53 → 2.20	0.302	1.33 → 0.60	**0.026**	0.576
YBT Sinistra composite (%)	90.95 → 94.24	**0.010**	90.01 → 97.49	**<0.001**	0.051
YBT Dextra composite (%)	89.81 → 93.45	**0.007**	91.09 → 96.46	**<0.001**	0.254

*Within-group: Wilcoxon Signed-Rank test. *Between-group: Mann-Whitney U test on delta scores. Bold = p<0.05. (source: primary data, 2026)*

The Shapiro-Wilk test indicated that the control group's static balance data were normally distributed, whereas the intervention group's data were not. The post-test Y Balance Test scores were also non-normally distributed for both groups. Thus, non-parametric tests were utilised for all analyses. The control group showed no significant change in static balance (p=0.346 left, p=0.302 right) but a substantial improvement in

dynamic balance (p=0.010 left, p=0.007 right). Static balance (p=0.014 left, p=0.026 right) and dynamic balance (p<0.001 both sides) improved significantly within intervention group. Static balance (p=0.393 left, p=0.576 right) and dynamic balance (p=0.051 left, p=0.254 right) delta scores were not statistically significantly different between groups, while the intervention group had bigger delta scores for dynamic balance in magnitude.

3.3 Comparison of static-dynamic balance improvement

In the intervention group, the mean delta score for dynamic balance was significantly higher than static balance on both sides (sinistra: 7.48 Â± 6.44 vs. 0.73 Â± 1.10; dextra: 5.37 Â± 3.46 vs. 0.73 Â± 1.03) (sinistra p=0.001; dextra p<0.001). Descriptively a similar trend was seen in the control group (sinistra: 3.29 ± 4.75 vs. 0.40 ± 1.50; dextra: 3.64 ± 4.10 vs. 0.33 ± 1.23), with significant results only on the dominant (dextra) side (p=0.017), but not on the sinistra side (p=0.088).

4 Discussion

4.1 Effect ofPlyometric Training on Static Balance

The improvement in static balance in intervention group after plyometric training is significant and is in accordance with the physiological significance of the SSC mechanism in increasing proprioceptive feedback. During the eccentric phase, elastic energy is stored and muscle spindles are activated; mechanoreceptors located throughout muscle, tendon, joint, fascia, and skin convert this mechanical deformation into afferent neural signals that inform the central nervous system about static joint position (joint position sense) and dynamic movement (kinaesthesia) [13]. Although the six exercises used in this program (drop jump, box jump, squat jump, split squat jump, overhead slam, plyometric push-up) are primarily explosive, bilateral movements similar to dynamic motor patterns, each still contributes to static balance through the landing and stabilisation phase: repeated impact absorption during drop jump, box jump, squat jump, and split squat jump stimulates muscle spindles and Golgi tendon organs at the ankle and knee to improve joint position sense [14], consistent with the finding of Huang et al. [14], who reported that plyometric training improved ankle joint position error in athletes. The overhead slam activates core and trunk stabilisers to maintain the base of support during an explosive action, consistent with data that core-focused plyometric work improves postural stability via increased neuromuscular activation of the kinetic chain [15]. Similarly, plyometric push-up trains forceful contraction of the upper-body and core stabilisers, thereby aiding postural control through enhanced segmental load transfer [14]. Taken together, the frequent landing-and-stabilization demands of the program appear sufficient to produce increases in static balance, despite the training not being particularly designed for that goal.

Although there was a large within-group shift, the difference between the groups was not statistically significant. This presumably reflects that both groups continued routine volleyball training throughout the trial, which in itself delivers postural stimulation through defensive positioning, landing after attacks, and ball-reception stability. There may also have been a ceiling effect limiting observable change, given several people in the intervention group were approaching the smallest possible Flamingo score (close-to-zero falls) by post-test, which could have masked further neuromuscular gains that were not detected by the instrument [16]. Statistical power to detect a between-group difference was likely further hampered by the relatively modest group size (n=15 each arm) in combination with substantial interindividual variability. These data indicate that the null between-group result is more likely a consequence of methodological limitations rather than a genuine absence of effect, and that a longer intervention, larger sample size, and more static-balance-specific activities would show a clearer between-group advantage.

4.2 The Influence of Plyometric Training on Dynamic Balance

The intervention group demonstrated considerable improvement in dynamic balance, which is consistent with the explosive, sport-specific movement pattern of the plyometric program, which regularly requires the neuromuscular system to adjust the body's position during motion. Kinaesthesia, the dynamic-movement component of proprioception, including sensing acceleration, force, and velocity [13], is enhanced by the same SSC-driven proprioceptive stimulation described above, and kinaesthesia is known to support gait speed, trunk control, and dynamic neuromuscular control more broadly [17]. Proprioceptive input is closely linked to the quality of balance, meaning that decreased input correlates with worse balance performance [18].

Importantly, the control group also demonstrated a significant improvement in dynamic balance, which is likely due to the inherently dynamic demands of regular volleyball training itself, including rapid lateral movement in defence, landings after jump spikes and jump serves, and multidirectional coordination during reception, which also stimulate the proprioceptive and neuromuscular systems underlying dynamic balance [19]. However, the intervention group improved statistically more ($p<0.001$ vs. $p=0.010–0.007$) and descriptively more (7.48 and 5.37 points on the left and right vs. 3.29 and 3.64 points in controls), suggesting that the added plyometric stimulus produced a greater neuromuscular adaptation than regular volleyball training alone. The large within-group effect size (which is clinically meaningful) for the intervention group on the Y Balance Test (YBT) was likely influenced by the anthropometric variability (i.e., wide leg-length range in the intervention group [75–99 cm], a known biomechanical contributor to Y Balance Test reach distance [20]) that was present in this group, combined with the near-ceiling composite score close to 99.6% in both groups

at post-test [16], and similar baseline scores between groups (control 90.95 vs. intervention 90.01 on the left). This indicates restricted instrument sensitivity and sample size instead than a lack of a meaningful training effect, similar to static balancing.

4.3 Comparison of postural control improvement in static and dynamic conditions

Both groups showed greater improvement in dynamic balance than static balance, with greater improvement in the intervention group. This supports the training specificity principle, as plyometric exercise targets primarily rapid motor-unit recruitment, intermuscular coordination and fast postural correction during movement [21], so its physiological stimulus more closely resembles the challenges of dynamic balance tasks than static, single-position holds. This interpretation is reinforced by the identical pattern in the control group, whose only stimulus was ordinary (inherently dynamic) volleyball instruction. Limb dominance may be a second contributor to the striking sinistra–dextra asymmetry in the control group's static-versus-dynamic comparison (significant only on the dominant/dextra side). Typically, the non-dominant limb exhibits more variable and less organised muscle-recruitment patterns during postural tasks compared to the dominant limb [22], and dominant-limb balance tends to be more consistent under both static and dynamic conditions [23], which might make dominant-side differences easier to detect statistically. The high variability of dynamic-balance delta scores within the control group (SD 4.10–4.75) further suggests that there are substantial inter-individual differences in neuromuscular capacity, injury history or general physical activity level [24], consistent with previous evidence that inter-limb asymmetry in Y Balance Test reach is itself associated with non-contact injury risk in volleyball players [4].

4.4 Implications for Injury Prevention and Sustainable Healthcare in Sports

From a prevention and resource-efficiency point of view, these results have ramifications beyond sports performance. Balance deficits are a well-established risk factor for lower extremity injuries, especially ankle sprains and knee injuries, which are common in volleyball and often require prolonged rehabilitation. A organised plyometric program may help minimise the occurrence of such accidents and, consequently, the downstream demand for medical care and rehabilitation services by improving neuromuscular control and postural stability . As a low-cost, equipment-light intervention that can be implemented directly into ordinary club training, plyometric exercise is particularly suited to youth sports contexts with limited healthcare access, matching with sustainable healthcare's emphasis on preventive, resource-efficient care. Balance-outcome data can potentially serve as a platform for future integration with wearable motion sensors or app-based movement tracking tools, providing continuous, technology-assisted monitoring of injury risk and training preparation in adolescent athletes.

4.5 Limitations

The present study has some limitations, including: a relatively small sample size (30 participants divided into two groups), a short intervention period (6 weeks/18 sessions), which may not have been long enough to obtain a clearly superior effect to regular training, especially for static balance, limited control over participants' physical activity outside the study protocol, and a plyometric program that, although effective, was not specifically designed to isolate static-balance adaptations. Future research should use larger samples, longer intervention periods, better control of extraneous activity and balance-specific modifications in exercise. Additionally, instruments with increased sensitivity at the upper end of the performance range should be used to lessen the constraints of the ceiling effect.

5 Conclusion

Plyometric training resulted in considerable improvement in both static and dynamic balance in adolescent volleyball players at PBV Rajawali, with a more prominent effect on dynamic balance, in line with the training's explosive, movement-specific stimulus. Regular volleyball training alone improved dynamic but not static balance, showing the extra value of a targeted plyometric component. Although there were no statistically significant between-group differences (likely due to sample size, ceiling effects, and the dynamic nature of volleyball training), the consistent within-group gains suggest that plyometric training is a promising, low-cost, and sustainable exercise strategy for improving balance and potentially reducing lower-extremity injury risk in youth volleyball athletes. Coaches and sports physiotherapists may explore adding structured plyometric protocols as an additional aspect of juvenile training programs, with future study geared on larger and longer length trials with technology assisted balance monitoring.

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