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Changes in Flying Shot Performance Following a 4-Week Circuit Training Programme among University Handball Athletes

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ABSTRACT

Background and Purpose: Flying-shot accuracy in handball requires coordinated lower-limb power, upper-body force production, approach movement, and whole-body control. Although resistance, plyometric, and ballistic training can improve selected throwing outcomes, evidence concerning short, multi-component circuit training and flying-shot accuracy in university athletes remains limited. This study examined changes in flying-shot performance following a 12-session, four-week circuit training programme in male university handball athletes.

Materials and methods: A pre-experimental one-group pretest–posttest design was used. Thirty-two male university handball athletes (19–23 years) from Universitas Islam Riau participated through total sampling. The intervention comprised three sessions per week for four weeks and included push-up, squat jump, 20-m shuttle run, medicine-ball chest throw, and bounding, with progressive loading across adaptation (Sessions 1–4), development (Sessions 5–8), and intensification (Sessions 9–12). Flying-shot accuracy was assessed using a standardized three-trial target-scoring test (maximum score = 12). Descriptive statistics, Shapiro–Wilk testing of change scores, Wilcoxon signed-rank testing, and a paired-sample t-test as sensitivity analysis were used. Effect sizes were estimated using r and Cohen's d_z .

Results: Mean performance increased from 4.25 ± 0.92 at pretest to 8.88 ± 1.52 at posttest, with a mean paired change of 4.625 ± 1.755 points (95% CI, 3.992–5.258) and a 108.82% increase based on group means. All 32 participants improved. Change scores were non-normally distributed (Shapiro–Wilk $W = 0.901$, $p = 0.0065$). The Wilcoxon signed-rank test showed a significant pretest-to-posttest change ($W = 0$, $p < 0.001$, $r = 0.877$). The sensitivity paired t-test was also significant, $t(31) = 14.906$, $p < 0.001$, Cohen's $d_z = 2.635$.

Conclusions: The findings provide preliminary evidence of substantial improvement in flying-shot performance following a brief, progressively structured circuit training programme in male university handball athletes. The study extends international evidence by examining a sport-specific accuracy outcome in an Indonesian university context. However, the absence of a control group limits causal attribution and generalization.

Keywords

handball; athletes; circuit training; shooting accuracy; resistance training; physical conditioning.

INTRODUCTION

Global and Theoretical Context

Team handball is a high-intensity intermittent sport in which successful performance depends on the ability to repeatedly combine sprinting, acceleration and deceleration, jumping, rapid changes of direction, physical contact, and high-velocity throwing (Kamış et al., 2025, p. 2; Stanković et al., 2025, p. 52). These demands vary according to playing position, sex, and competitive level, but the sport consistently requires the integration of physical capacities with technically efficient actions under time and space constraints (García-Sánchez et al., 2023; Wei et al., 2024, p. 3206). Throwing is particularly important because offensive success ultimately depends on the ability to convert possession into an accurate and sufficiently powerful shot. Accordingly, conditioning strategies that improve the physical determinants of throwing may have implications for sport-specific performance.

Flying-shot performance represents a particularly complex handball action because it requires the coordination of an approach run, lower-limb propulsion, control of the body during the flight phase, and upper-limb ball release (Ortega-Becerra et al., 2017; Tillaar & Ettema, 2007). Biomechanical evidence

indicates that throwing performance is influenced not only by the throwing arm but also by the ability of the lower limbs to generate and subsequently control momentum before force is transferred through the kinetic chain. Rousanoglou et al. (2014), for example, found differences in ground-reaction-force characteristics between elite and novice players and suggested that the ability to regulate forward momentum and establish an effective base of support contributes to throwing performance. Thus, flying-shot accuracy can be understood as an integrated technical outcome emerging from the interaction of lower-body power, upper-body force production, postural control, and movement coordination rather than as an isolated arm skill.

This perspective provides a theoretical rationale for specific and multi-component conditioning. If the physical requirements underlying a technical movement are distributed across several body segments and performance qualities, a training programme that simultaneously targets relevant strength, power, locomotor, and coordination capacities may have greater potential for functional transfer than an intervention restricted to a single physical quality (Esposito et al., 2026, p. 873; Liu et al., 2014, p. 104). Circuit training offers one such framework because it allows

several exercises to be organized sequentially within the same training session while controlling work duration, recovery, and progression (Hardiansyah et al., 2025, p. 955; Hornby et al., 2019, p. 70). The present intervention operationalizes this concept through push-ups, squat jumps, a 20-m shuttle run, medicine-ball chest throws, and bounding, thereby combining upper-body strength, lower-limb explosive power, locomotor ability, and plyometric demands within a progressively overloaded programme.

Critical Review of Existing Evidence

The international evidence base supports the general proposition that structured physical conditioning can improve handball performance, but the strength of evidence differs substantially according to the outcome examined. A recent systematic review and meta-analysis of 30 studies involving 727 handball players found strong evidence that resistance training improves throwing velocity, with mean standardized effects of 1.128 for jumping-throw velocity, 1.756 for running-throw velocity, and 1.098 for standing-throw velocity (Hadjisavvas et al., 2024, p. 85). However, the authors emphasized substantial heterogeneity among interventions and concluded that evidence for several resistance-training modalities, particularly with respect to throwing accuracy, remains limited (Hadjisavvas et al., 2024). This distinction is important because improvements in the capacity to generate throwing force cannot automatically be assumed to produce improvements in spatial accuracy.

Evidence from individual controlled trials reinforces this concern. In Germany and Spain, Raeder et al. (2015) randomized 28 competitive female handball players to a six-week, three-times-per-week medicine-ball training programme or control condition. The intervention substantially increased throwing velocity and shoulder-rotator strength, but throwing precision did not differ significantly between groups. In contrast, Sinka et al. (2024), studying elite female players from nine Hungarian first-league teams, reported significant improvements in throwing velocity and throwing accuracy following a trunk- and shoulder-strength programme compared with controls. The apparent discrepancy between these findings suggests that the effect of conditioning on accuracy may depend on intervention specificity, the physical qualities emphasized, training duration, participant characteristics, and the measurement construct used to define accuracy. Furthermore, existing research has frequently focused on heavy-load and plyometric methodologies to enhance muscular power, yet the methodological heterogeneity across these studies often obscures the mechanisms driving specific performance gains (Bragazzi et al., 2020).

The broader evidence for plyometric and ballistic training is similarly positive for selected physical outcomes but less conclusive for accuracy-specific performance. A systematic review and meta-analysis of 20 studies involving 563 handball players found medium-to-large effects of plyometric training on countermovement jump, squat jump, horizontal jump, sprint performance, agility, and muscle-power-related outcomes (Wang et al., 2024). More recent evidence also indicates that plyometric training can improve several throwing-related outcomes, including three-step running throw and jumping throw performance, although effects vary according to the specific outcome and programme design. These findings support the inclusion of plyometric exercises such as squat jumps and bounding in handball conditioning, but they do not by themselves establish a direct effect on flying-shot accuracy. Moreover, while muscle power is central to handball throwing ability, several investigations have demonstrated that general strength and

power interventions do not necessarily yield significant improvements in shooting accuracy percentages (Asan, 2023, p. 528).

Ballistic training studies further illustrate the importance of training dose and population. Bouagina et al. (2022) conducted an eight-week randomized controlled trial among 26 junior handball players and reported improvements in upper-body power, muscle volume, and throwing velocity following twice-weekly ballistic training in addition to normal handball practice. By comparison, the present intervention is shorter, lasts four weeks, and uses a broader multi-component circuit rather than a specialized ballistic device. Such differences in age, training status, intervention duration, frequency, and exercise modality make direct comparison of effect sizes inappropriate but highlight an unresolved question concerning whether a brief, resource-efficient programme can produce meaningful changes in a sport-specific accuracy outcome. Furthermore, while prior meta-analyses indicate that plyometric-based protocols significantly enhance vertical jump height and sprint performance in handball athletes, results often exhibit considerable heterogeneity that complicates the establishment of standardized dose-response relationships (Hang et al., 2025, p. 29299).

Another important issue is measurement heterogeneity. Handball studies have used throwing velocity, throwing distance, hit counts, percentage accuracy, target-zone scores, and other indicators of throwing quality. Recent evidence synthesis has noted particularly high heterogeneity in studies of throwing accuracy because apparently similar constructs are often operationalized using different scoring systems and testing conditions (Hadjisavvas et al., 2026). Consequently, conclusions concerning “shooting performance” cannot be transferred automatically across studies unless population, intervention dose, testing protocol, and analytical method are considered together. Additionally, the lack of consensus regarding the transferability of performance gains to match-play scenarios necessitates future investigations that compare improvements in laboratory-based metrics with actual on-court competition results (Aloui et al., 2020, p. 604993; Henrique et al., 2023, p. 315).

Evidence from Indonesia is also emerging but remains relatively fragmented. Yani et al. (2026, p. 571), working with athletes from the same university handball club examined in the present study, reported significant associations between lower-limb explosive power, arm-muscle strength, and flying-shot performance. Rahmadi et al., (2024) similarly reported improved flying-shot accuracy following a combined drilling and plyometric programme among university handball players. These findings provide contextual support for the relevance of lower- and upper-body physical capacities, but both studies differ from the present investigation in design and intervention structure. Neither directly addresses the specific question of whether a progressively overloaded, multi-component circuit programme is associated with changes in flying-shot accuracy in a male university sample. Furthermore, while research has often underscored the role of the lower limbs in generating kinetic energy for throwing, evidence remains divided on whether this translates into improved target-directed precision in the absence of specialized technical drills (Deng et al., 2023, p. 16; Zecchin et al., 2025, p. 458).

Research Gap, Novelty, and International Contribution

Although previous studies show that resistance, plyometric, ballistic, and sport-specific conditioning can improve selected physical and throwing outcomes in handball players, it remains unclear whether a short, progressively overloaded multi-

component circuit training programme is associated with improved flying-shot accuracy among male university handball athletes. This uncertainty is particularly relevant because much of the controlled international evidence has focused on elite or junior athletes, throwing velocity rather than accuracy, specialized resistance protocols rather than integrated circuit training, and intervention periods of approximately six to eight weeks or longer (Bouagina et al., 2021; Hadjisavvas et al., 2024; Raeder et al., 2015; Wang et al., 2024).

The novelty of the present study lies in the combination of four elements. First, the primary outcome is flying-shot accuracy, a sport-specific technical measure rather than a general strength or velocity indicator. Second, the intervention integrates several physical qualities within a single circuit structure, combining upper-body strength, lower-limb explosive power, locomotor conditioning, and plyometric exercise. Third, the study examines male university handball athletes in Indonesia, extending the evidence base beyond the elite and professional settings that dominate international research. Fourth, the analysis uses complete participant-level paired observations and emphasizes the change score as the basis for inferential testing, with non-parametric analysis used when the distributional assumption for paired differences was not satisfied.

The international contribution is therefore not the claim that circuit training is universally superior to other conditioning approaches. Rather, the study extends the evidence base by examining whether a feasible, progressively structured circuit programme is accompanied by meaningful change in a handball-specific accuracy outcome within an underrepresented university population. This provides a basis for subsequent controlled, multicenter research capable of determining whether the

observed change exceeds that attributable to regular training, repeated testing, or other time-dependent factors.

Objectives and Hypotheses

The primary objective of this study was to examine the change in flying-shot performance from pretest to posttest following a 12-session circuit training programme delivered over four weeks, with three sessions per week, among male university handball athletes at Universitas Islam Riau, Indonesia. The intervention progressed through three phases—adaptation (Sessions 1–4), development (Sessions 5–8), and intensification (Sessions 9–12)—using five exercise stations selected to address physical qualities relevant to flying-shot execution. The secondary objective was to quantify the magnitude and precision of the observed pretest-to-posttest change using an appropriate effect-size estimate and confidence interval. The directional hypothesis was:

H₁: Flying-shot performance scores will be higher at posttest than at pretest following completion of the 12-session circuit training programme.

The null hypothesis was:

H₀: There will be no systematic difference in flying-shot performance scores between pretest and posttest.

Because the study employed a one-group pretest–posttest design without a randomized control group, these hypotheses concern within-participant change and do not by themselves establish that circuit training was the sole cause of the observed change. This formulation keeps the Introduction, Methods, Results, and Conclusion aligned with the actual design and statistical analysis.

MATERIALS AND METHODS

Study Design and Setting

This study employed a pre-experimental one-group pretest–posttest design to examine changes in flying shot performance following a structured circuit training programme. The study sequence consisted of a baseline assessment (pretest), a 12-session circuit training intervention delivered over four consecutive weeks, and a post-intervention assessment (posttest):

Pretest → 12-Session Circuit Training Intervention → Posttest

The intervention was conducted at the Indoor Sports Hall (GOR Indoor) of Universitas Islam Riau, Pekanbaru, Indonesia. Training was administered three times per week for four weeks, resulting in 12 training sessions. Because the study did not include a separate control group or random allocation, the design was intended to evaluate within-participant pretest-to-posttest change following participation in the intervention rather than establish definitive causal effectiveness.

Participants and Sampling

The study involved 32 male university handball athletes affiliated with the University Handball Club (UKM Bola Tangan) of Universitas Islam Riau, Pekanbaru, Indonesia. Participants were 19–23 years of age and had at least one year of organized handball training experience. Total sampling was used because the target population comprised a defined university handball club and all eligible athletes available within the study population were included.

Participants were eligible if they: (1) were actively registered members of the university handball club; (2) had a minimum of

one year of organized handball training experience; (3) had no musculoskeletal injury or known contraindication to high-intensity physical exercise at the time of data collection; and (4) agreed to participate in the study and comply with the intervention schedule. Participants were excluded if they: (1) participated concurrently in another structured external physical-conditioning programme during the intervention period; or (2) completed fewer than 80% of the prescribed training sessions. The final analytical dataset consisted of 32 participants, with complete pretest and posttest flying shot observations.

Circuit Training Intervention

The circuit training programme consisted of 12 sessions over four weeks, with three sessions per week. Each session comprised a 15-minute general warm-up, the prescribed circuit training programme, and a 10-minute cool-down. The circuit consisted of five exercise stations performed sequentially: 1) Push-up; 2) Squat jump; 3) 20-m shuttle run; 4) Medicine ball chest throw; and 5) Bounding.

A 30-second recovery interval was provided between stations, followed by a 2-minute rest interval between circuits. The programme employed progressive overload across three consecutive training phases.

Table 1. Structure and Progression of the 12-Session Circuit Training Programme

Training phase	Sessions	Sets	Prescription	Station duration
Adaptation	1–4	2	8 repetitions for strength-based exercises; 2 repetitions for	25 s

Development	5–8	2	distance-based exercises 10 repetitions for strength-based exercises; 3 repetitions for distance-based exercises	30 s
			12 repetitions for strength-based exercises; 4 repetitions for distance-based exercises	
Intensification	9–12	2		35 s

The progressive structure was designed to increase training demand while maintaining the same five-station circuit format throughout the intervention.

Exercise Stations

Push-Up. Push-ups were included to develop upper-body pushing strength involving the pectoral, triceps, and anterior shoulder musculature, which contributes to upper-limb force production during ball release. The exercise was performed using body mass as resistance according to the prescribed repetition and station-duration progression.

Squat Jump. Squat jumps were included to develop lower-limb explosive power relevant to the take-off phase of the flying shot. The exercise targeted the major lower-limb extensor musculature and was performed according to the prescribed training phase.

20-m Shuttle Run. The 20-m shuttle run was included to develop speed-related and reactive movement capacity relevant to the approach phase of flying shot execution. The exercise was performed over a standardized 20-m distance according to the prescribed progression.

Medicine Ball Chest Throw. Medicine ball chest throws were included to develop upper-body power and coordinated force production involving the upper extremities and trunk. A standardized medicine ball was used throughout the intervention.

Bounding. Bounding was included as a horizontal plyometric exercise intended to develop lower-limb power, stretch-shortening-cycle function, and dynamic balance relevant to single-leg propulsion during the flying shot.

The five exercises were selected because they addressed physical qualities considered relevant to the approach, take-off, force production, and propulsion demands of flying shot execution.

Flying Shot Performance Assessment

Measurement Instrument

Flying shot performance was assessed using a structured flying shot accuracy test based on the protocol described by (Sepdanius et al., 2019). The assessment quantified shooting accuracy using standardized target zones and a three-trial procedure.

The equipment consisted of IHF size 3 handballs, three chairs or benches for ball placement, a vertical wall-mounted target corresponding to official handball goal dimensions, a scoring grid, a measuring tape, and chalk or marking tape.

Test Procedure

Three handballs were positioned on separate benches at standardized distances from the shooting area: **500 cm, 350 cm, and 750 cm**, respectively. At the assessor's signal, the athlete approached the designated bench, collected the ball, and executed a flying shot from the predetermined take-off area near the six-metre boundary. The procedure was repeated for all three balls.

Each participant performed **three flying shot trials** during both the pretest and posttest under the same testing arrangement and procedural conditions. Two trained assessors independently observed and scored each attempt without altering the predefined scoring criteria.

Scoring Procedure

The target area was divided into four scoring zones based on the location of the shot relative to the target area. Scores were assigned as follows:

Table 2. Scoring Target zone Procedure

Target zone	Score
Zone 4	4 points
Zone 3	3 points
Zone 2	2 points
Zone 1	1 point
Outside target	0 points

Each trial therefore yielded a score from 0 to 4 points. The three trial scores were summed to obtain a total flying shot performance score ranging from 0 to 12 points for each assessment occasion. The same equipment arrangement, target configuration, shooting procedure, scoring criteria, and testing conditions were applied during the pretest and posttest to minimize procedural variation.

Inter-Rater Reliability

Inter-rater reliability was assessed because two trained assessors independently scored all flying shot trials. The scores of Rater 1 and Rater 2 were retained separately for each of the three pretest trials and three posttest trials for all 32 participants. The primary measure of inter-rater reliability was the intraclass correlation coefficient (ICC) using a two-way random-effects model for absolute agreement with single measures [ICC(2,1)]. ICC estimates were calculated separately for the pretest and posttest total scores, together with 95% confidence intervals. Because individual trial scores were discrete ordinal values ranging from 0 to 4, weighted Cohen's kappa with linear weights was additionally calculated as a supplementary measure of trial-level inter-rater agreement. Exact agreement between the two assessors was also calculated. For the primary intervention analysis, the total scores recorded by Rater 1 were used as the participant-level pretest and posttest outcome measures, while the corresponding Rater 2 scores were used to quantify inter-rater reliability. This separation ensured that the reliability assessment did not alter the primary outcome dataset.

Data Processing and Statistical Analysis

All statistical analyses were conducted using paired participant-level observations. Descriptive statistics were calculated for the pretest, posttest, and change scores and included the mean, standard deviation, median, minimum, and maximum values.

The individual change score was calculated as: Change = Posttest – Pretest

Positive values therefore indicated an improvement in flying shot performance.

Before inferential analysis, the distribution of the paired change scores was assessed using the Shapiro–Wilk test. The normality assessment focused on the within-participant differences because this is the relevant distributional assumption for paired comparisons.

Because the distribution of the paired differences did not satisfy the normality assumption, the Wilcoxon signed-rank test was specified as the primary inferential analysis for evaluating the pretest-to-posttest change. The analysis was two-tailed, and statistical significance was set at $\alpha = 0.05$.

The paired-samples t-test was additionally conducted as a sensitivity analysis to determine whether the inference regarding

the pretest-to-posttest change was materially affected by the choice of statistical test. The mean paired difference and its 95% confidence interval were reported together with the corresponding test statistic.

Effect magnitude for the Wilcoxon analysis was summarized using the rank-based effect size r , whereas Cohen's d_z was reported for the paired-samples t -test. The effect-size estimates were interpreted in conjunction with the magnitude and precision of the observed change rather than statistical significance alone. For the descriptive interpretation of change, the percentage increase in the group mean was calculated as:

$$\text{Percentage increase} = \frac{\text{Posttest Mean} - \text{Pretest Mean}}{\text{Pretest Mean}} \times 100$$

All statistical tests were two-tailed, and the analytical unit was the individual participant.

RESULTS

A total of 32 male university handball athletes participated in the study. The participants had a mean age of 20.91 ± 1.44 years (range, 19–23 years) and a mean handball training experience of 2.00 ± 1.16 years (range, 1–5 years). Complete pretest and posttest observations were available for all 32 participants. The intervention was conducted over four weeks at a frequency of three sessions per week, resulting in 12 training sessions.

Table 3. Participant Characteristics (N = 32)

Characteristic	Value
Sample size	32
Sex	Male
Age, mean $\pm$ SD (years)	20.91 ± 1.44
Age range (years)	19–23
Training experience, mean $\pm$ SD (years)	2.00 ± 1.16
Training experience range (years)	1–5
Intervention duration	4 weeks
Training frequency	3 sessions/week
Total intervention sessions	12

Descriptive Statistics of Flying Shot Performance

The descriptive analysis showed an increase in flying shot performance from pretest to posttest. The mean pretest score was 4.25 ± 0.92 points, with individual scores ranging from 3 to 6 points. The mean posttest score increased to 8.88 ± 1.52 points, with scores ranging from 7 to 12 points.

The mean within-participant change was 4.625 ± 1.755 points, with a 95% confidence interval of 3.992 to 5.258 points. Calculated from the group means, the relative increase from pretest to posttest was 108.82%. All 32 participants showed a positive change in flying shot performance, with individual improvements ranging from 2 to 9 points. The group-level pattern is illustrated in Figure 1, while individual participant trajectories are shown in Figure 2.

Table 4. Descriptive Statistics of Flying Shot Performance (N = 32)

Variable	Mean	SD	Median	Min	Max
Pretest	4.25	0.92	4.00	3	6
Posttest	8.88	1.52	8.00	7	12
Change (Posttest – Pretest)	4.63	1.76	4.00	2	9

Note. SD = standard deviation. Change represents the individual posttest score minus the corresponding pretest score. The maximum possible total score was 12 based on three trials with a maximum of 4 points per trial.

Ethical Considerations

Ethical approval for the study was obtained from the Research Institute of the Faculty of Teacher Training and Education (FKIP), Universitas Islam Riau, under approval/reference number UIR/FKIP-skripsi-6611. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and applicable institutional research-ethics requirements. Before participation, all athletes received information regarding the study objectives, procedures, potential risks and benefits, confidentiality arrangements, and their right to withdraw from participation without penalty. Written informed consent was obtained from all participants before any study-related procedures were initiated. Participant identities were protected through coded records and confidential handling of the research data.

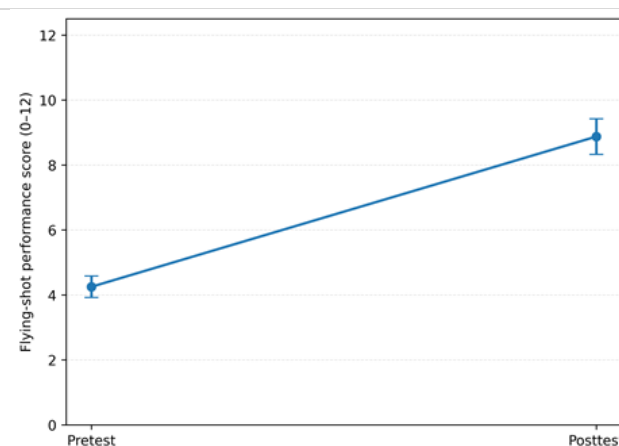


Figure 1. Pretest and posttest flying-shot performance (mean $\pm$ 95% CI), N = 32.

Trial-Level Flying Shot Performance

Improvement was observed across all three flying shot trials. At pretest, the mean scores for Trials 1, 2, and 3 were 1.50 ± 0.51 , 1.38 ± 0.49 , and 1.38 ± 0.49 points, respectively. Following the intervention period, the corresponding posttest means increased to 2.91 ± 0.69 , 2.94 ± 0.62 , and 3.03 ± 0.59 points. The mean improvements were 1.41, 1.56, and 1.66 points for Trials 1, 2, and 3, respectively. Thus, the observed improvement was consistent across all three shooting attempts rather than being restricted to a single trial.

Table 5. Trial-Level Flying Shot Performance

Trial	Pretest, Mean $\pm$ SD	Posttest, Mean $\pm$ SD	Mean Change
Trial 1	1.50 ± 0.51	2.91 ± 0.69	1.41
Trial 2	1.38 ± 0.49	2.94 ± 0.62	1.56
Trial 3	1.38 ± 0.49	3.03 ± 0.59	1.66

Inter-Rater Reliability

Because each flying shot attempt was scored independently by two trained assessors, inter-rater reliability was examined before the intervention effect was interpreted. For the pretest total score, the two-way random-effects absolute-agreement ICC for a single measure [ICC(2,1)] was 0.892 (95% CI 0.786–0.959). The corresponding exact agreement between assessors was 81.25%. For the posttest total score, the ICC(2,1) was 0.691 (95% CI 0.399–0.870), with 81.25% exact agreement. At the individual-trial level, ICC values for the three pretest trials were 0.903,

0.870, and 0.889, respectively. The corresponding posttest ICC values were 0.737, 0.659, and 0.500. Weighted Cohen's kappa provided supplementary trial-level agreement estimates. The coefficients ranged from 0.867 to 0.889 across the three pretest trials and from 0.484 to 0.724 across the three posttest trials. These results indicate stronger agreement during the pretest assessment and more variable agreement among the posttest trial scores.

Table 7. Trial-Level Inter-Rater Agreement

Trial	Pre/Post	ICC(2,1)	Weighted Cohen's κ	Exact Agreement
Trial 1	Pretest	0.903	0.889	93.75%
Trial 2	Pretest	0.870	0.867	93.75%
Trial 3	Pretest	0.889	0.877	93.75%
Trial 1	Posttest	0.737	0.724	93.75%
Trial 2	Posttest	0.659	0.644	93.75%
Trial 3	Posttest	0.500	0.484	93.75%

Assessment of Distributional Assumptions

Because the primary comparison involved paired observations, the distribution of the individual change scores (posttest minus pretest) was examined using the Shapiro–Wilk test. The paired change scores significantly departed from normality ($W = 0.901$, $p = 0.0065$). The pretest and posttest total-score distributions were also non-normal ($W = 0.785$, $p < 0.001$ and $W = 0.679$, $p < 0.001$, respectively). Accordingly, the Wilcoxon signed-rank test was selected as the primary inferential analysis for the pretest-to-posttest comparison.

Table 8. Shapiro–Wilk Normality Tests

Variable	W	p-value	Interpretation
Pretest	0.785	<0.001	Non-normal
Posttest	0.679	<0.001	Non-normal
Paired difference	0.901	0.0065	Non-normal

Wilcoxon Signed-Rank Test

The Wilcoxon signed-rank analysis demonstrated a statistically significant within-participant increase in flying shot performance from pretest to posttest ($W = 0$, $p < 0.001$). All 32 participants showed positive changes, with no participant

Table 6. Inter-Rater Reliability of Flying Shot Scoring			
Assessment	ICC(2,1)	95% CI	Exact Agreement
Pretest total score	0.892	0.786–0.959	81.25%
Posttest total score	0.691	0.399–0.870	81.25%

Note. ICC(2,1) = two-way random-effects, absolute-agreement, single-measure intraclass correlation coefficient; CI = confidence interval.

showing a zero or negative change. The rank-based effect size was $r = 0.877$, indicating a substantial magnitude of within-participant change. Thus, the observed increase was statistically significant and accompanied by a large standardized change in the paired observations.

Table 9. Wilcoxon Signed-Rank Test for Flying Shot Performance

Comparison	N	W	p-value	Effect size (r)
Posttest vs. Pretest	32	0	<0.001	0.877

Note. W represents the Wilcoxon signed-rank statistic.

Paired-Sample t-Test as a Sensitivity Analysis

Although the paired difference scores did not meet the Shapiro–Wilk normality criterion, a paired-samples t-test was conducted as a sensitivity analysis. The analysis yielded a statistically significant difference between pretest and posttest scores, $t(31) = 14.906$, $p < 0.001$.

The mean paired difference was 4.625 points (95% CI 3.992–5.258), and the standardized paired effect size was $*Cohen's dz = 2.635^*$. The direction and statistical significance of the sensitivity analysis were consistent with the Wilcoxon signed-rank analysis.

Table 10. Paired-Sample t-Test and Effect Size

Comparison	Mean Difference	SD Difference	95% CI	t	df	p-value	Cohen's dz
Posttest – Pretest	4.625	1.755	3.992–5.258	14.906	31	<0.001	2.635

Summary of Main Findings

Overall, flying shot performance increased from 4.25 ± 0.92 points at pretest to 8.88 ± 1.52 points at posttest, corresponding to an absolute mean change of 4.625 points and a 108.82% increase relative to the pretest group mean. Improvement was observed across all three flying shot trials, and all 32 participants demonstrated a positive individual change. Given the non-normal distribution of the paired differences, the Wilcoxon signed-rank test was treated as the primary inferential analysis and showed a statistically significant pretest-to-posttest change ($W = 0$, $p < 0.001$, $r = 0.877$). The paired-samples t-test sensitivity analysis yielded a consistent result ($*t(31) = 14.906$, $p < 0.001$, Cohen's $dz = 2.635^*$). The inter-rater analysis showed ICC(2,1) = 0.892 for the pretest total score and ICC(2,1) = 0.691 for the posttest total score, indicating that agreement between the two assessors was higher during pretest assessment than during posttest assessment.

DISCUSSION

Interpretation of the Principal Findings

The present study examined whether a 12-session circuit

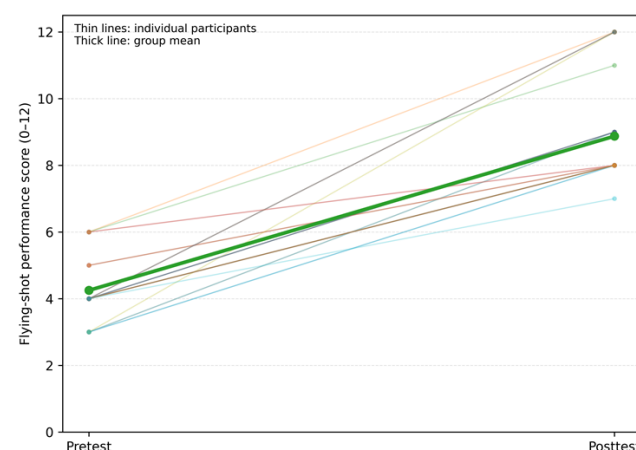


Figure 2. Individual participant trajectories from pretest to posttest; the thicker line represents the group mean.

training programme delivered over four weeks was accompanied by changes in flying shot performance among male university

handball athletes. The principal finding was a marked increase in flying shot scores from a pretest mean of 4.25 ± 0.92 to a posttest mean of 8.88 ± 1.52 points, corresponding to a mean within-participant increase of 4.625 points and a 108.82% increase relative to the pretest group mean. All 32 participants demonstrated a positive change, with individual improvements ranging from 2 to 9 points. Because the paired differences were non-normally distributed, the Wilcoxon signed-rank test was used as the primary inferential analysis and showed a statistically significant pretest-to-posttest change ($W = 0$, $p < 0.001$, $r = 0.877$). The paired-samples t-test conducted as a sensitivity analysis yielded a consistent result ($t(31) = 14.906$, $p < 0.001$, Cohen's $d_z = 2.635$), supporting the robustness of the observed within-participant change across alternative analytical approaches.

The magnitude and consistency of the change are noteworthy, but they should be interpreted in relation to the study design. The absence of a randomized control group means that the observed pretest-to-posttest improvement cannot be attributed exclusively to the circuit training programme. Repeated exposure to the flying shot test, ongoing handball practice, changes in motivation, familiarization with the testing procedure, and other time-dependent influences may have contributed to the observed improvement. Therefore, the present findings provide evidence of substantial performance change following participation in the circuit programme, but they do not by themselves establish that circuit training was the sole cause of that change.

The improvement was also evident at the individual trial level. Mean performance increased from 1.50 to 2.91 points in Trial 1, from 1.38 to 2.94 points in Trial 2, and from 1.38 to 3.03 points in Trial 3. The corresponding mean changes were 1.41, 1.56, and 1.66 points, respectively. This pattern suggests that the improvement was distributed across the complete three-trial assessment rather than being driven by a single unusually successful attempt. Such consistency strengthens the interpretation that the observed change reflected a broader improvement in the tested flying shot outcome, although it should still be interpreted as a change in the specific test score rather than a direct measure of competitive match performance. These findings align with prior research demonstrating that structured physical training interventions consistently enhance sport-specific mechanical outputs and neuromuscular performance in athletes (Balaji et al., 2024, p. 47; Hammami et al., 2020, p. 29).

Possible Physiological and Neuromuscular Explanations

Several features of the intervention provide plausible explanations for the observed improvement. The flying shot is a multi-phase action that requires coordinated execution of the approach run, single-leg take-off, aerial control, and ball release. The programme therefore combined exercises targeting several physical qualities relevant to these phases rather than relying on a single conditioning modality. This design is consistent with previous descriptions of the flying shot as an integrated movement requiring lower-limb explosive capacity, upper-body force production, and coordinated transfer of force through the kinetic chain (Akramov, 2025; Benyahia et al., 2026, p. 6; Boltabayev, 2025).

The upper-body components of the circuit, particularly push-ups and medicine ball chest throws, were intended to increase the force-production capacity of the musculature involved in the throwing action. Previous evidence has linked resistance-based training with improvements in throwing-related performance

through adaptations in muscular force production and neuromuscular coordination (Bragazzi et al., 2020; Wahyudi, 2018). In the context of the present study, these exercises may therefore have contributed to improved control and force transmission during the release phase of the flying shot. However, because no direct measures of upper-limb strength or ball velocity were collected, this explanation remains mechanistic rather than directly demonstrated by the present data. Furthermore, the observed enhancements may be partially attributed to improved neuromuscular efficiency and motor unit synchronization, which facilitate more forceful and coordinated muscle contractions during explosive throwing movements (Wang & Xu, 2025, p. 1539746).

The inclusion of squat jumps and bounding provided repeated exposure to explosive lower-limb actions that correspond to the take-off demands of the flying shot. Plyometric exercises have been associated with improvements in lower-limb explosive capacity in handball and other team-sport populations (Chelly et al., 2013; Kale, 2016, p. 146; Şanta et al., 2025). Improved lower-limb force production could plausibly support more effective propulsion during take-off, while the repeated coordination demands of the movement may also contribute to more stable execution of the approach-to-take-off sequence.

The 20-m shuttle run additionally targeted locomotor speed, repeated acceleration, and movement control during the approach phase. This component may have contributed indirectly to flying shot performance by improving the athlete's ability to enter the take-off phase with greater consistency. Similarly, the sequential structure of the circuit required repeated transitions between lower- and upper-body tasks, which may have increased opportunities for inter-muscular coordination across the movement system. Such an interpretation is compatible with the kinetic-chain perspective of handball throwing, in which effective transfer of force across body segments contributes to efficient execution of projectile actions (García-Buendía et al., 2022, p. 15928; Goranovic et al., 2023, p. 1884; Wagner et al., 2011).

The progressive-overload structure may also be relevant. The programme progressed from an adaptation phase to development and intensification, while preserving the same five-station structure. This gradual increase in repetition demand and station exposure is consistent with established strength-and-conditioning principles and provides a plausible training stimulus for adaptation within a short intervention period (Feito et al., 2018, p. 6; Ratamess, 2012). Nevertheless, the present study did not include physiological, neuromuscular, or biomechanical measurements, so these proposed mechanisms should be regarded as plausible explanations rather than experimentally confirmed mediators.

Comparison with Previous Research

The present findings are broadly consistent with previous research showing that physical conditioning can influence handball throwing and flying shot performance. (Petružela et al., 2023) reported improvements in flying shot performance following upper-limb resistance exercises involving push-ups and pull-ups. The present study extends that line of work by using a multi-component programme that combined upper-body strength, lower-limb explosive exercise, locomotor conditioning, and plyometric exercise within a single progressively structured circuit.

The relevance of lower- and upper-body physical capacities to flying shot performance is also supported by Chelly et al. (2010), who reported significant associations between lower-limb explosive power, arm-muscle strength, and flying shot

performance among athletes from the same university handball environment. These findings provide a rationale for incorporating exercises such as squat jumps and medicine ball throws into a programme designed to support flying shot execution.

Evidence from other conditioning settings is also consistent with these findings. Circuit training has been associated with increased VO_2max in handball athletes (Adel et al., 2024), while circuit-based programmes in other athletic populations have been linked to gains in agility and lower-limb power (Hermassi et al., 2017; Muñoz-Martínez et al., 2017, p. 2554; Rameshkannan & Chittibabu, 2024). Collectively, these studies suggest that circuit training can address multiple physical capacities relevant to complex sporting movements. In addition, combining different training modalities may be effective for developing anaerobic capacity and helping athletes maintain physical performance during the competitive season (Cherif et al., 2012, p. 27).

At the same time, direct comparisons of effect sizes across studies should be made cautiously. Previous investigations have differed substantially in participant age, competitive level, training status, intervention duration, weekly frequency, exercise selection, and outcome measurement. For example, Bouagina et al. (2021) examined an eight-week ballistic training intervention in 26 junior handball players and reported improvements in upper-body power, muscle volume, and throwing velocity. The present study differed in both population and intervention design, using a shorter four-week multi-component circuit and a flying shot accuracy outcome rather than throwing velocity. Consequently, the large standardized change observed in the present study should not be interpreted as evidence that the current programme is quantitatively superior to the interventions examined in previous studies.

Measurement heterogeneity is another important consideration when comparing studies of handball performance. Research has used throwing velocity, throwing distance, hit counts, percentage accuracy, target-zone scores, and other operational definitions of throwing performance. Because apparently similar constructs may be measured under substantially different protocols, differences in effect magnitude across studies may partly reflect differences in measurement rather than differences in intervention potency. This issue is particularly relevant to flying shot accuracy, for which the present study used a three-trial target-zone scoring system.

Within the Indonesian context, these findings contribute to the developing evidence base on handball conditioning (Yani et al., 2026, p. 583). Previous research has examined lower-limb power, upper-limb strength, and combined drill- or plyometric-based approaches to flying-shot performance (Henrique et al., 2023, p. 314). The present study adds a distinct programme structure, integrating several physical qualities into a brief, progressively overloaded circuit delivered in a university training environment.

Measurement Quality and Inter-Rater Reliability

An additional contribution of the present study is the explicit examination of inter-rater reliability for the flying shot scoring procedure. The total-score analysis produced an ICC(2,1) of 0.892 (95% CI 0.786–0.959) for the pretest and 0.691 (95% CI 0.399–0.870) for the posttest. Trial-level analyses showed consistently higher agreement across the three pretest trials, whereas agreement was more variable across the posttest trials. Weighted Cohen's kappa showed the same general pattern.

These findings have two implications for interpretation. First, the relatively high pretest agreement supports the consistency of the scoring procedure under baseline conditions. Second, the

lower and more variable posttest agreement indicates that the measurement process was not perfectly invariant across assessors, particularly at the individual-trial level. This is important because any measurement disagreement can introduce error into the observed change. The magnitude and consistency of the pretest-to-posttest improvement therefore should be interpreted together with the observed inter-rater agreement rather than assuming that the outcome measure was entirely free from measurement error.

The reliability findings also highlight the value of maintaining explicit scoring criteria and assessor training in future studies. Because the flying shot score depends on the location of the shot within predefined target zones, assessor calibration and clear operational definitions may reduce disagreement, particularly when performances become more accurate and shots cluster within higher-scoring zones.

Practical Implications

The practical relevance of the findings lies primarily in the feasibility of the intervention. The programme required a limited set of conventional training resources and was delivered within a four-week period at three sessions per week. This structure may be applicable to university handball environments in which training time and equipment are constrained.

From a programme-design perspective, the current intervention provides a practical example of integrating several physical qualities within a single session. Lower-limb explosive exercises such as squat jumps and bounding may be incorporated alongside upper-body power exercises such as medicine ball chest throws and push-ups, while the 20-m shuttle run provides a locomotor-conditioning component relevant to the approach phase. The progressive structure used in the present programme can also serve as a template that coaches adapt according to athlete training status, available space, and overall training load.

Nevertheless, the findings should not be interpreted as evidence that circuit training should replace technical handball practice. Flying shot performance is a complex skill, and conditioning exercises are more appropriately viewed as complementary components of a broader programme that includes technical, tactical, and sport-specific practice.

Strengths and Limitations

Several features strengthen the interpretability of this study. First, the analysis was based on complete paired observations from 32 participants, allowing each athlete to serve as his own reference across the two assessment occasions. Second, the intervention was explicitly structured around progressive overload and included exercises selected to target multiple physical demands associated with flying shot execution. Third, the outcome was assessed using three attempts at both pretest and posttest rather than relying on a single shot, thereby reducing the influence of one isolated performance. Fourth, the study reported a non-parametric primary analysis appropriate to the observed distribution of the paired differences, together with a sensitivity analysis, confidence interval, and standardized effect estimate. Fifth, the study included an explicit assessment of inter-rater reliability, providing additional information about measurement consistency.

These strengths should be considered alongside several limitations. The most important is the one-group pretest–posttest design without a randomized control group, which prevents definitive causal attribution of the observed improvement to circuit training alone. Repeated testing, regular handball practice, motivational changes, and other temporal influences may also

have contributed to the change. Second, the sample was limited to 32 male university handball athletes from a single institutional setting, which restricts the extent to which the findings can be generalized to female athletes, younger athletes, elite athletes, or athletes from other coaching environments. Third, the intervention lasted only four weeks, so the persistence of the observed improvement after the programme ended remains unknown. Fourth, the study did not include direct biomechanical or physiological measures such as jump height, force production, electromyographic activity, or ball velocity. As a result, the proposed physiological and neuromuscular mechanisms cannot be directly verified from the present dataset. Finally, the posttest inter-rater reliability estimates were more variable than those observed at pretest, indicating that scoring consistency may warrant further standardization in future work.

Directions for Future Research

Future studies should use randomized controlled designs with appropriate comparison groups to determine whether the improvement observed in the present study exceeds changes attributable to repeated testing, regular practice, or other time-

dependent factors. Larger and more heterogeneous samples would also improve the generalizability of the findings, particularly through the inclusion of female athletes, different age groups, and athletes from multiple universities or competitive levels.

Longer intervention periods would allow researchers to examine whether the early improvements observed over four weeks are maintained or continue to increase with extended training exposure. Future studies should also combine the flying shot accuracy test with biomechanical and physiological outcomes, including jump height, lower-limb power, ball velocity, movement kinematics, and other measures of performance. Such a multidimensional approach would help determine which components of the circuit programme contribute most strongly to changes in flying shot execution. Finally, future investigations should strengthen assessor standardization through formal calibration procedures and repeated reliability assessment. This would be particularly valuable when scoring post-intervention performances, where the present study showed greater variability in inter-rater agreement. Multicenter studies involving Indonesian university handball programmes would further strengthen the external validity of the evidence base.

CONCLUSION

The present study examined changes in flying shot performance following a 12-session circuit training programme delivered over four weeks among male university handball athletes. Flying shot performance increased substantially from pretest to posttest, with the primary non-parametric analysis demonstrating a statistically significant within-participant improvement and a large effect size. The consistency of improvement across the three flying shot trials, together with the sensitivity analysis, supports the conclusion that participation in the structured circuit training programme was associated with meaningful improvement in the measured flying shot performance.

The main contribution of this study is the provision of evidence

from an underrepresented university handball population in Indonesia concerning a short, progressively structured, multi-component circuit programme targeting a sport-specific technical outcome. The findings provide a feasible basis for further investigation of integrated conditioning approaches in university handball. However, because the study used a one-group pretest-posttest design without a randomized control group and involved male athletes from a single university, the findings should not be interpreted as definitive evidence of a causal training effect or generalized automatically to other athlete populations, competitive levels, or training environments.

DECLARATION

Ethical Approval

Ethical approval for this study was obtained from the Research Institute of the Faculty of Teacher Training and Education (FKIP), Universitas Islam Riau, under approval/reference number UIR/FKIP-skripsi-6611. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and applicable institutional research-ethics requirements.

Consent to Participate

Written informed consent was obtained from all participants before participation in the study. Participants were informed about the study objectives, procedures, potential risks and benefits, confidentiality arrangements, and their right to withdraw from the study at any time without penalty.

Consent for Publication

The manuscript does not contain personally identifiable information, individual photographs, or other materials that would permit identification of individual participants.

Author Contributions (CRediT)

Budi Arif Setiawan: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Writing—original draft; Visualization.

Raffly Henjilito: Conceptualization; Methodology; Supervision; Validation; Writing—review and editing; Project administration.

Both authors: Interpretation of the findings, critical revision of the

manuscript, and approval of the final version of the manuscript.

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Conflict of Interest

The authors declare that they have no competing interests or conflicts of interest that could have influenced the design, conduct, analysis, interpretation, or reporting of this study.

Data Availability

The de-identified research dataset underlying the findings of this study is available from the corresponding author upon reasonable request, subject to applicable ethical, privacy, and institutional restrictions.

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checking, and statistical presentation/review based on the researchers' supplied research materials and de-identified dataset. AI-generated suggestions were reviewed, verified, and,

where necessary, revised by the authors, who retain full responsibility for the accuracy, integrity, interpretation, and final content of the manuscript.

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