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CONDITIONING-TO-SKILL TRANSFER IN BASKETBALL: A LARGE-SAMPLE COMPARATIVE TRIAL OF CIRCUIT TRAINING, PLYOMETRIC TRAINING, AND COMBINED TRAINING ON VERTICAL JUMP HEIGHT AND SHOOTING ACCURACY

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ABSTRACT
Background and Theoretical Rationale: The major issue yet to be sorted out in the scientific study of conditioning in basketball is whether any improvement in physical capabilities brought about through planned training can result in an observable effect in terms of sports specific technical skill capability. Although there have been numerous studies related to CT, PT, and COMB as forms of conditioning exercises, no study based on a significant sample size has done a direct comparison between CT, PT, and COMB in relation to VJH and SA.
Objective: Fo r comparison of the within and between group effects of CT, PT, and COMB on VJH and SA among the population of amateur basketball players as well as assessment of the conditioning-to-skill-transfer mechanism via theoretical basis involving the SAID principle, neuromuscular adaptation theory, and transfer of training theory.
Methods: Three-group quasi-experimental pre-post design (TREND-compliant). Nine hundred amateur basketball players (Male: n = 485, Female: n = 415; age: 20.3 ± 3.1 years; training experience: 5.5 ± 2.6 years) were enrolled from university, school, and community programmes and assigned to CT (n = 274), PT (n = 323), or COMB (n = 303). Interventions ran for eight weeks at three sessions per week. VJH was assessed via standardised counter-movement jump (CMJ; ICC = 0.96); SA was assessed via the AAHPERD basketball shooting test (ICC = 0.91). Within-group effects: paired-samples t-tests, Cohen's d, Hedges' g, 95% confidence intervals. Between-group effects: one-way ANOVA, Tukey HSD post-hoc, partial eta-squared (η^2p). Individual-level practical significance was evaluated using Smallest Worthwhile Change (SWC = 0.2 × pre-test SD).
Results: All three modalities produced statistically significant and practically large within-group improvements (all $p < 0.001$). VJH: CT +4.70 cm (9.2%, d = 2.40, 95% CI [4.46, 4.93]); PT +4.32 cm (8.7%, d = 2.24, 95% CI [4.11, 4.53]); COMB +4.61 cm (9.1%, d = 2.33, 95% CI [4.39, 4.84]). SA: CT +7.01% (10.4%, d = 2.44, 95% CI [6.67, 7.35]); PT +6.91% (10.3%, d = 2.56, 95% CI [6.62, 7.21]); COMB +7.26% (10.6%, d = 2.54, 95% CI [6.94, 7.58]). Between-group: statistically significant but trivially small VJH difference ($F(2,897) = 3.18$, $p = 0.042$, $\eta^2p = 0.007$; CT > PT: Tukey p = 0.048, d = 0.20); SA not significant ($F(2,897) = 1.23$, $p = 0.293$, $\eta^2p = 0.003$). SWC analysis: 88–91% of participants exceeded VJH SWC; ≥99% exceeded SA SWC across all groups.
Conclusion: The effectiveness of all three modalities in eliciting conditioning-to-skill transfer is unequivocal and leads to consistently large performance effects on physical performance and skills. Inter-group differences exist but are statistically significant yet practically meaningless for VJH, while none exist for SA. This suggests a lack of differential clinical effect between the modalities from the perspective of basketball conditioning practice. The results offer benchmarking measures for effect sizes within basketball conditioning research and contribute towards the conditioning-to-skill transfer controversy through evidence showing the importance of periodisation and context when selecting a modality.

KEYWORDS: Basketball conditioning; conditioning-to-skill transfer; vertical jump; shooting accuracy; circuit training; plyometric training; combined training; SAID principle; neuromuscular adaptation; transfer of training

1. INTRODUCTION
The physical demands of playing basketball are extremely challenging. In essence, basketball can be described as a combination of repeated bursts of energy production and expenditure combined with technical skills and tactical decisions over the course of 40 minutes of competition (Ben Abdelkrim et al., 2007; McInnes et al., 1995). Modern match analysis shows that elite players perform more than 1,000 individual moves per match, out of which about 15% involve intense actions like sprinting, jumping, cutting, and deceleration (Scanlan et al., 2014). Given the physiological background mentioned above, the key challenge for researchers of basketball is to ensure the transference of any gained physical improvements into technical abilities of the sport.

These challenges are most evident with regard to two performance indicators which are critical to basketball success: vertical jump height (VJH) and shooting accuracy (SA). Indeed, VJH is essential for the successful performance in such tasks as rebounding, shot blocking, finishing in the lane and defensive recovery – actions which distinguish winning from losing teams (Pojskic et al., 2018).Shooting accuracy is the primary scoring mechanism in basketball and is acutely sensitive to neuromuscular fatigue; accumulating evidence demonstrates significant late-game declines in shooting efficiency when physical stress is highest (Hoffman et al., 2000). Conditioning that simultaneously enhances explosive power and preserves shooting mechanics under fatigue therefore represents the highest-value target for evidence-based basketball preparation.

However, there is a major evidentiary gap in the conditioning to skill transfer research in basketball. The majority of research conducted regarding CT, PT, and COMB has emphasized physical performance improvements such as jumping ability, sprinting velocity, and agility, yet not included assessments regarding the potential translation of these improvements into technical performance gains in the sport. Even when researchers have examined basketball skills, studies have been hampered by a number of factors including sample size (smaller than n = 20 to 60 participants), short training period, lack of comparisons between groups, and poor reporting of statistics, thus preventing an analysis of practical significance (Pojskic et al., 2018; Slimani et al., 2016).

In the context of this research study, the three different forms of training used in this paper reflect various theoretical pathways of potential mediation of conditioning-skill transfer. The first such modality is circuit training (CT). Circuit training involves simultaneous engagement of several physical qualities — muscular strength, muscular endurance, cardiorespiratory fitness, and neuromuscular co-ordination in successive exercise stations separated by short periods of transition between each station (Gettman & Pollock, 1981; Morgan & Anderson, 1953). In terms of physiological specificity, CT resembles basketball activities and offers an excellent ecological validity for facilitating skill conditioning transfer (Annasai et al., 2023). On the other hand, plyometric training (PT) relies on the principle of stretch-shortening cycle (SSC), which is the coupling of eccentric contraction pre-activity with concentric muscular actions in order to produce maximal explosive force production by way of elastic energy storage and potentiation of the nervous system (Komi, 2003). PT has the most established evidence base for VJH improvement across meta-analyses (Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2020), though its technical skill transfer pathway is less characterised. Combined training (COMB) integrates CT and PT within a periodised block, theoretically activating both aerobic-metabolic and neuromuscular SSC pathways and offering breadth of adaptation that specialist modalities may not achieve (Bompa & Buzzichelli, 2018; Wilson et al., 2012).

In this regard, the current study helps fill the existing gap in research in that it recruits the largest sample size (N = 900) yet used in a comparison study on basketball training, evaluating both VJH and SA, while employing a comprehensive statistical analysis including effect sizes, confidence intervals, practical significance tests, and sub-group comparisons. The main aim of this study was to find out if the path of transfer from conditioning to skill is the same in each condition (CT, PT, COMB), or if there is some kind of modality-specific advantage in either case.

Four a priori hypotheses were postulated. Hypothesis one (H1): Significant gains in VJH and SA performance would be observed in all three training programs, which is supported by the SAID concept and previous research on all three types of training. Hypothesis two (H2): Superior gains in SA would be demonstrated by the CT group, since the endurance and coordination activities in CT stimulate the shooting mechanics more directly than other forms of exercise. Hypothesis three (H3): Superior gains in VJH would be demonstrated by the PT group, since it involves SSC specific neuromuscular adaptation.

2. THEORETICAL FRAMEWORK

In this current study, there exist four overlapping theoretical models explaining how physical conditioning in a systematic manner results in performance improvement on the basketball court. This theoretical model, consisting of four theoretical frameworks that overlap with each other, has been integrated to form a theoretical model (Figure 1).

2.1 Principle of Specific Adaptation to Imposed Demands (SAID)

SAID Principle, which states that physiological adaptations are maximized when the stimuli used in training is similar to the demands encountered in the target activity, forms the basis of all three types of conditioning being discussed (Baechle & Earle, 2008). Basketball's physiological profile, characterised by repeated 2–6 second bouts of maximal or near-maximal effort interspersed with brief incomplete recovery, places simultaneous demands on anaerobic power, glycolytic capacity, aerobic recovery, neuromuscular coordination, and sport-specific technical precision (McInnes et al., 1995; Ben Abdelkrim et al., 2007). CT's intermittent station-based structure most directly approximates this profile at the system level — engaging multiple energy systems and muscle groups within a single session in patterns that parallel the alternating work-rest demands of competition. PT's SSC-dominant stimulus, while metabolically narrower, provides the highest degree of mechanical specificity for the explosive jump actions that dominate basketball's decisive moments. COMB attempts to satisfy SAID demands for breadth and specificity simultaneously by alternating CT and PT stimuli across the training week.

The SAID principle also provides the theoretical basis for predicting that conditioning-to-skill transfer will be greatest when training content includes movements and physiological demands that overlap with the technical skill being assessed. Both VJH (directly trained in PT; partially trained in CT's jump stations) and SA (trained via fatigue-resistance development in CT and core stability in all modalities) should therefore exhibit significant improvement — but potentially through distinct mechanisms.

2.2 Neuromuscular Adaptation Theory

The physiological adaptation process results in performance enhancement via a series of neuromuscular adaptations which occur in a sequential order. During the initial stages of conditioning (first four weeks), performance enhancement is mainly achieved via neural factors which include: enhanced motor unit recruitment, increased discharge rate, improved muscle coordination and reduced co-contraction of antagonist muscles (Kraemer & Ratamess, 2004). The neural adaptations result in an improved ability to generate more force with the same existing muscle mass. During later stages of conditioning (five and eight weeks and beyond), morphological adaptations play a bigger role in performance enhancement (Komi, 2003).

However, with regards to VJH, PT is specifically geared towards targeting the SSC through exercises such as depth jumps, bounding, and reactive jumps. Muscles used during these exercises go through eccentric preloading followed by concentric contraction for maximal elasticity of energy storage and potentiation. CT, on the other hand, can be used to enhance VJH through an entirely different neural pathway. Through progressively accumulating metabolic fatigue during exercises where one must develop their force, CT has the ability to increase RFD and neuromuscular efficiency despite the accumulation of the metabolic fatigue. Such skills are necessary for maintaining performance levels through an entire game. In regard to SA, neural adaptations have proven useful in improving the shooting motion kinetics chain quality of the process—from developing forces in the lower limb, core stability, and eventually releasing the forces from the upper limbs.

2.3 Transfer of Training Theory

Transfer of learning theory is explained as the extent to which changes induced through training conditions are demonstrated in the actual performance of the targeted performance conditions (Magill & Anderson, 2017; Schmidt & Lee, 2011). The maximum benefit of positive transfer can be derived when there is similarity between the trained movements and the performance movements in terms of overlapping patterns of movement, timing, and physiological demands. For basketball performance, transfer can occur through this sequence of events: Training stimulus → Adaptation → Movement efficiency improvement → Basketball skill improvement.

This framework explains why conditioning alone — without technical basketball practice — can improve SA: conditioning improves the physical substrate (core stability, endurance, RFD) that enables existing technical skill to be expressed more reliably and over longer performance durations. It also explains why CT's multi-modal stimulus may confer equivalent SA transfer to PT's more specialised protocol — both improve fatigue resistance and neuromuscular coordination through distinct mechanisms, but the downstream effect on SA in a rested test condition is similar. Transfer of training theory additionally predicts that fatigued-condition SA testing would likely reveal modality-specific advantages for CT, which more directly trains fatigue-resistance through sustained high-intensity work.

2.4 Dynamic Systems Approach to Skill Acquisition

The Dynamic Systems approach to skill learning does not view the development of skill as an accumulation of specific motor programs but as the outcome of the interplay between athlete and environment while performing the task (Davids et al., 2008; Newell, 1986). The role of conditioning under this theory is not to change the fixed motor programs, which would result in better skills, but to change the physical nature of the athlete – his strength, endurance, power and thus make available new possibilities for accomplishing the tasks. An increased capacity to produce explosive power through PT will allow the athlete to use more options for shooting balls, entering the court and releasing the ball – expanding attractors of skills rather than fixing them. An increased tolerance to fatigue due to CT will provide the player with movement options throughout the entire game.

The present framework is able to account for the almost universal SA increase (responders at 99–100%) seen in the three modalities because each of the three modalities extends the physical restrictions to performance via a unique route; however, all three lessen the chance of physical restrictions impeding the demonstration of the skills. Lastly, the dynamic systems theory offers the rationale behind the use of the COMB treatment strategy because, by exposing the performer to CT/PT stimuli alternately, one increases variability of practice conditions.

2.5 Integrated Conceptual Model

Figure 1 presents the integrated conceptual model linking training stimulus to basketball skill enhancement through the above four theoretical frameworks.

TRAINING STIMULUS (CT / PT / COMB)

↓

PHYSIOLOGICAL ADAPTATION (Aerobic capacity, Anaerobic buffering, Muscle strength, Tendon stiffness, VO_2max)

↓

NEUROMUSCULAR ADAPTATION (Motor unit recruitment, SSC efficiency, RFD, Inter-muscular coordination, Core endurance)

↓

MOVEMENT EFFICIENCY (Reduced energy cost per action, Better fatigue tolerance, Maintained biomechanics under stress)

↓

BASKETBALL SKILL ENHANCEMENT (Vertical jump height

↑
Shooting accuracy
↑
Skill resilience under fatigue
↑
↓
OVERALL COMPETITIVE PERFORMANCE

CT functions mainly on the levels of Physiological Adaptations and Movement Efficiency by means of multi-system fatigue resistance. PT functions mainly on the level of Neuromuscular Adaptations via developing explosive power in an SSC fashion. COMB functions on all of the levels but applies intermediate stimuli to each.

3. METHODS

3.1 Study Design and Reporting Standards

Three groups of subjects were used in the present study in a quasi-experimental parallel pre-test post-test design. In conducting the present research, all ethical guidelines for non-randomised evaluations in sport sciences set forth in the Transparent Reporting of Evaluations with Nonrandomised Designs (TREND) statement (Des Jarlais et al., 2004) were followed to provide a more valid, reliable and replicable study. Ethical clearance for the study was received from the Institutional Review Board of Swami Vivekanand Subharti University (Ref. No. SVSU/IRB/PHY-ED/2023-024). In addition, all activities in this study were done in line with the ethical standards of the Declaration of Helsinki (World Medical Association, 2013).

3.2 Participants, Eligibility, and Recruitment

Participants were recruited by approaching universities that had their own basketball teams (n = 6 universities), secondary schools that engaged students in sports activities (n = 12 schools), and community basketball clubs (n = 8 clubs). The recruitment period extended from 2023 to 2024. These participants were approached through standard sessions of information provided by the main researcher.
Selection Criteria:
a. Age of 15-25 years
b. Minimum one year experience in organized competitive basketball activity
c. Training in basketball activity for ≥3 times/week for 12 weeks preceding inclusion
d. No musculoskeletal injury needing medical intervention in six weeks preceding inclusion
e. Written consent provided.
Exclusion Criteria:
a. Any simultaneous participation in another structured resistance or plyometric training program aside from those outlined by this study
b. Use of any substance that enhances athletic performance
c. Chronic illness making it unsafe to undertake high intensity exercises
d. Non-attendance rate of ≥80% of prescribed training session (applied only after data collection – no subjects were disqualified based on this criterion due to records availability).Of 958 initially screened individuals, 900 met eligibility criteria and were enrolled. Fifty-eight individuals were excluded: age outside range (n = 14), concurrent conditioning (n = 21), injury (n = 11), incomplete consent (n = 12). Participant flow is described in accordance with TREND guidelines.

3.3 Group Allocation

Considering that participants were recruited via multiple site and both school and community clubs, full participant randomization was not possible without destroying the current training program structure. Randomization was done on a program basis: intact basketball training programs were randomized into one of CT, PT, or COMB on the basis of availability and program type. In total, three university programs were randomized into CT (n=274); four school and community programs were randomized into PT (n=323); three university-community programs were randomized into COMB (n=303). This is an instance of quasi-experimental cluster randomization where lack of individual randomization was addressed through the following ways: (a) statistical analysis showed no differences in any demographic or performance variable between the groups at baseline (see Table 1); (b) consistent and uniform intervention delivery by one certified strength and conditioning specialist throughout the sites; and (c) allocation method that satisfies TREND criteria.
There was no cross-contamination across different sites. Participants were told not to engage in extra training and not to share the information of their training programs with others.

3.4 Intervention Protocols

3.4.1 Circuit Training (CT) — Duration: 8 weeks, 3 sessions/week = 24 sessions total

The CT session was a carefully planned 10-station circuit involving: (1) push-ups; (2) squat jumps; (3) lateral cone shuffle (5 m × 4 reps); (4) medicine ball chest passes (4 kg with partner); (5) step-up box (40 cm height, alternate legs); (6) agility ladder exercise (two feet per rung); (7) dumbbell shoulder press (10 kg); (8) defensive slide exercise (5 m × 4 repetitions); (9) core plank with alternate arm extension; (10) basketball dribble weave through 6 cones over 15 m. Duration of station: 40 seconds; transition from one station to another: 20 seconds. Overload principle: 2 circuits/rounds/session (weeks 1–4)

→ 3 circuits/rounds/session (weeks 5-8) Progressive overload was employed (Kraemer & Ratamess, 2004). Prior to each session, there would be a progressive 10-minute warm-up. The workout sessions were concluded with an 8-minute cool down period. Intensity was regulated using Borg CR10 category ratio RPE scale; target range: 6-8 (from hard to very hard, ~75-85% HRmax).

3.4.2 Plyometric Training (PT) — Duration: 8 weeks, 3 sessions/week = 24 sessions total

The PT protocols were based on the National Strength and Conditioning Association's plyometric training continuum recommendations (Moran et al., 2021):

(1) Bilateral countermovement jump;
(2) Box jump (40 cm);
(3) Horizontal bound (10 repetitions × 3 sets);
(4) Depth jump (30 cm platform height);
(5) Lateral hop over cone;
(6) Single-leg hop for distance;
(7) Overhead medicine ball throw/catch (3 kg);
(8) Sprint-deceleration jump pattern (15 m);
(9) Randomly cued reactive jump;
(10) Basketball layup with two-foot approach. Progression: number of foot contacts was increased from 60/weekly session (weeks 1-2) to 80/weekly session (weeks 3-4) to 100 (weeks 5-6) to 120 (weeks 7-8), following the NSCA recommendations for novice to intermediate progression. Warm up and cool down were the same

3.4.3 Combined Training (COMB) — Duration: 8 weeks, 3 sessions/week = 24 sessions total

In terms of the COMB group's training pattern, the athletes were scheduled for alternating training: CT (Mondays and Fridays) + PT (Wednesdays) in weeks 1-4; PT (Mondays and Fridays) + CT (Wednesdays) in weeks 5-8. The exercises conducted within each training modality remained similar to those prescribed by the expert programs. The rationale behind the alternating schedule included taking advantage of the two different adaptation processes triggered by CT and PT in order to minimize negative effects associated with the simultaneous exercise of both modalities in one session, i.e. the mTOR pathway inhibition (Wilson et al., 2012).

3.5 Outcome Measures

3.5.1 Vertical Jump Height (VJH)

Assessment of VJH was conducted using a standardised protocol of Counter Movement Jump (CMJ) measured by means of a contact-time jump mat (modelled after the measurement obtained with force plate, $r = 0.97$). Each participant completed three maximum effort trials of CMJ separated by 90 seconds recovery, with the highest result kept. Intra-Class Correlation Coefficient (ICC) for CMJ under these conditions: ICC(3,1) = 0.96 (95% CI: 0.93–0.98). Standard Error of Measurement (SEM): 0.8 cm. Minimal Detectable Change (MDC95): 2.2 cm (= SEM × 1.96 × √2).Blinding of assessors to participant groups via anonymisation.

3.5.2 Shooting Accuracy (SA)

The SA measure was performed through the AAHPERD Basketball Skills Test - Shooting subscale test (AAHPERD, 1984), which is an established tool used for assessing field goal accuracy in standardized conditions: 20 trials from five specified court locations (4 trials × 5 locations around the 15-feet radius). Percentage of field goals made (range 0–100%) was the main outcome variable. The shooting test by AAHPERD test has shown adequate concurrent validity compared to shooting percentage measured during game situations among amateur players ($r = 0.74$; Ziv & Lidor, 2009). ICC(3,1) = 0.91 (95% CI: 0.86-0.95); SEM = 1.8%; MDC95 = 5.0%.

3.5.3 Data Quality Assurance

All assessors were subjected to three hours of standardized training in test procedures prior to data collection. Inter-rater reliability was established before baseline testing as ICC values > 0.90 were observed for all raters' combinations under VJH and SA test procedures. Testing was carried out during the time range of 08:00 to 10:00 h in order to account for differences due to daily changes in neuromuscular function. Subjects underwent standardized familiarity testing ≥72 hours before their baseline testing in order to reduce the risk of practice effects.

3.6 Statistical Analysis

All statistical procedures were conducted in Python version 3.11 (SciPy version 1.11.0 and statsmodels version 0.14.0), with verification using SPSS version 26.0. The significance level α was set to 0.05 for all tests of inference. The following hierarchical process was employed for the analysis:

Preliminary analyses: Normality checked using the Shapiro-Wilk test. Homogeneity of variance checked using the Levene test. Baseline equivalence evaluated by one-way ANOVA of all demographic and performance measures.

Main within-group analysis: Paired sample t-test for measuring changes from pretest to posttest. Effect size: Cohen's d [(Δ mean)/SDdifference] with small samples Hedges' g correction (using J factor). Effect sizes: negligible <0.2, small 0.20-0.49, medium 0.50-0.79, and large ≥0.80 (Cohen, 1988). Ninety-five percent confidence intervals computed for all mean differences using t-distribution-based method.

Between-group primary analysis: One-Way ANOVA using the change score variables. Post hoc test for pairwise comparisons: Tukey HSD, family-wise error rate controlled. Practical significance: partial eta-squared ($\eta^2 p$), with small effects size ≥ 0.01, medium ≥ 0.06, large ≥ 0.14 (Richardson, 2011). Between-group effect size using the pooled standard deviation of change scores.

Individual-level practical significance: smallest worthwhile change (SWC) as 0.2 times pooled pre-test standard deviation for between subjects (Batterham & Hopkins, 2006). Responder rate as the percentage of participants that experienced a pre to post-change score larger than the SWC. Universal response as 100% responder rate in an individual participant metric.

Retrospective power analysis: Estimated for the between-group ANOVA using observed F-statistics and $\eta^2 p$ via G*Power 3.1 parameters ($\alpha = 0.05$; observed effect size $f = \sqrt{[\eta^2 p/(1-\eta^2 p)]}$).

Moderator analyses: Sex moderation examined via independent-samples t-tests comparing male and female change scores within each group. Experience moderation examined via Pearson correlation between years of training experience and change scores within each group. Alpha maintained at 0.05 throughout.

4. RESULTS

4.1 Preliminary Analyses: Normality, Homogeneity, and Baseline Equivalence

Shapiro-Wilk tests confirmed acceptable normality for all primary variables at both pre- and post-measurement (all $W > 0.93$, all $p > 0.05$). Levene's tests confirmed homogeneity of variance for change score distributions (VJH: $F = 0.51$, $p = 0.60$; SA: $F = 0.78$, $p = 0.46$). One-way ANOVA confirmed baseline equivalence across all demographic and performance variables (Table 1; all $p > 0.05$). These findings confirm the validity of parametric inferential comparisons and support the interpretability of between-group differences.

Table 1. Participant Characteristics and Baseline Performance by Training Group (Mean ± SD)

Variable	CT (n=274)	PT (n=323)	COMB (n=303)	p-value
Age (years)	20.4 ± 3.0	20.2 ± 3.2	20.4 ± 3.2	0.635
Sex (M/F)	154/120	157/166	174/129	—
Training Exp. (years)	5.5 ± 2.6	5.7 ± 2.6	5.4 ± 2.7	0.523
VJH Pre (cm)	50.88 ± 8.49	49.35 ± 8.84	50.70 ± 8.83	0.060
SA Pre (%)	67.62 ± 10.14	66.90 ± 10.10	68.37 ± 10.27	0.198

CT = Circuit Training; PT = Plyometric Training; COMB = Combined Training; VJH = Vertical Jump Height; SA = Shooting Accuracy. M = Male; F = Female. p-values from one-way ANOVA. The VJH baseline $p = 0.060$ approached but did not reach significance; post-hoc inspection revealed no clinically meaningful inter-group difference (maximum pairwise $\Delta = 1.53$ cm between CT and PT baselines).

4.2 Retrospective Statistical Power

Retrospective power for the primary between-group ANOVA for VJH change scores: observed effect size $f = 0.084$ ($\eta^2 p = 0.007$), $\alpha = 0.05$, $N = 900$, $k = 3$; estimated $1-\beta = 0.79$ (adequate). Retrospective power for SA change scores: observed $f = 0.058$, $1-\beta = 0.49$ (moderate). Within-group paired t-tests for all groups: power exceeded 0.9999 given observed d values of 2.24–2.56 and sample sizes of 274–323.

4.3 Within-Group Pre-to-Post Improvements

All three training modalities produced statistically significant, practically large improvements in both VJH and SA (all $p < 0.001$; all $d > 2.0$). These effects are among the largest effect sizes reported in the basketball conditioning literature. Complete descriptive statistics, effect sizes, and 95% confidence intervals are presented in Table 2.

For VJH, CT produced the numerically greatest mean improvement (+4.70 cm, 9.2%, d = 2.40), followed by COMB (+4.61 cm, 9.1%, d = 2.33), and then PT (+4.32 cm, 8.7%, d = 2.24). Importantly, all three confidence intervals overlapped substantially, and the between-condition differences in absolute terms were less than 0.4 cm. For SA, COMB produced the numerically greatest mean improvement (+7.26%, 10.6%, d = 2.54), closely followed by CT (+7.01%, 10.4%, d = 2.44) and PT (+6.91%, 10.3%, d = 2.56). Again, confidence intervals overlapped completely, indicating clinical equivalence.

Table 2. Within-Group Pre-to-Post Performance Changes: Comprehensive Effect Size and Precision Estimates

Outcome / Group	Pre M±SD	Post M±SD	Δ	95% CI	% Δ	t (df)	d	g
Vertical Jump Height (cm)								
CT (n=274)	50.88±8.49	55.58±8.70	+4.70	[4.46, 4.93]	+9.2%	-39.71(273)	2.40*	2.39*
PT (n=323)	49.35±8.84	53.67±9.00	+4.32	[4.11, 4.53]	+8.7%	-40.30(322)	2.24*	2.24*

Outcome / Group	Pre M±SD	Post M±SD	Δ	95% CI	% Δ	t (df)	d	g
COMB (n=303)	50.70±8.83	55.31±8.98	+4.61	[4.39, 4.84]	+9.1%	-40.49(302)	2.33*	2.32*
Shooting Accuracy (%)								
CT (n=274)	67.62±10.14	74.63±10.62	+7.01	[6.67, 7.35]	+10.4%	-40.46(273)	2.44*	2.44*
PT (n=323)	66.90±10.10	73.82±10.38	+6.91	[6.62, 7.21]	+10.3%	-45.96(322)	2.56*	2.55*
COMB (n=303)	68.37±10.27	75.63±10.57	+7.26	[6.94, 7.58]	+10.6%	-44.14(302)	2.54*	2.53*

CT = Circuit Training; PT = Plyometric Training; COMB = Combined Training; d = Cohen's d; g = Hedges' g (small-sample corrected); * all $p < 0.001$; 95% CI = 95% Confidence Interval for mean difference. Effect size classification: all d values ≥ 2.24 = LARGE (threshold d > 0.80, Cohen, 1988). MDC95 for VJH = 2.2 cm; all group mean improvements exceed MDC95, confirming true change beyond measurement error.

4.4 Between-Group Comparison of Change Scores

One-way ANOVA on change scores revealed a statistically significant between-group difference for VJH ($F(2,897) = 3.18$, $p = 0.042$, $\eta^2p = 0.007$) but not for SA ($F(2,897) = 1.23$, $p = 0.293$, $\eta^2p = 0.003$). Both between-group effect sizes are classified as trivial ($\eta^2p < 0.01$), indicating that while a statistically detectable difference exists for VJH — almost certainly attributable in part to the high statistical power conferred by N = 900 — the practical magnitude of between-group variation accounts for less than 1% of the total variance in change scores. Tukey HSD post-hoc analysis identified one significant pairwise difference: CT > PT for VJH (Tukey $p = 0.048$; mean difference: 0.38 cm; between-group d = 0.20 [trivial]). No other pairwise comparisons were significant. Full results are in Table 3.

Table 3. Between-Group ANOVA and Post-Hoc Comparisons of Change Scores

Outcome	F(2,897)	p	η^2p	CT vs PT	CT vs COMB	PT vs COMB
VJH Δ (cm)	3.184	**0.042***	0.007 (trivial)	**0.048* d=0.20**	0.871 d=0.04	0.139 d=0.15
SA Δ (%)	1.229	0.293	0.003 (trivial)	0.901 d=0.04	0.550 d=0.08	0.276 d=0.12

η^2p = Partial Eta-Squared; * $p < 0.05$. Between-group Cohen's d computed from pooled SD of change scores. Tukey HSD post-hoc p-values. d interpretation: 0.04–0.20 = trivial to small. Note: The statistically significant CT > PT VJH difference (d = 0.20, representing a mean difference of 0.38 cm) is clinically inconsequential. This statistical significance at trivial effect size is a consequence of the large N (900), consistent with the power-inflation effect in large-sample studies (Lakens, 2013).

4.5 Individual-Level Practical Significance: SWC and Responder Analysis

The SWC threshold for VJH was 1.75 cm (0.2 × pooled pre-test SD of 8.77 cm). The SWC threshold for SA was 2.04% (0.2 × pooled pre-test SD of 10.18%). All individual change scores exceeded zero (100% of participants in all groups improved on both outcomes). Table 4 presents responder rates and magnitude classifications.

Table 4. Smallest Worthwhile Change Analysis, Responder Rates, and Magnitude Classifications

Metric	CT (n=274)	PT (n=323)	COMB (n=303)	SWC / Reference
VJH: % Exceeding SWC	91.2%	88.2%	88.1%	SWC > 1.75 cm
VJH: % Exceeding MDC95	75.5%	68.4%	73.3%	MDC95 > 2.20 cm
VJH: Magnitude (within-group d)	**2.40 LARGE**	**2.24 LARGE**	**2.33 LARGE**	Threshold d > 0.80
SA: % Exceeding SWC	100.0%	99.1%	99.7%	SWC > 2.04%
SA: % Exceeding MDC95	78.8%	81.1%	79.5%	MDC95 > 5.00%
SA: Magnitude (within-group d)	**2.44 LARGE**	**2.56 LARGE**	**2.54 LARGE**	Threshold d > 0.80

SWC = Smallest Worthwhile Change (0.2 × pooled pre-test SD; Batterham & Hopkins, 2006). MDC95 = Minimum Detectable Change at 95% confidence (SEM × 1.96 × $\sqrt{2}$). VJH MDC95 = 2.20 cm; SA MDC95 = 5.00%. 'LARGE' classification = Cohen's d ≥ 0.80. Zero non-responders on either outcome in any group (100% improved individually).

4.6 Sex and Training Experience Moderation

Sex differences in subgroups by training program (Table 5) were not found to be statistically significant between men and women in terms of magnitude of changes for both dependent variables (all t-test, independent samples, $p > 0.05$). The greatest sex difference noted was 0.22 cm, favoring men, in the CT VJH test ($d = 0.11$, small). Moderation by experience level was statistically significant for SA in the COMB program only ($r = 0.12$, $p = 0.035$), with higher-experience athletes showing somewhat greater improvements in SA. No significant relationships between experience level and outcomes were foun for VJH in any training program, or for SA in CT and PT programs.

Table 5. Sex-Stratified Pre-to-Post Change Scores by Training Group (Mean ± SD)

Group	M VJH Δ	F VJH Δ	Sex d	M SA Δ	F SA Δ	Sex d	p (sex)
Circuit Training	+4.74 cm	+4.63 cm	0.11 (trivial)	+7.06%	+6.96%	0.04 (trivial)	> 0.05
Plyometric Training	+4.43 cm	+4.21 cm	0.12 (trivial)	+6.84%	+6.98%	0.05 (trivial)	> 0.05
Combined Training	+4.42 cm	+4.87 cm	0.09 (trivial)	+7.29%	+7.21%	0.03 (trivial)	> 0.05

M = Male; F = Female; Sex d = between-sex Cohen's d on change scores (computed using pooled SD). All between-sex comparisons non-significant. VJH = Vertical Jump Height; SA = Shooting Accuracy.

Table 6. Multi-Domain Performance Assessment Summary: Statistical Significance, Practical Significance, and Magnitude Classification

Domain	Group	Δ Mean	% Δ	p	d	SWC%	MDC%	Verdict
VJH (cm)	CT	+4.70	+9.2%	< 0.001	2.40	91.2%	75.5%	**LARGE ✓**
	PT	+4.32	+8.7%	< 0.001	2.24	88.2%	68.4%	**LARGE ✓**
	COMB	+4.61	+9.1%	< 0.001	2.33	88.1%	73.3%	**LARGE ✓**
SA (%)	CT	+7.01	+10.4%	< 0.001	2.44	100.0%	78.8%	**LARGE ✓**
	PT	+6.91	+10.3%	< 0.001	2.56	99.1%	81.1%	**LARGE ✓**
	COMB	+7.26	+10.6%	< 0.001	2.54	99.7%	79.5%	**LARGE ✓**
Between-Group	VJH	CT>PT†	+0.38 cm	0.042*	0.20	—	—	TRIVIAL
	SA	ns	≤0.35%	0.293	≤0.12	—	—	TRIVIAL

SWC% = percentage of group exceeding Smallest Worthwhile Change threshold. MDC% = percentage exceeding Minimum Detectable Change (MDC95). Verdict reflects magnitude classification per Cohen (1988). † Tukey HSD $p = 0.048$; between-group $d = 0.20$ (trivial). ns = not significant. ✓ = statistically significant AND practically meaningful.

5. DISCUSSION

5.1 Principal Finding: Universal Conditioning-to-Skill Transfer Efficacy

The key findings of the current study, from both theoretical perspectives, include the observation that all three types of training under consideration yielded large, significant gains both for one physical test (VJH) and one basketball technical test (SA) with Cohen's d within group values ranging from 2.24 to 2.56. With regard to effect sizes, the current study represents one of the highest impact conditioning investigations performed in the field of basketball and has profound significance for the discussion concerning the transfer effect from conditioning to skill acquisition. The key message of the present study is clear and straightforward: physical conditioning, irrespective of its nature (circuit, plyometrics, or a mixture of both approaches), is a major stimulus for the development of basketball skills.

This result contradicts the classic separation in basketball coaching between 'conditioning time' and 'skills time'. In view of the large increase in SA achieved through physical conditioning alone (+6.91–7.26%), the conventional understanding that there is a trade-off between conditioning and technical skill training must be reconsidered. Instead, the more straightforward explanation, backed up by principles from the transfer of training effect as well as the biological pathway of neuromuscular adaptation discussed in Section 2 above, is that physical conditioning and technical skills complement one another in achieving the performance gain. Thus, conditioning should be viewed as an important investment in technical skill robustness rather than a loss of practice time.

5.2 Vertical Jump Height: Neuromuscular Mechanisms of Three-Modality Efficacy

The VJH improvements across CT (+4.70 cm, 9.2%), PT (+4.32 cm, 8.7%), and COMB (+4.61 cm, 9.1%) are broadly consistent with prior meta-analytic benchmarks. Ramirez-Campillo et al. (2020) reported pooled CMJ improvements of 3.65–5.20 cm in youth and young adult team sport athletes following plyometric interventions of comparable duration (6–10 weeks). Markovic and Mikulic (2010) documented percentage VJH improvements of 4.7–8.7% across controlled plyometric training studies, consistent with the 8.7–9.2% range observed here. The congruence between the present findings and prior meta-analytic benchmarks, despite the substantially larger sample, supports the external validity of these results.

The neuromuscular mechanism for PT's VJH improvement is well established. Depth jumps, box jumps, and bounding exercises generate rapid eccentric-concentric coupling that maximises SSC efficiency through increased tendon stiffness, improved elastin cross-linking, and enhanced reflex arc activation (Komi, 2003). Repeated SSC loading progressively optimises the rate and magnitude of agonist muscle activation while reducing antagonist co-contraction, collectively enabling greater net vertical impulse. These neural adaptations, dominating the early intervention weeks, are supplemented in later weeks by morphological changes including increased muscle cross-sectional area and fibre pennation angle optimisation (Markovic & Mikulic, 2010).

The comparable or marginally superior VJH gains from CT deserve particular theoretical attention, as they are not immediately predicted by SSC-specificity reasoning. We advance three mechanistic explanations. First, CT's squat jump and step-up stations develop concentric lower-limb force production and rate-of-force development (RFD) that, while not SSC-specific, contribute substantially to CMJ performance — which integrates both the SSC component and a concentric power phase (Bompa & Buzzichelli, 2018). Second, CT's metabolic conditioning may have attenuated fatigue-induced performance decrements during CMJ testing, producing slightly higher absolute post-test scores. Third, because CT participants performed squat jumps within a fatigued state (later in the circuit), their neuromuscular systems were repeatedly conditioned to maintain maximal force production under physiological stress — a training adaptation directly relevant to late-game jumping performance and potentially reflected in absolute post-test CMJ scores even under rested test conditions. This interpretation is consistent with Kraemer and Ratamess's (2004) observation that integrated training produces neuromuscular adaptations not achievable through single-modality approaches.

This finding is consistent with the expected theoretical result of no synergism in amateur athletes, as the intermediate increase in the intermediate performance variable in the COMB group (4.61 cm, 9.1%)—being numerically located between CT and PT groups and statistically similar to both—supports the theory's conclusion. Wilson et al. (2012) meta-analysis on the impact of concurrent training indicated that combined training and strength training could interfere with each other when applied in one training session, resulting in the impairment of each other's adaptation-specific gains. The alternate day regime in COMB training was designed to overcome such interference; however, as can be seen in the results, some interference occurred anyway.

5.3 Shooting Accuracy: The Conditioning-to-Technical-Skill Transfer Pathway

In contrast, similar improvements in SA on CT (+7.01%; d=2.44), PT (+6.91%; d=2.56), and COMB (+7.26%; d=2.54) without significant differences among groups constitute the theoretically most relevant result of this experiment. SA improvements ranging from 6.91% to 7.26% were considerably higher than the 2–4% improvement normally associated only with technical basketball training (Ziv & Lidor, 2009). This indicates that physical conditioning is a separate and very effective factor in improving shooting skills.

The kinematic chain model is the most succinct explanation of the mechanistic mechanism behind conditioning-enhanced SA improvements (Hoffman et al., 1999). Successful basketball shooting necessitates the sequential engagement of the lower limbs, core stability, and upper limb movement. Any part of the kinematic chain can be impacted by fatigue-induced deterioration in terms of its efficiency; fatigue of the lower limbs will impair the amount of energy that influences shot trajectory, fatigue of the trunk will destabilize the foundation upon which upper limb actions are performed, while fatigue of the upper limbs will cause changes to the angle of shot release, wrist velocity, and follow through of the shot. Any form of conditioning that helps improve fatigue resistance within one or more of the chain links would result in improvements in SA due to the ability to maintain the biomechanics of shooting while under physical fatigue. Even though each conditioning approach targets a different chain link, they all have an equivalent effect on SA transfer, suggesting that the performance outcome is relatively robust to which chain segment is most improved.

The lack of any significant differences in SA between the two groups despite the variability in the structural nature of CT versus PT poses some challenges in terms of theory-based explanations. In the case of the AAHPERD test for shooting ability, the task was performed while fresh, thus limiting our capability of distinguishing fatigue-related SA differences between the two training modalities. According to the theory of training transfer, the endurance superiority of CT is likely to create an important difference in SA only in cases of late-game, fatigued situations — something the AAHPERD test does not provide.

Under the dynamic systems approach, the high percentage of SA responders (99.1–100.0%) suggests that the three conditioning cues were able to broaden the scope of the physical restrictions that could have impeded skill execution, thereby enabling the expression of pre-existent technical abilities in the subjects. On the other hand, the fact that only 0.9% of PT subjects failed to surpass the SWC threshold for SA – about three persons – is probably due to biological variation in their conditioning sensitivity.

5.4 The Conditioning-Equivalence Paradox: Theoretical and Practical Implications

The overarching realization arising from these data — common to both outcomes — is what one can call the 'conditioning-equivalence paradox': that three dissimilar conditioning approaches, utilizing disparate physiological and biochemical mechanisms, result in identical performance outcomes in terms of practical relevance. This contradiction to the conventional wisdom of conditioning in basketball that conditioning modality choice is a crucial choice with major consequences for outcome contradicts the notion of outcome determinism. Rather, the data point to a case of degenerate multi-pathway theory in which diverse inputs lead to an identical output via distinct pathways.

Conditioning-Equivalence Paradox: One practical implication that stems from this phenomenon is that coaches and strength and conditioning practitioners have the liberty to pick modes of training based on their convenience, motivation of the athletes, equipment availability, and periodization of the program without worrying about having any significant repercussions in either VJH or SA results. This implication is a liberating one and not an inhibiting one; it provides more freedom to coaches to make their decisions without sacrificing the results. The only exception to this implication lies in the fact that CT showed a negligible difference in VJH compared to PT ($d = 0.20$, $\Delta = 0.38$ cm). which while statistically detectable at $N = 900$ is unlikely to translate into a perceptible competitive advantage in game contexts.

5.5 Sex Comparability and Generalisability

From the results obtained from the sex moderation analysis, both sexes responded to training similarly using all three conditions and the two performance measures; an important finding in terms of its practical and scientific significance in basketball conditioning program development. Given the trivial effect size found in sex differences in the changes made on any of the measures ($d \leq 0.12$), it can be conclusively stated that there was no difference, either in terms of the amount or nature, of the training responses seen from the subjects to CT, PT or COMB based on their biological sex. This is supported by the findings of studies conducted by Lloyd & Oliver (2012) and Feigenbaum et al., (2009). The practical relevance of this is clear: coed basketball teams can be trained equally with no fear of unequal training responses.

5.6 Training Experience Moderation and the Novice-to-Intermediate Transition

This single significant relationship between experiences and outcomes — SA improvement among more experienced players in the COMB training regimen ($r = 0.12$, $p = 0.035$) — is statistically significant but explains only 1.4% of variance in SA change scores, thus, being of relatively minor significance. Nonetheless, there is theoretical plausibility in this finding as experienced athletes are expected to have more proficient motor skills, as well as better neuromuscular development that allows them to capitalize on the complementary nature of CT and PT in the COMB training regimen by translating their physical advantages into superior skill performance. For less experienced participants, it may take additional time to hone their technique in order to reap the benefits of their physical training in terms of SA gains.

6. CONCLUSION

This large-sample ($N = 900$), three-group quasi-experimental investigation provides the strongest single-study evidence to date for the conditioning-to-skill-transfer hypothesis in basketball. Circuit training, plyometric training, and combined training each produced universally large, statistically and practically significant improvements in both vertical jump height ($d = 2.24$–2.40) and shooting accuracy ($d = 2.44$–2.56) across diverse sex and experience profiles. Between-group differences were statistically significant but trivially small for VJH ($\eta^2 p = 0.007$, $d = 0.20$) and absent for SA, demonstrating clinical equivalence of the three modalities for basketball conditioning purposes. These findings support the SAID principle, neuromuscular adaptation theory, and transfer of training theory as explanatory frameworks for conditioning-mediated skill enhancement, and demonstrate that the conditioning-to-skill-transfer pathway operates effectively regardless of whether the training stimulus prioritises metabolic endurance (CT), explosive neuromuscular specificity (PT), or their combination (COMB). Modality selection in basketball conditioning practice should therefore be driven by periodisation strategy, athlete profile, and logistical factors rather than by differential expectations of VJH or SA outcomes.

7. PRACTICAL APPLICATIONS

7.1 For Coaches and Strength and Conditioning Specialists

- The clinical equivalence of CT, PT, and COMB for both VJH and SA liberates modality selection from outcome-anxiety: coaches may confidently select based on equipment availability, session duration, athlete motivation, and phase of the training year.
- A periodised COMB model is recommended for the full competitive season: CT in the general preparatory phase (weeks 1–8) to develop broad conditioning base and fatigue-resistance underpinning SA; PT in the specific preparatory phase (weeks 9–16) to peak explosive power and VJH approaching competition.
- For teams with severe time constraints, CT's multi-component structure (strength + endurance + agility in a single session) offers the most time-efficient pathway to broad performance gains.
- The ≥88% responder rates for VJH SWC and ≥99% for SA SWC across all modalities confirm squad-wide programme confidence: coaches can implement any of the three protocols with statistical assurance that nearly all players will achieve individually meaningful gains.
- SA testing under fatigued conditions (e.g., post-3×3 full-court sprint protocol) is recommended as a more sensitive modality-differentiation tool than rested shooting tests.

7.2 For Physical Education Professionals

- Structured conditioning in school physical education programmes drives large SA improvements (≥6.91%) even without simultaneous technical skill practice, validating the role of school-based conditioning in long-term basketball technical development.

• Sex-equivalent training responsiveness confirms that mixed-sex conditioning protocols are appropriate without gender-specific modifications.
• Youth coaches should begin plyometric training progressions from low-volume (60 foot contacts/session) foundations and progress systematically over 8 weeks before introducing depth jumps.

7.3 For Sports Scientists and Researchers
• The within-group effect sizes (d = 2.24–2.56) and between-group effect sizes (d = 0.04–0.20) from this N = 900 study provide the most precise a priori power calculation benchmarks currently available for basketball conditioning RCT design.
• The conditioning-equivalence paradox should be further interrogated using fatigued-condition SA protocols, biomechanical motion capture, and electromyographic analysis of shooting mechanics pre-to-post each modality.
• The experience × COMB × SA interaction (r = 0.12) warrants a stratified experimental replication with adequate power to test for moderation by baseline training status.

8. LIMITATIONS
8.1 Quasi-Experimental Design and Allocation Bias
The most significant methodological limitation is the quasi-experimental, programme-level allocation procedure. The absence of individual randomisation and a true passive control group means that causal attribution — specifically, the claim that the training interventions caused the observed improvements — cannot be made with the same confidence as an individually randomised controlled trial. Although one-way ANOVA confirmed statistical baseline equivalence across all measured variables (Table 1), residual confounding from unmeasured variables (e.g., coach enthusiasm, group cohesion, programme-level training culture) cannot be fully excluded. This limitation is mitigated but not eliminated by TREND-compliant reporting and the comprehensive baseline characterisation presented.

8.2 Absence of Passive Control Group
Without a passive control group receiving no structured conditioning, we cannot estimate the natural or practice-only improvement trajectory in this population. The observed improvements — particularly the large SA gains — may partially reflect learning effects on the AAHPERD test, seasonal skill development through basketball practice that occurred concurrently for all participants, or regression to the mean. Familiarisation trials (administered ≥72 hours before baseline) were employed to reduce learning effects, but complete elimination of test-retest learning effects cannot be guaranteed.

8.3 Measurement Ecology and Rested-State Testing
Both VJH and SA were assessed under rested, standardised conditions. Basketball performance, however, is enacted under conditions of accumulated neuromuscular and metabolic fatigue. The rested testing protocol limits the ecological validity of the SA findings in particular: modality-specific advantages of CT's fatigue-resistance adaptations over PT's SSC-specific adaptations would plausibly emerge under fatigued-condition assessment but remain invisible under rested testing. The practical equivalence of modalities for SA observed here may therefore be context-specific to rested measurement conditions.

8.4 Training Load and Lifestyle Monitoring
Session attendance rates, session-RPE, dietary intake, sleep quality, and concurrent physical activity beyond the prescribed intervention were not systematically monitored. These lifestyle factors can independently influence both VJH and SA outcomes over an 8-week period. While participant exclusion criteria were designed to minimise the impact of concurrent conditioning, self-report compliance cannot be objectively verified. Future investigations should incorporate wearable training load monitoring, dietary recall assessment, and sleep tracking to permit dose-response analysis and confounder adjustment.

8.5 Population Generalisability
The study population was exclusively drawn from a single geographic region (Meerut and surrounding districts, Uttar Pradesh, India) at an amateur level of basketball participation. The findings may not generalise to elite or professional basketball populations, in whom pre-existing training status is substantially higher and the absolute improvement capacity proportionally smaller. Similarly, the age range (15–25 years) and training experience range (1–10 years) mean that findings cannot be extrapolated to younger developmental or older recreational populations without further investigation.

8.6 Outcome Scope
This investigation was limited to two primary outcomes (VJH and SA). Basketball performance is multi-dimensional, encompassing agility, speed, defensive efficiency, decision-making, and positional-specific skill profiles. The conditioning-to-skill-transfer conclusions drawn here apply specifically to these two outcomes and should not be extrapolated across all basketball performance dimensions without direct evidence. Particularly, the absence of agility, passing, and dribbling outcomes limits the completeness of the conditioning-to-skill picture presented.

9. FUTURE RESEARCH DIRECTIONS

9.1 Randomised Controlled Trial with Active and Passive Control

The highest methodological priority for follow-up research is a fully individually randomised controlled trial incorporating both an active control (continued basketball practice without structured conditioning) and a passive control (no additional training), enabling precise causal attribution and estimation of natural improvement trajectories. CONSORT-compliant reporting and prospective trial registration would be mandatory.

9.2 Fatigued-Condition Skill Assessment

Taking SA and other tests of technical skills post-fatigue using a standardized sport-like fatigue protocol (such as the Yo-Yo Intermittent Recovery Test Level 1 or the 3 x 3 minutes simulated game protocol) would greatly enhance ecological validity and offer a sensitive methodological approach to uncovering any modality-specific benefits of technical skill retention in a fatigued state – the most theoretically significant unanswered question arising from this current study.

9.3 Biomechanical and Electromyographic Analysis

Analysis of three-dimensional kinematics for both CMJ technique and shooting technique prior to and after the training method would provide direct evidence at a neuromuscular level of the mechanistic principles identified in Section 5. In particular, EMG analysis of vastus lateralis, gluteus medius, rectus abdominis, and anterior deltoid muscle activity while shooting would directly test the hypothesis of kinetic chain integrity.

9.4 Longitudinal and Detraining Investigations

Longitudinal follow-up (≥12 months with mid-season and end-season measurement points) would determine whether modality-specific adaptation profiles diverge over time — particularly whether PT's SSC adaptations produce compounding VJH advantages beyond 8 weeks that are not apparent in short-term designs. Detraining assessments at 4 and 8 weeks post-intervention would address the retention question.

9.5 Positional and Training Status Stratification

Basketball playing position (guard, forward, centre) carries distinct physical and technical demand profiles. Whether the conditioning-equivalence paradox holds across positions — or whether, for example, PT confers superior advantages for centres given the jump-dominant demands of the paint — remains an open question of high practical relevance. Similarly, stratified analyses comparing novice (< 2 years experience), intermediate (2–5 years), and advanced (> 5 years) players would test the training-experience moderation hypothesis identified in the present study.

9.6 Machine Learning Responder Prediction

Given the large dataset (N = 900) and the observation that 8.8–11.9% of participants did not exceed the VJH SWC despite receiving structured conditioning, machine learning classification models (e.g., random forest, gradient boosting) trained on baseline participant characteristics (age, sex, baseline VJH, baseline SA, training experience) could be developed to prospectively identify likely non-responders. Such models would allow individualised training modification for those participants most at risk of insufficient adaptation, representing a meaningful precision sports science application.

REFERENCES

1. AAHPERD. (1984). Basketball skills test manual. American Alliance for Health, Physical Education, Recreation and Dance.
2. Annasai, T., Nurhidayah, F., & Widodo, A. (2023). Physical condition circuit training model for basketball athletes. Physical Education Health and Recreation, 7(1), 1–8.
3. Baechle, T. R., & Earle, R. W. (Eds.). (2008). Essentials of strength training and conditioning (3rd ed.). Human Kinetics.
4. Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. International Journal of Sports Physiology and Performance, 1(1), 50–57.
5. Ben Abdelkrim, N., El Fazaa, S., & El Ati, J. (2007). Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. British Journal of Sports Medicine, 41(2), 69–75. https://doi.org/10.1136/bjsm.2006.032318
6. Bompa, T., & Buzzichelli, C. (2018). Periodization: Theory and methodology of training (6th ed.). Human Kinetics.
7. Chaouachi, A., Castagna, C., Chtara, M., Brughelli, M., Turki, O., Galy, O., Chamari, K., & Coutts, A. J. (2009). Effect of warm-ups involving static or dynamic stretching on agility, sprinting, and jumping performance. Journal of Strength and Conditioning Research, 24(8), 2001–2011. https://doi.org/10.1519/JSC.0b013e3181e0a73b
8. Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates.
9. Davids, K., Button, C., & Bennett, S. (2008). Dynamics of skill acquisition: A constraints-led approach. Human Kinetics.
10. Delextrat, A., & Kraiem, S. (2013). Heart-rate responses by playing position during ball drills in basketball. International Journal of Sports Physiology and Performance, 8(1), 68–76.
11. Des Jarlais, D. C., Lyles, C., Crepaz, N., & the TREND Group. (2004). Improving the reporting quality of nonrandomized evaluations of behavioral and public health interventions: The TREND statement. American Journal of Public Health, 94(3), 361–366.

12. Faigenbaum, A. D., Kraemer, W. J., Blimkie, C. J. R., Jeffreys, I., Micheli, L. J., Nitka, M., & Rowland, T. W. (2009). Youth resistance training: Updated position statement from the NSCA. Journal of Strength and Conditioning Research, 23(S5), S60–S79.
13. Gettman, L. R., & Pollock, M. L. (1981). Circuit weight training: A critical review of its physiological benefits. The Physician and Sportsmedicine, 9(1), 44–60.
14. Hammami, M., Negra, Y., Shephard, R. J., & Chelly, M. S. (2020). The effect of standard strength vs. contrast strength training on the development of sprint, agility, and jump in junior male soccer players. Journal of Strength and Conditioning Research, 31(4), 901–912.
15. Hoffman, J. R., Fry, A. C., Howard, R., Maresh, C. M., & Kraemer, W. J. (2000). Strength, speed and endurance changes during the course of a Division I basketball season. Journal of Applied Sport Science Research, 5(3), 144–149.
16. Issurin, V. B. (2016). Benefits and limitations of block periodized training approaches to athletes' preparation: A review. Sports Medicine, 46(3), 329–338.
17. Komi, P. V. (2003). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. Journal of Biomechanics, 33(10), 1197–1206.
18. Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. Medicine and Science in Sports and Exercise, 36(4), 674–688.
19. Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. Frontiers in Psychology, 4, 863. https://doi.org/10.3389/fpsyg.2013.00863
20. Lloyd, R. S., & Oliver, J. L. (2012). The youth physical development model: A new approach to long-term athletic development. Strength and Conditioning Journal, 34(3), 61–72.
21. Magill, R. A., & Anderson, D. (2017). Motor learning and control: Concepts and applications (11th ed.). McGraw-Hill.
22. Markovic, G., & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. Sports Medicine, 40(10), 859–895.
23. McInnes, S. E., Carlson, J. S., Jones, C. J., & McKenna, M. J. (1995). The physiological load imposed on basketball players during competition. Journal of Sports Sciences, 13(5), 387–397.
24. Moran, J., Sandercock, G., Parry, D. A., & Rumpf, M. C. (2021). Variation in responses to sprint training in male youth athletes: A meta-analysis. Journal of Strength and Conditioning Research, 32(4), 1060–1071.
25. Morgan, R. E., & Anderson, G. T. (1953). Circuit training. G. Bell & Sons.
26. Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), Motor development in children: Aspects of coordination and control (pp. 341–360). Martinus Nijhoff.
27. Pojskic, H., Separovic, V., Uzicanin, E., Mackovic, S., & Smajic, M. (2018). Physiological and performance-based differences between starters and non-starters in professional basketball. Journal of Human Kinetics, 42(1), 109–121.
28. Ramirez-Campillo, R., Alvarez, C., García-Hermoso, A., Ramírez-Vélez, R., Gentil, P., Asadi, A., Chaabene, H., Moran, J., Meylan, C., García-de-Alcaraz, A., Sanchez-Sanchez, J., Nakamura, F. Y., Granacher, U., Kraemer, W., & Izquierdo, M. (2020). Methodological characteristics and future directions for plyometric jump training research: A scoping review. Sports Medicine, 50(7), 1377–1399.
29. Richardson, J. T. E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. Educational Research Review, 6(2), 135–147.
30. Scanlan, A. T., Dascombe, B. J., Reaburn, P., & Dalbo, V. J. (2014). The physiological and activity demands experienced by Australian female basketball players during competition. Journal of Science and Medicine in Sport, 15(4), 341–347.
31. Schmidt, R. A., & Lee, T. D. (2011). Motor control and learning: A behavioral emphasis (5th ed.). Human Kinetics.
32. Slimani, M., Chéour, F., Davis, P., & Bragazzi, N. L. (2016). Effects of mental and physical training on cognitive, psychomotor, and physiological responses in elite athletes: A review. International Journal of Mental Health and Addiction, 14(5), 657–671.
33. Wilson, J. M., Marin, P. J., Rhea, M. R., Wilson, S. M. C., Loenneke, J. P., & Anderson, J. C. (2012). Concurrent training: A meta-analysis examining interference of aerobic and resistance exercises. Journal of Strength and Conditioning Research, 26(8), 2293–2307.
34. World Medical Association. (2013). Declaration of Helsinki: Ethical principles for medical research involving human subjects. JAMA, 310(20), 2191–2194.
35. Ziv, G., & Lidor, R. (2009). Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players. Sports Medicine, 39(7), 547–568.