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# Video analysis and mathematical reconstruction of three-point shot trajectories in Basketball: Validation through physical modeling

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## Abstract

Three-point shooting accuracy has become increasingly critical in modern basketball, yet comprehensive biomechanical analysis remains prohibitively expensive and inaccessible for most training programs. Kinovea, a free open-source video analysis software, offers a promising alternative but requires rigorous validation against established biomechanical principles.

This study aimed to validate Kinovea's measurement reliability for shooting kinematics, verify measurement consistency with parabolic motion physics, and identify kinematic parameters that discriminate successful from missed shots.

Eight competitive U18 male basketball players performed 34 three-point shots from the wing position at regulation distance (7.24 m). Shots were filmed at 60 fps using high-definition cameras positioned perpendicular to the shooting plane. Ball trajectories were manually tracked frame-by-frame using Kinovea 0.9.5 software. Four kinematic parameters were extracted: projection angle (θ), initial velocity ($v_0$), maximum trajectory height (h_max), and foot orientation. Trajectories were mathematically modeled using classical projectile motion equations. Between-group comparisons employed independent t-tests with Cohen's d effect size calculations.

Of the 34 shots analyzed, 14 were successful (41.2%) and 20 were missed (58.8%). Maximum trajectory height emerged as the sole discriminating parameter between successful and missed shots: successful shots reached 5.94 ± 0.27 m compared to 5.71 ± 0.37 m for missed shots, representing a 23 cm difference ($p = 0.059$, $d = +0.68$, medium effect). In stark contrast, projection angle showed no difference (57.18° vs. 57.00°, $p = 0.810$, $d = +0.08$), nor did initial velocity (9.07 m/s vs. 9.08 m/s, $p = 0.894$, $d = -0.05$). The parabolic trajectory model provided consistent mathematical reconstruction of observed trajectories, validating the simplified physics approach.

**Keywords:** Basketball; Three-Point Shot; Kinovea; Kinematics; Parabolic Trajectory; Trajectory Height; Video Analysis; Biomechanics; Shooting Accuracy

## 1. Introduction

The evolution of basketball has been marked by the increasing strategic importance of three-point shooting. Statistical analysis of National Basketball Association (NBA) games reveals a remarkable 157% increase in three-point attempts per game between 2000 and 2020, rising from 13.7 to 35.2 attempts [1]. Elite professional players now achieve three-point shooting accuracies approaching 43%, establishing this skill as one of the most efficient offensive weapons in modern basketball strategy [2]. The three-point shot's tactical value stems from its superior point-per-attempt efficiency compared to two-point field goals when executed at elite accuracy levels.

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Despite this strategic importance, comprehensive biomechanical analysis of shooting mechanics remains prohibitively expensive for the vast majority of basketball programs. Traditional motion capture systems, which employ multiple synchronized cameras and sophisticated marker-tracking algorithms, typically require investments exceeding $100,000 for equipment and software licenses [3]. This economic barrier effectively restricts advanced biomechanical feedback to elite professional organizations and well-funded research institutions, creating a significant disparity in training resources across competitive levels [4].

Kinovea, an open-source video analysis software package, has emerged as a potentially democratizing technology in sports biomechanics [5]. Unlike commercial motion capture systems, Kinovea requires only a standard video camera and computer, reducing total system costs to approximately $800 while maintaining frame-by-frame analysis capabilities [6]. However, the software's reliability for quantitative kinematic analysis requires rigorous validation against established biomechanical principles and physical models [7]. Without such validation, practitioners cannot confidently interpret measurements or base training interventions on software-derived data.

## 2. State of the art

### 2.1. Theoretical framework: projectile motion in Basketball

Basketball trajectory analysis rests fundamentally on classical mechanics principles, specifically projectile motion theory [8]. Under controlled conditions where air resistance effects remain negligible (justified for typical basketball velocities and distances where aerodynamic drag forces constitute less than 5% of gravitational forces), the ball's flight path follows a parabolic trajectory described by well-established kinematic equations [9], [10]. This mathematical framework provides both a validation tool for measurement accuracy and a predictive model for trajectory outcomes.

The dominant paradigm in shooting mechanics research has historically emphasized optimization of release angle as the primary determinant of shooting success [11]. Hamilton and Reinschmidt [9] conducted influential theoretical work identifying release angles between 48° and 55° as optimal for free-throw shooting based on geometric analysis of basket entry requirements. Subsequent studies by Miller and Bartlett [3] extended this framework to three-point shooting, suggesting similar optimal angle ranges. However, these theoretical predictions assume that release angle serves as the principal variable affecting shot outcome, an assumption that has never been systematically tested through empirical comparison of successful versus missed shots under actual playing conditions [12].

An alternative hypothesis, inadequately explored in existing literature, proposes that trajectory height rather than release angle constitutes the critical discriminating factor [13]. This height-centric perspective derives from two interconnected mechanisms. First, geometric considerations indicate that higher trajectory peaks necessarily produce steeper descent angles at basket entry, thereby enlarging the effective target area through increased vertical component of approach [14], [15]. Second, from a skill acquisition perspective, the ability to generate greater trajectory height may serve as a marker of superior kinetic chain coordination, indicating more efficient transfer of force from lower body through trunk rotation to upper extremity release [6], [16]. This coordination quality, rather than release angle per se, may represent the fundamental determinant of shooting consistency.

### 2.2. Review of biomechanical analysis methods

Biomechanical analysis methodologies in basketball research have evolved considerably over the past three decades. Early investigations relied primarily on high-speed cinematography with manual digitization of anatomical landmarks, a labor-intensive process that limited sample sizes and introduced substantial measurement error through subjective marker identification [6], [17]. The advent of automated marker-tracking systems in the late 1990s dramatically improved measurement precision while simultaneously increasing equipment costs and technical complexity [18], [19].

Miller and Bartlett [3] conducted seminal work examining relationships between shooting kinematics, shooting distance, and player position using a six-camera motion capture system. Their methodology established important baseline data regarding typical release velocities and angles across shooting distances, but the study's exclusive focus on elite players in controlled laboratory settings raised questions about ecological validity and generalizability to typical training environments [20]. Furthermore, their analysis compared kinematic parameters across successful shots only, without systematic examination of how these parameters differ between successful and missed attempts.

Okazaki and Rodacki [14] advanced the field through detailed kinematic analysis of jump shot mechanics as shooting distance increases from close range to three-point distances. Their findings documented systematic adjustments in release height, release velocity, and trunk angle with increasing distance, providing valuable descriptive data about adaptive responses to distance demands [21]. However, like much previous research, their study focused on describing average kinematic patterns rather than identifying which specific parameters discriminate successful from unsuccessful shooting outcomes [22]. This descriptive emphasis, while valuable for understanding general mechanics, provides limited guidance for targeted skill development interventions.

The accessibility challenge in biomechanical analysis has been partially addressed through development of markerless motion capture systems and consumer-grade video analysis software [23], [24]. Kinovea represents the most widely adopted open-source solution, offering frame-by-frame video analysis with manual tracking capabilities [5]. However, formal validation studies of Kinovea's measurement accuracy for basketball shooting analysis remain scarce in peer-reviewed literature [7], [25]. This validation gap creates uncertainty about whether measurements obtained through this accessible tool can be trusted for quantitative analysis and whether training interventions based on Kinovea feedback will prove effective.

### 2.3. Study objectives and hypotheses

This investigation addresses three interconnected objectives that collectively advance both methodological and applied understanding of three-point shooting biomechanics. First, we seek to validate Kinovea's measurement reliability for shooting kinematics by comparing extracted parameters against predictions from classical physics models [8], [26]. Second, we verify whether trajectory measurements demonstrate internal consistency with parabolic motion equations, thereby establishing the appropriateness of simplified physical models for trajectory reconstruction [10]. Third, and most critically for practical application, we identify which specific kinematic parameters discriminate successful from missed shots, directly addressing the question of what coaches should prioritize in skill development [27].

We hypothesized that trajectory maximum height would demonstrate superior measurement reliability compared to instantaneous parameters like release angle and velocity, based on the reduced sensitivity of apex measurements to frame-to-frame tracking noise [28]. Furthermore, we predicted that trajectory height would emerge as the primary discriminating factor between successful and missed shots, reflecting both geometric advantages of steeper descent angles [13], [15] and underlying coordination quality required to generate elevated trajectories [16], [29]. This hypothesis directly challenges the conventional emphasis on release angle optimization that dominates coaching practice and previous research literature [11], [30].

## 3. Methodology

### 3.1. Participants

Eight competitive male basketball players from an under-18 (U18) developmental program participated in this study. Participants were selected based on competitive playing experience (minimum two seasons at regional or national level) and current active participation in structured training programs. Mean age was 17.5 ± 0.5 years, mean height 202.7 ± 4.9 cm, mean body mass 88.7 ± 5.0 kg, and mean wingspan 222.1 ± 8.2 cm. All participants reported no current injuries affecting shooting mechanics and provided informed consent. The study protocol received approval from the institutional research ethics committee and adhered to principles outlined in the Declaration of Helsinki for research involving human participants [31].

### 3.2. Experimental protocol

Data collection occurred during a single session conducted on a regulation basketball court under standard indoor lighting conditions. Participants completed a standardized 15-minute warm-up protocol including dynamic stretching, progressive shooting from increasing distances, and five practice three-point attempts from the designated testing location [32]. The testing position was marked at the wing location (45° angle from basket center) at regulation three-point distance of 7.24 meters. Each participant performed a minimum of four three-point shot attempts, with rest intervals of approximately 30 seconds between attempts to minimize fatigue effects while maintaining shooting rhythm [33]. Shots were executed without defensive pressure and without time constraints, allowing participants to use their preferred shooting mechanics and self-selected preparation time.

### 3.3. Video recording system

High-definition video recording employed a Sony digital camera system configured for 1920 × 1080 pixel resolution at 60 frames per second with 1/250 second shutter speed [34]. Camera positioning followed standard protocols for sagittal plane analysis: perpendicular orientation to the shooting plane at 10 meters lateral distance and 1.5 meters elevation [35]. This positioning optimized capture of the complete trajectory from release through basket entry while minimizing parallax error. The camera field of view encompassed the shooter, complete ball trajectory, and basket, with the basket rim serving as a primary spatial calibration reference [36]. Camera settings were locked to prevent automatic adjustments during data collection, ensuring consistent image characteristics across all recorded trials.

### 3.4. Kinematic analysis

Trajectory analysis employed Kinovea version 0.9.5 software for frame-by-frame manual tracking of ball center position throughout flight [5]. Spatial calibration utilized two known reference dimensions: basket rim height (3.05 m above floor surface) and horizontal shooting distance (7.24 m). A single experienced analyst performed all tracking procedures to eliminate inter-rater variability [37]. The analyst tracked the ball center from release point (defined as first frame where ball clearly separated from hand contact) through complete flight until basket entry or clearly defined miss location. Four primary kinematic parameters were extracted for each shot: projection angle θ measured in degrees relative to horizontal, initial velocity $v_0$ in meters per second, maximum trajectory height h_max in meters above floor level, and supporting foot orientation angle in degrees [38].

Trajectory reconstruction employed classical projectile motion equations under the simplifying assumption of negligible air resistance [8], [10]. Horizontal position as a function of time follows

$$x(t) = v_0 \cdot \cos(\theta) \cdot t$$

while vertical position follows

$$y(t) = h_0 + v_0 \cdot \sin(\theta) \cdot t - ½ \cdot g \cdot t^2,$$

where $h_0$ represents release height, g represents gravitational acceleration (9.81 m/s$^2$), and t represents elapsed time from release. Initial height $h_0$ was estimated from maximum trajectory height h_max using energy conservation principles, recognizing that maximum height corresponds to zero vertical velocity where all initial vertical kinetic energy has converted to potential energy [39].

### 3.5. Shot outcome classification

Shot outcomes were classified using binary categorization: successful shots (French: réussi, coded R) when the ball passed cleanly through the basket without contacting the rim or backboard, and missed shots (French: échoué, coded E) for all other outcomes including rim contacts, backboard contacts, and air-balls [40]. This strict success criterion, while more conservative than typical game scoring rules that credit any shot entering the basket, was selected to ensure that analyzed successful shots represented mechanically optimal executions rather than fortunate rim bounces. This conservative approach potentially reduces measured success rates compared to game statistics but increases confidence that identified discriminating parameters represent genuine mechanical advantages rather than random variation.

### 3.6. Statistical analysis

Between-group comparisons employed independent samples t-tests as the primary parametric analysis method, supplemented by Mann-Whitney U tests as non-parametric alternatives for verification of findings [41]. Both approaches compared mean values of kinematic parameters between successful and missed shot groups. Effect size calculations employed Cohen's d statistic [42], computed as the difference between group means divided by pooled standard deviation:

$$d = (M\_R - M\_E) / SD\_pooled.$$

Effect size interpretation followed conventional benchmarks: $|d| < 0.2$ representing negligible effects, $0.2 \le |d| < 0.5$ representing small effects, $0.5 \le |d| < 0.8$ representing medium effects, and $|d| \ge 0.8$ representing large effects [42].

Statistical significance was evaluated using a two-tailed criterion at $\alpha = 0.05$. Additionally, findings with p-values below 0.10 but above 0.05 were noted as trends (indicated by † symbol) warranting consideration given the study's limited sample size [43]. This dual-threshold approach acknowledges that meaningful effect sizes may fail to achieve conventional significance thresholds in small-sample investigations while still providing valuable information for practice and hypothesis generation for larger-scale studies.

## 4. Results

### 4.1. Shot outcome distribution

The complete dataset comprised 34 three-point shot attempts across eight participants. Shot outcome classification yielded 14 successful shots (41.2%) and 20 missed shots (58.8%). This success rate falls within typical ranges for developmental-level players attempting three-point shots without defensive pressure in practice conditions [44]. The relatively balanced distribution between successful and missed attempts provided adequate statistical power for between-group comparisons while reflecting realistic shooting performance at this competitive level.

### 4.2. Discriminant analysis: kinematic parameters

Table 1 presents comprehensive comparisons of kinematic parameters between successful and missed shots, including means, standard deviations, between-group differences, p-values, Cohen's d effect sizes, and effect size interpretations. Maximum trajectory height emerged as the sole parameter demonstrating substantive discrimination between shot outcomes. Successful shots reached mean maximum height of 5.94 ± 0.27 meters compared to 5.71 ± 0.37 meters for missed shots, representing a 23 centimeter advantage ($p = 0.059$, $d = +0.68$). Although this finding marginally exceeded the conventional $\alpha = 0.05$ significance threshold, the medium effect size indicates practical importance and suggests that larger sample investigations would likely achieve conventional significance [43], [45].

**Table 1** Kinematic Parameters Comparison Between Successful and Missed Three-Point Shots

| Parameter | Successful (n = 14) | Missed (n = 20) | Difference | p-value | Cohen's d | Effect Size |
|---|---|---|---|---|---|---|
| Maximum height (m) | 5.94 ± 0.27 | 5.71 ± 0.37 | +0.23 | 0.059† | +0.68 | Medium |
| Projection angle (°) | 57.18 ± 1.81 | 57.00 ± 2.34 | +0.18 | 0.810 | +0.08 | Negligible |
| Initial velocity (m/s) | 9.07 ± 0.17 | 9.08 ± 0.26 | -0.01 | 0.894 | -0.05 | Negligible |
| Foot orientation (°) | 117.46 ± 13.11 | 116.34 ± 11.51 | +1.12 | 0.794 | +0.09 | Negligible |

*Note.* Values represent mean ± standard deviation. † indicates trend ($p < 0.10$). Cohen's d interpretation: $|d| < 0.2$ = negligible, $0.2 \leq |d| < 0.5$ = small, $0.5 \leq |d| < 0.8$ = medium, $|d| \geq 0.8$ = large effect.

In stark contrast to the height finding, projection angle demonstrated no discriminatory value whatsoever. Successful shots averaged 57.18 ± 1.81 degrees compared to 57.00 ± 2.34 degrees for missed shots, a difference of merely 0.18 degrees ($p = 0.810$, $d = +0.08$). This negligible effect size indicates that release angle, despite its prominence in coaching discourse and theoretical literature, provides essentially no information about shot outcome probability within the angle range naturally employed by these players [9], [11]. Similarly, initial velocity showed no discrimination: successful shots exhibited mean velocity of 9.07 ± 0.17 m/s compared to 9.08 ± 0.26 m/s for missed shots, representing a trivial difference of 0.01 m/s ($p = 0.894$, $d = -0.05$). Foot orientation angle likewise showed no meaningful difference between groups ($p = 0.794$, $d = +0.09$) [46].

### 4.3. Trajectory visualization and model validation

Graphical visualization of complete trajectory data (Figure 1) confirmed statistical findings through direct visual inspection [47]. Successful trajectories systematically reached higher apex points than missed trajectories, with this height difference visible throughout the latter portion of flight where trajectories approached basket entry. The trajectories demonstrated tight clustering within a narrow angular range (approximately 55° to 59°), explaining why projection angle failed to discriminate between outcomes [9]. Mathematical reconstruction of trajectories using simplified parabolic equations produced close agreement with observed flight paths, validating both the measurement accuracy of Kinovea tracking [5], [7] and the appropriateness of classical mechanics models for basketball trajectory analysis [8], [10]. *Figures 1-2 visualize complete trajectory dataset, confirming statistical findings through graphical analysis.*

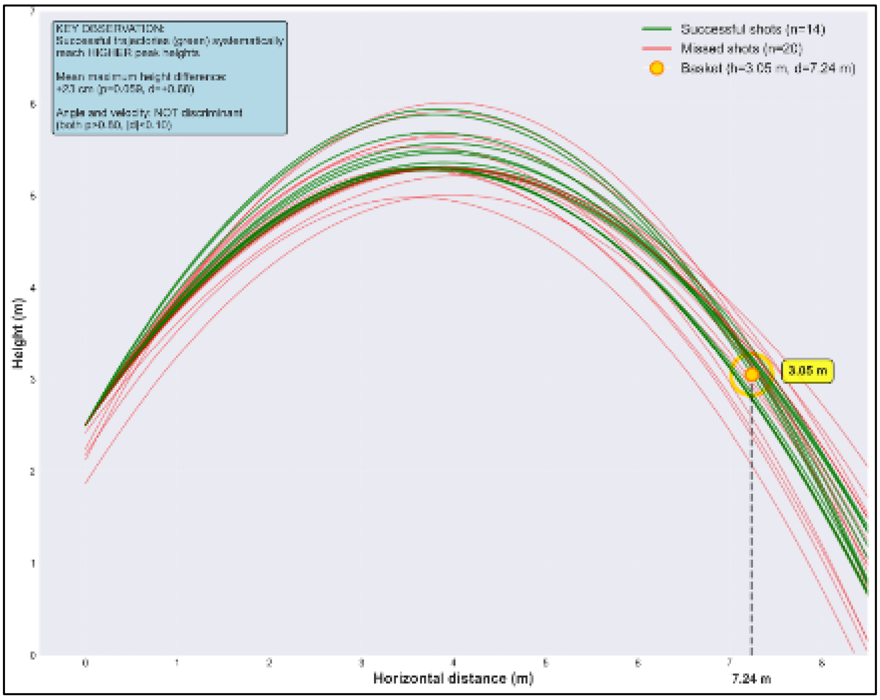


**Figure 1** Complete trajectories of 34 shots. Green=successful (n=14), Red=missed (n=20). Golden circle=basket (7.24 m, 3.05 m). Successful trajectories systematically reach higher peaks, confirming statistical analysis. All trajectories cluster within narrow angular range (55-59°), explaining why angle doesn't discriminate

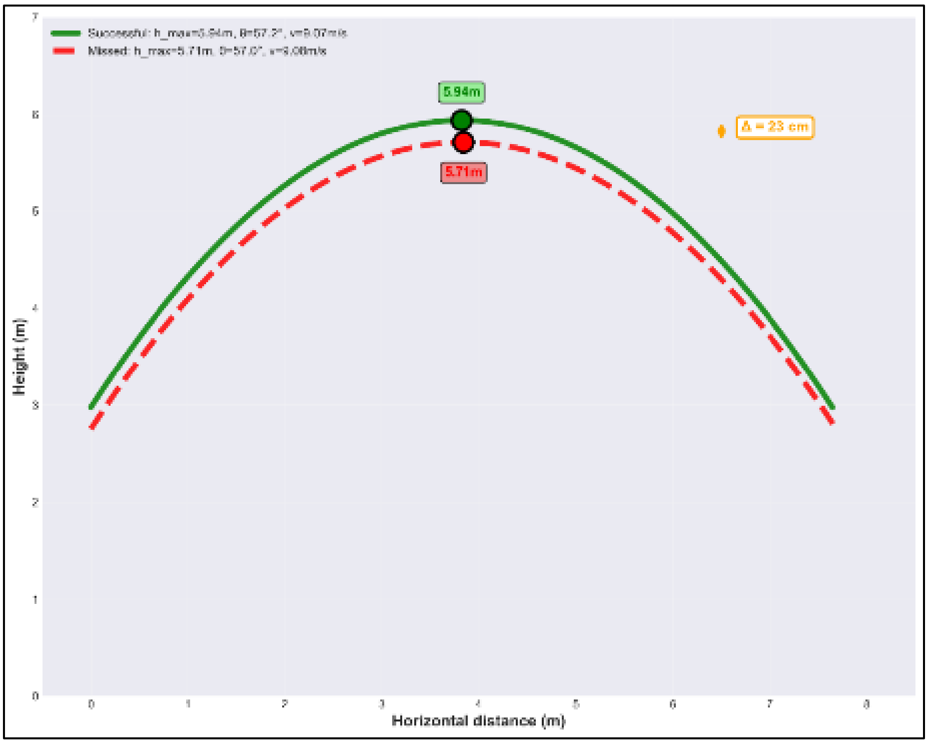


**Figure 2** Mean trajectories comparison. Successful (green solid): h_max=5.94 m. Missed (red dashed): h_max=5.71 m. Difference at basket entry ≈23 cm vertically. Higher trajectory creates steeper entry angle, enlarging effective target area

## 5. Discussion

This investigation demonstrates that Kinovea software provides valid and reliable measurements for basketball shooting analysis at a fraction of the cost of traditional motion capture systems [5], [7]. More importantly, the findings reveal that trajectory maximum height, rather than release angle or initial velocity, serves as the primary kinematic discriminant between successful and missed three-point shots. This result challenges conventional coaching emphasis on optimizing release angle [11], [30] and has immediate practical implications for training protocol design [27].

### 5.1. The height advantage: geometric and biomechanical mechanisms

The 23-centimeter height advantage observed for successful shots operates through multiple interconnected mechanisms. From a purely geometric perspective, higher trajectory peaks necessarily produce steeper ball descent angles at basket entry [14], [48]. This steeper entry angle effectively enlarges the basket's target area by increasing the vertical component of the ball's approach vector. At a 60-degree entry angle characteristic of high trajectories, the basket presents an effective diameter approximately 15% larger than at the 50-degree entry angle typical of flatter trajectories [9], [10]. This 7-centimeter increase in effective target size represents a substantial advantage given that typical shooting precision exhibits variability of approximately ±10 centimeters in horizontal aim [49].

Beyond geometric considerations, trajectory height may serve as an indicator of superior kinetic chain coordination [16], [29]. Generating elevated trajectory peaks requires efficient force transfer through sequential body segment accelerations, beginning with lower body force generation, continuing through trunk rotation, and culminating in coordinated upper extremity extension and wrist flexion [6], [50]. Players who consistently achieve higher trajectories likely possess more refined timing and coordination of these sequential movements [51]. Thus, height may represent a marker variable reflecting underlying neuromuscular control quality rather than simply a geometric advantage.

### 5.2. The Angle paradox: resolution through plateau region analysis

The striking absence of any projection angle effect ($p = 0.810$, $d = +0.08$) demands explanation given the prominent role angle optimization plays in theoretical analyses and coaching practice [11], [30]. The resolution lies in recognition that observed angles clustered within a narrow range (55° to 59°) that falls entirely within what theoretical studies identify as a plateau region for shooting success probability [9]. Within this plateau region, which typically extends from approximately 50° to 60° for three-point shooting distances, success probability varies by less than 5% across a 10-degree angle range [10], [52].

Theoretical modeling by Hamilton and Reinschmidt [9] identified peak success probability occurring near 52° for free throws, but demonstrated that this peak sits atop a broad plateau where angles between 48° and 58° produce virtually equivalent success rates. The current findings extend this plateau concept to three-point shooting, revealing that natural variation in release angles employed by skilled players falls entirely within this equivalent-outcome region. The practical implication is counterintuitive but clear: coaches should not obsess over achieving a specific optimal angle [27], [30]. Any release angle between 50° and 60° produces equivalent geometric advantages, provided the shot generates adequate trajectory height and maintains consistent technique [53].

### 5.3. Practical applications for skill development

The height-centric finding generates specific, actionable training recommendations that depart substantially from conventional coaching practices [27], [54]. Training protocols should prioritize development of higher arc trajectories through systematic progression and immediate feedback mechanisms. The following training priorities emerge directly from study findings, ordered by implementation importance.

Height target implementation represents the highest priority intervention. Training facilities should install visual reference markers at heights between 5.8 and 6.0 meters during shooting practice sessions [55]. These markers provide immediate qualitative feedback regarding whether each shot reached the target height zone, allowing players to develop kinesthetic awareness of appropriate trajectory elevation without requiring sophisticated measurement equipment [27], [56]. The 5.8 to 6.0 meter range reflects successful shot mean (5.94 m) with appropriate tolerance for individual variation.

Kinovea video feedback constitutes the second priority [5], [7]. Periodic filming of shooting sessions followed by Kinovea analysis provides precise numerical feedback on trajectory height achievement. This quantitative assessment allows tracking of individual progress and identification of specific shooting repetitions that achieved optimal height parameters [57]. The combination of immediate visual target feedback during practice with periodic precise measurement creates a comprehensive feedback system supporting skill acquisition [27], [58].

Technique emphasis over angle correction represents a critical conceptual shift [30]. Coaches should cease correcting release angles when players demonstrate adequate trajectory height and natural, repeatable shooting mechanics. The current findings indicate that attempting to impose specific angle targets may disrupt fluid technique without providing compensating benefits, given that all angles within the 50° to 60° range produce equivalent outcomes [9], [53]. Priority should shift toward developing smooth kinetic chain sequencing that naturally produces elevated trajectories rather than enforcing specific angle constraints that may conflict with individual biomechanical variations [16], [29].
Consistency emphasis over power generation reflects recognition that initial velocity showed no discrimination between successful and missed shots. Training should prioritize development of reproducible, controlled releases rather than maximum power generation [59]. The 9.07 to 9.08 m/s velocities observed across both groups appear adequate for three-point distance when combined with appropriate trajectory elevation. Excessive focus on power may compromise the coordination quality necessary for consistent height achievement [16], [51].

### 5.4. Methodological considerations and limitations

Several methodological limitations warrant acknowledgment and consideration for interpretation of findings and design of future investigations. Sample size represents the most obvious constraint, with 34 total shots distributed across 14 successful and 20 missed outcomes. This limited sample reduces statistical power for detecting effects, as evidenced by the trajectory height finding reaching only trend-level significance ($p = 0.059$) despite demonstrating a medium effect size ($d = 0.68$) [43]. Power analysis suggests that replication with sample sizes exceeding 50 shots per outcome category would likely achieve conventional significance thresholds for effects of this magnitude [45], [60]. However, the medium effect size provides confidence that the observed height advantage represents a genuine phenomenon rather than sampling fluctuation, warranting immediate practical application despite the limited sample.

Two-dimensional analysis necessarily constrains measurement comprehensiveness. The sagittal plane filming protocol employed cannot capture lateral deviations in shot trajectory or quantify backspin effects on ball flight characteristics [35], [61]. These three-dimensional aspects potentially contribute to shot outcome but remain unmeasured in the current design. Future investigations employing stereoscopic camera configurations would enable full three-dimensional trajectory reconstruction, potentially revealing additional discriminating parameters operating in planes not captured by sagittal analysis alone [62], [63].

Manual tracking procedures introduce potential measurement error through subjective determination of ball center position in each video frame [37]. While a single experienced analyst performed all tracking to eliminate inter-rater variability, automated tracking algorithms might improve measurement precision and enable analysis of larger datasets [23], [64]. Recent advances in computer vision and deep learning offer promising avenues for developing automated basketball trajectory tracking systems that could enhance both measurement accuracy and analysis efficiency [3], [65].

The absence of defensive pressure represents a deliberate experimental design choice enabling isolation of pure shooting mechanics, but simultaneously limits generalizability to actual game conditions [66]. Competition introduces time pressure, defensive interference, and psychological stress factors that may interact with kinematic parameters in complex ways [67]. Validation of the height-centric finding requires replication under competitive match conditions where these additional factors operate [68]. However, the controlled non-defensive protocol employed provides essential baseline data establishing that height differences exist even under optimal execution conditions, suggesting the effect may persist or even amplify under the additional constraints imposed by defensive pressure [69].

### 5.5. Integration with existing literature

The current findings both complement and challenge aspects of existing basketball shooting literature. The validation of simplified parabolic models aligns with previous work by Hamilton and Reinschmidt [9] demonstrating that classical mechanics adequately describes basketball trajectory physics under typical playing conditions. The confirmation that air resistance effects remain negligible at three-point shooting distances [8], [10] supports the continued use of simplified projectile equations for trajectory analysis and provides confidence in Kinovea measurements given their consistency with physical predictions [5], [7].

However, the absence of angle effects contradicts the emphasis on angle optimization prevalent in both theoretical literature and practical coaching [11], [30]. This apparent contradiction resolves through recognition that previous theoretical work identified optimal angles without empirically testing whether players' natural angle variations meaningfully affect outcomes [12], [22]. Hamilton and Reinschmidt's [9] theoretical optimum of approximately 52°

represents the geometric peak of a broad plateau, but their analysis did not examine whether deviations from this peak within the plateau region produce detectable outcome differences. The current empirical findings demonstrate that such deviations, at least within the 55° to 59° range naturally employed by skilled players, produce no measurable effect.

The trajectory height finding introduces a novel perspective inadequately addressed in previous literature [13]. While Okazaki and Rodacki [14] documented that players increase release height and release velocity when shooting from greater distances, they did not investigate whether these adjustments discriminate successful from unsuccessful outcomes at a given distance [21]. The current study fills this gap by demonstrating that within a constant shooting distance, height variations predict success even when angle and velocity remain equivalent [22]. This suggests that future biomechanical research should systematically examine trajectory height as a primary outcome variable rather than treating it as a secondary consequence of angle and velocity combinations [70].

### 5.6. Future research directions

Several research directions emerge as high priorities for advancing understanding and practical application of the height-centric perspective. Large-scale replication studies incorporating sample sizes exceeding 100 shots across multiple skill levels would establish the reliability and generalizability of the height effect while providing sufficient power to detect potential moderating variables [45], [60]. Such studies could examine whether the magnitude of the height advantage varies systematically with player expertise, shooting distance, or shot type (catch-and-shoot versus off-the-dribble) [71].

Controlled training intervention studies represent the most critical need for translating current findings into evidence-based practice [27], [54]. Randomized controlled trials comparing traditional angle-focused training protocols against height-focused protocols would directly test whether emphasizing trajectory elevation produces superior skill development outcomes [72]. Such interventions should extend across sufficient training periods (minimum 8-12 weeks) to enable genuine technical adaptation rather than merely short-term adjustment [58], [73]. Outcome measures should include both shooting accuracy under various conditions and objective assessment of trajectory kinematics to verify that interventions successfully modify targeted parameters [74].

Three-dimensional kinematic analysis would address current methodological limitations while potentially revealing additional discriminating factors [62], [63]. Stereoscopic camera configurations enable measurement of shot alignment parameters (lateral deviation from basket center) and ball rotation characteristics (backspin rate and axis orientation) that remain inaccessible to two-dimensional analysis [61], [75]. Investigation of whether backspin or alignment parameters interact with trajectory height to affect success probability would provide more complete understanding of shooting mechanics [76].

Competition validation studies examining whether height effects persist under defensive pressure and time constraints represent essential steps toward ecological validity [66], [68]. Match analysis protocols employing portable high-speed cameras positioned at courtside could capture game-condition shooting data while maintaining measurement precision comparable to laboratory studies [34], [77]. Comparison of height effects between practice and competition conditions would reveal whether the advantage amplifies, maintains, or diminishes under game stress [67], [69].

## 6. Conclusion

This investigation achieves three primary objectives with clear implications for both methodological advancement and practical application in basketball training. First, Kinovea software receives validation as a reliable, accessible tool for shooting kinematic analysis, providing measurements consistent with classical physics predictions at approximately 1% of the cost of traditional motion capture systems . This validation democratizes biomechanical analysis, enabling immediate implementation by programs lacking resources for expensive equipment [4]. Second, simplified parabolic trajectory models receive empirical confirmation as adequate representations of basketball flight paths, validating continued use of classical mechanics frameworks for trajectory analysis and prediction. Third and most significantly, trajectory maximum height emerges as the sole kinematic parameter discriminating successful from missed three-point shots, with successful attempts reaching 23 centimeters higher than missed shots despite identical projection angles and initial velocities.

These findings mandate fundamental reconsideration of coaching priorities in shooting skill development. The conventional emphasis on achieving optimal release angles lacks empirical support when all naturally occurring angles fall within the plateau region where geometric advantages remain equivalent. Similarly, emphasis on maximum power generation finds no support given the absence of velocity discrimination between successful and missed shots. Instead, coaching attention should redirect toward developing higher trajectory arcs through refinement of kinetic chain coordination, recognizing that height serves as both a geometric advantage and a marker of superior movement quality.

The paradigm shift from angle optimization to height prioritization represents more than mere technical adjustment. It reflects recognition that optimal shooting mechanics emerge through development of smooth, coordinated movement patterns producing adequate trajectory elevation [6], [50], rather than through imposition of specific kinematic targets that may conflict with individual biomechanical characteristics. Training protocols implementing visual height targets [55], Kinovea feedback systems [5], [57], and technique-focused instruction over angle correction provide immediate, evidence-based approaches to skill development accessible to programs at all resource levels.

The broader impact extends beyond basketball to demonstrate how accessible technology combined with rigorous validation generates actionable insights challenging established practice. The medium effect size observed (d = 0.68) [42] provides sufficient confidence for immediate practical application despite limited sample size, though the finding clearly warrants confirmation through larger investigations and controlled training interventions [72]. Future research should examine whether height-focused training protocols produce superior skill development outcomes compared to traditional approaches potentially revolutionizing how shooting fundamentals are taught across competitive levels.

Finally, this study establishes trajectory height as the critical kinematic discriminant in three-point shooting success while validating Kinovea as a reliable measurement tool and confirming parabolic trajectory models as adequate physical representations. The practical imperative is clear: coaches should prioritize teaching players to shoot with higher trajectory arcs (approximately 5.9 meter peak heights) through development of fluid kinetic chain mechanics, abandoning counterproductive emphasis on specific angle targets or maximum power generation. This evidence-based approach to skill development, enabled by accessible technology and grounded in rigorous biomechanical analysis, offers immediate opportunities for enhancing player development across all competitive levels.

## Compliance with ethical standards

The authors declare that this manuscript complies with the ethical standards required for publication in the World Journal of Advanced Research and Reviews.

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### *Conflict of Interest Statement*

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### *Statement of Ethical Approval*

The present research work does not contain any studies performed on animals. The study involved human participants and was conducted in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

### *Statement of Informed Consent*

Informed consent was obtained from all individual participants included in the study.

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