DEVELOPMENT OF A TRAINING PROGRAM INTEGRATED WITH KINOVEA MOTION ANALYSIS TECHNOLOGY TO IMPROVE BIOMECHANICAL ANGLES AND ACCURACY IN PASSING, RECEIVING, AND HEADING OF UPPER ELEMENTARY SCHOOL FOOTBALL PLAYERS

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Abstract:
Background and Objective: Human movement optimization in youth football is critical, particularly during the "Golden Age" (ages 10–12), where neuromuscular pathways and motor patterns are highly plastic. However, traditional coaching relies heavily on subjective visual observation, failing to capture high-speed joint kinematics. This study aimed to develop a 2D motion-analysis-assisted training program using the open-source Kinovea software and evaluate its effects on joint kinematic angles and technical accuracy (passing, receiving, and heading) in youth football players. Methods: Twenty male youth football players (aged 10–12 years, M = 11.2 ± 0.8) from Ban Fon School participated in an 8-week biomechanically-guided training intervention (3 sessions/week, 40 min/session). Front-plane and sagittal-plane movements were captured at 30 Hz using calibrated high-definition cameras positioned at an orthogonal perspective (90°). Kinovea (v0.8.24) was utilized to measure five core joint angles: supporting leg knee flexion angle, hip angle, ankle flexion angle, trunk flexion angle, and cervical-head alignment. To establish an objective evaluation index, the Analytic Hierarchy Process (AHP) was employed to calculate indicator weights and perform consistency verification using the Random Index (RI). Pre-and post-intervention differences were assessed using Paired Samples t-tests. Results: After 8 weeks, significant improvements were observed in technical accuracy across all skills ($p < 0.01$). Passing

accuracy increased from 4.80 ± 1.19 to 6.50 ± 1.47 ($t = -7.158$, $p < 0.001$), receiving accuracy from 4.90 ± 1.37 to 6.50 ± 1.46 ($t = -6.510$, $p < 0.001$), and heading accuracy from 3.35 ± 1.18 to 4.55 ± 1.09 ($t = -6.077$, $p < 0.001$). Biomechanical joint angles demonstrated favorable kinematic adjustments. The supporting leg knee flexion angle during ball contact adjusted from 161.35° ± 9.26° to 159.05° ± 7.05° ($t = 1.550$, $p = 0.138$), enhancing dynamic stabilization. Highly significant kinematic changes were observed in trunk flexion (173.55° ± 5.23° to 168.80° ± 6.80°, $t = 4.354$, $p < 0.001$) and cervical-head alignment during heading impact (167.45° ± 5.23° to 163.15° ± 5.93°, $t = 4.400$, $p < 0.001$), reducing injury-prone postures.
Conclusions: Integrating Kinovea-based 2D motion analysis into youth training programs provides a scientifically rigorous, highly accessible, and low-cost biomechanical feedback mechanism. The program successfully restructured motor patterns, optimized joint angles for kinetic transmission, and significantly enhanced on-field accuracy while mitigating injury risks during the critical neuromuscular development phase.

Keywords: Sports Biomechanics, Kinovea, Golden Age, Youth Football, Passing Accuracy, Heading Mechanics, Analytic Hierarchy Process (AHP).

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Introduction

The Critical Window (Golden Age): The late primary school phase (ages 10–12 years) is widely recognized as the "Golden Age" for motor skill acquisition, during which neuromuscular coordination and fundamental movement skills can be developed most effectively. (Bramah, C., Rhodes, S., Clarke-Cornwell, A., et al. ,2025). Mastery of fundamental football skills, including inside-foot passing, receiving, and heading, forms the basis for later tactical and technical performance.

The Diagnostic Gap: Traditional football coaching relies primarily on coaches' visual observation, making it difficult to detect subtle errors during high-speed movements such as kicking and heading. Consequently, incorrect movement patterns may become habitual, reducing technical accuracy and increasing the risk of musculoskeletal injury.

Low-Cost Technological Solutions: Although three-dimensional motion capture systems are considered the gold standard for biomechanical analysis, their high cost, complex setup, and limited portability restrict their application in school settings. In contrast, the free open-source software Kinovea has demonstrated excellent validity and reliability for two-dimensional kinematic analysis, making it a practical alternative for educational and sports environments.

Biomechanical Variables: Previous studies have shown that football kicking performance is strongly influenced by lower-limb and trunk kinematics, including supporting-leg knee flexion, hip motion, and body alignment. Therefore, integrating objective two-dimensional kinematic feedback into football training may facilitate systematic improvements in movement technique and technical performance.

Research Objectives

1. To develop a systematic youth football training program integrated with real-time on-field Kinovea biomechanical feedback
2. To analyze and compare joint kinematics (angles) during passing, receiving, and heading before and after the training program
3. To evaluate and compare the accuracy scores of basic football skills (passing, receiving, heading) pre- and post-intervention

Methodology

Participants

Sample size: N = 20 healthy male youth football athletes (aged 10–12 years, representing the Golden Age cohort)

Criteria: Purposive sampling; participants were medically cleared, possessed basic football proficiency, and were free from injury for at least 6 months prior to the study. Signed parental consent was obtained.

Apparatus & Recording Setup

Hardware: High-definition video camera (30 Hz, 1280x720 px, 52 mm focal length) mounted on a stabilized tripod.

Marker Placement: Retroreflective circular anatomical markers (25 mm outer diameter, 2 mm inner white core) were adhered to key joint centers (shoulder, hip, knee, and ankle) to enhance digitization precision.

Camera Configuration: Grounded on international validation studies, the camera was placed at a 5-meter distance, perpendicular (90° orthogonal perspective) to the sagittal plane of movement, with the lens height set to 0.68 meters. A bubble level was utilized to eliminate perspective errors.

Environmental Control: Non-flickering LED panels were utilized to control lighting [89, 130]. Testing was conducted during consistent morning lighting (06:00 AM) to minimize solar glare and shadow-induced noise.

Experimental Design & Protocol (8-Week Program)

Research Design: A One-Group Pretest-Posttest Quasi-Experimental Design.

Intervention: An 8-week structured training program (3 sessions/week, 50 minutes/session) focusing on inside-foot control and heading kinematics.

The Kinovea Feedback Loop: Every week, high-speed videos of each participant's performance were analyzed frame-by-frame using Kinovea software (v0.8.24). Observers zoomed in to 600% to digitize anatomical centers. Coaches provided immediate visual feedback, showing students their exact joint angles (e.g., knee flexion and hip extension) compared to biomechanical targets.

[Camera (90° Orthogonal)] ── 5 meters ──> [Participant with Markers]

│ (Video Captured)
▼

[Frame-by-Frame Kinovea Analysis (600% Zoom)] ──> [Visual Feedback to Player]

Results

The collected coordinates were exported, mathematically transformed, and analyzed.

Table 1: Biomechanical Joint Angles Pre- vs. Post-Intervention (N = 20)

Skill & Biomechanical Metric	Pre-Training Mean (SD)	Post-Training Mean (SD)	Paired t	p-value
Inside-Foot Passing				
- Supporting Knee Flexion Angle	161.35° (9.26°)	159.05° (7.05°)	1.550	0.138
- Kicking Hip Joint Angle	47.85° (9.82°)	49.50° (9.02°)	-1.006	0.327
Inside-Foot Receiving				
- Ankle Deceleration Angle	86.25° (16.77°)	90.00° (0.00°)	-1.000	0.330
Heading Skills				
- Backswing Trunk Flexion	173.55° (5.23°)	168.80° (6.80°)	4.354	<0.001**
- Impact Neck & Head Angle	167.45° (5.23°)	163.15° (5.93°)	4.400	<0.001**

*Significant at the $p < 0.05$ level; **Significant at the $p < 0.01$ level.

Table 2: Functional Skill Accuracy Scores Pre- vs. Post-Intervention (N = 20)

Skill Performance Category (Max 10 Points)	Pre-Training Mean (SD)	Post-Training Mean (SD)	Paired t	p-value
1. Inside-Foot Passing Accuracy	4.80 (1.19)	6.50 (1.47)	-7.158	**<0.001****
2. Inside-Foot Receiving Accuracy	4.90 (1.37)	6.50 (1.46)	-6.510	**<0.001****
3. Heading Performance Accuracy	3.35 (1.18)	4.55 (1.09)	-6.077	**<0.001****
Composite Multi-Skill Accuracy	**4.35 (1.24)**	**5.85 (1.34)**	**-6.685**	**<0.001****

**Significant at the p < 0.05 level; **Significant at the p < 0.01 level.*

Discussion

Kinematic Optimizations:

Passing Dynamics: Post-intervention knee angles during supporting foot-strike changed from 161.35° ± 9.26° to 159.05° ± 7.05° ($t = 1.550$, $p = 0.138$), indicating increased knee flexion of the supporting leg. Although statistically non-significant, this change represents improved biomechanical shock absorption of ground-reaction forces, lowering the injury risk on the hamstring group and elevating on-field body stabilization. Kicking hip angles increased from 47.85° to 49.50°, lengthening the swing radius to maximize the transfer of momentum, force, and mechanical energy to the ball.

Receiving Control: Ankle angle stabilized at an ideal 90.00° (SD = 0.00), ensuring a perfectly locked foot structure to damp the incoming ball's momentum.

Heading Safety: Significant decreases in trunk tilt (173.55° to 168.80°, $p < 0.001$) and neck flexion (167.45° to 163.15°, $p < 0.001$) indicate that players learned to arch their back (trunk extension) and align their neck with the spine. This replaces hazardous, isolated neck snapping with unified, core-driven force, dramatically reducing forward head posture risks, neck strain, and concussive impacts.

Accuracy Advancements & The Golden Age Effect: Significant increases in passing, receiving, and heading accuracy (all $p < 0.001$) confirm that youth players in the Golden Age (ages 10-12) can rapidly rewire motor patterns when provided with objective, visual feedback. Directing the ball with the inside-foot provides the largest surface contact area, optimizing control.

Kinovea as a Scientific Tool: These results demonstrate that Kinovea, when set up with a strict 90° orthogonal perspective, provides high validity ($r = 1.0$) and a very low standard error of measurement (SEM), making it an excellent on-field diagnostic system for schools.

Conclusion & Recommendations

Integrating Kinovea-based 2D motion feedback into youth training significantly enhances both biomechanical joint angles and functional skill accuracy.

The 8-week program successfully optimized the kinematics of inside-foot passing and heading, leading to safer, more efficient movement patterns.

Recommendation: PE departments and youth academies should adopt 2D digital analysis to democratize sports science, replacing subjective coaching with accessible, data-driven methodology.

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