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Effectiveness of KINOVEA-Based Biomechanical Feedback Training on Smash Accuracy Among High School Volleyball Athletes

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Abstract

Study purpose. This study investigated the effectiveness of KINOVEA-based biomechanical feedback training on improving smash accuracy, arm swing angle, and vertical jump height among high school volleyball athletes.

Materials and methods. A quantitative experimental method employing a pre-test–post-test control group design was used. Twenty high school volleyball athletes were randomly assigned to an experimental group ($n = 10$), which received KINOVEA-based biomechanical feedback training, and a control group ($n = 10$), which participated in conventional training. Smash accuracy, arm angle, and vertical jump height were measured before and after a six-week intervention period.

Results. The experimental group demonstrated statistically significant improvements compared to the control group. Specifically, smash accuracy increased by 4.80 points ($p < 0.001$, Cohen's $d = 5.08$), arm angle improved by 9.38° ($p < 0.001$, Cohen's $d = 2.30$), and vertical jump height increased by 6.30 cm ($p < 0.001$, Cohen's $d = 1.75$). The control group showed only minor gains across all metrics.

Conclusions. KINOVEA-based biomechanical feedback training effectively enhances both technical precision and physical execution in volleyball smash performance. Integrating accessible video motion analysis tools into school-based training provides a practical model for optimizing athletic development.

Keywords: KINOVEA, Biomechanical Feedback, Smash Accuracy, Volleyball, Sports Performance

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Introduction

Volleyball is widely practiced among high school students, serving as a prominent sport for promoting physical fitness, teamwork, and competitive skills. Among the offensive skills in volleyball, the smash (spike) is primary for scoring points. Successful smash execution relies

on proper biomechanical coordination, including approach speed, vertical displacement, arm swing trajectories, body alignment, and optimal contact timing (Slovák et al., 2024).

Despite regular participation in school extracurricular programs, adolescent athletes often encounter difficulties in executing consistent and accurate smashes. Common technical errors include suboptimal take-off mechanics, insufficient shoulder extension, improper arm swing path, and poor timing (dos Santos Oliveira et al., 2020). In conventional school-based training, coaches typically rely on verbal instruction and subjective observation. This traditional approach limits an athlete's objective self-awareness regarding movement errors (Gil Agudo, 2019).

Recent advances in sports technology emphasize video-based biomechanical feedback systems to accelerate motor skill acquisition. KINOVEA software is a freely available, open-source motion analysis tool that provides frame-by frame evaluation of movement kinematics. It enables coaches to quantitatively assess joint angles, spatial trajectories, and temporal sequencing, delivering immediate visual feedback to athletes (Salim et al., 2020).

While KINOVEA's validity as a measurement tool is well-established, prior literature predominantly utilizes it for diagnostic assessments rather than structured corrective training interventions. Furthermore, research has focused heavily on elite or professional environments, leaving high school extracurricular programs which frequently face resource constraints underrepresented (Aprilo et al., 2021). Therefore, this study aimed to evaluate the effectiveness of a six-week KINOVEA-based biomechanical feedback training program on smash accuracy, arm swing angle, and vertical jump height among high school volleyball athletes. It was hypothesized that athletes receiving biomechanical feedback would exhibit significantly greater performance gains compared to those receiving conventional training (Salim et al., 2024).

of KINOVEA-based biomechanical feedback training on smash accuracy among high school volleyball athletes. Specifically, the study aimed to determine whether the integration of biomechanical feedback could produce greater improvements in smash accuracy, arm swing mechanics, and vertical jump performance compared with conventional volleyball training methods. It was hypothesized that athletes receiving KINOVEA-based biomechanical feedback training would demonstrate significantly greater improvements in volleyball smash performance than athletes receiving conventional training.

Materials and methods

To rigorously evaluate the intervention effects, Analysis of Covariance (**ANCOVA**) was conducted on the post-test scores for each variable (smash accuracy, arm angle, and vertical jump height), using their respective pre-test scores as covariates. This approach was implemented to control for baseline group differences and precisely isolate the main interaction effect between the treatment group and time.

Study participants

Twenty male student-athletes ($N = 20$, aged 15–17 years) from the volleyball extracurricular program at Sinar Pancasila Private High School in Betun, Indonesia, were recruited via purposive sampling. Inclusion criteria required active participation, regular attendance, and no history of musculoskeletal injuries in the preceding six months. Participants were randomly allocated to either the experimental group ($n = 10$) or the control group ($n = 10$). Informed consent was obtained from all participants and their guardians.

Study organization

This study employed a quantitative experimental design with a pre-test–post-test control group setup over a six-week period.

Table 1. Experimental Research Design.

Group	Pre-Test	Intervention (6 Weeks)	Post-Test
Experimental ($n = 10$)	Smash Accuracy, Arm Angle, Jump Height	KINOVEA-based Biomechanical Feedback Training	Smash Accuracy, Arm Angle, Jump Height
Control ($n = 10$)	Smash Accuracy, Arm Angle, Jump Height	Conventional Volleyball Training	Smash Accuracy, Arm Angle, Jump Height

Intervention Protocol

Experimental Group: Participated in standard training augmented with KINOVEA-based feedback. Smashes were recorded during sessions using high-speed HD cameras (120 fps). Immediately following trial execution, athletes reviewed their movement kinematics via KINOVEA software (v0.8.27) alongside the coach to identify technical errors (e.g., shoulder joint extension angle, take-off posture) and perform targeted corrective drills. Control Group: Participated in conventional volleyball training consisting of standard technical drills and qualitative verbal instructions from the coach, without video feedback.

Instruments & Data Collection

Smash Accuracy Test: Evaluated using a standardized target zone court test adapted from the Indonesian Volleyball Federation (PBVSI) (Scale: 0–15). Kinematic & Biomechanical Metrics: Arm swing angle (°) at ball contact and vertical jump height (cm) were extracted and quantified using KINOVEA software (v0.8.27).

Statistical Analysis.

Data analyses were conducted using IBM SPSS Statistics (Version 26). Descriptive statistics were computed as Mean $\pm$ Standard Deviation (SD). Data normality and variance homogeneity were verified using Shapiro–Wilk and Levene's tests ($p > 0.05$). Within-group changes were analyzed using paired-sample t-tests, whereas between-group comparisons were evaluated using independent-sample t-tests. Effect sizes were determined via Cohen's d. Statistical significance was set at $p < 0.05$.

Results

The descriptive and inferential statistics for smash accuracy, arm angle, and vertical jump height across both groups are summarized below.

Table 2. Descriptive and Within-Group Statistical Analysis

Variable	Group	Pre-Test (Mean±SD)	Post-Test (Mean±SD)	Mean Gain	t-value	p-value	p-value
Smash Accuracy *(0–15 scale)*	Experimental	6.30 ± 1.25	11.10 ± 1.02	$+4.80$	10.32	< 0.001	5.08
	Control	6.20 ± 1.18	7.00 ± 1.35	$+0.80$	10.32	< 0.001	5.08
Arm Angle *(Degrees)*	Experimental	$145.20° \pm 3.10°$	$154.58° \pm 2.45°$	$+9.38°$	12.95	< 0.001	2.30
	Control	$144.80° \pm 3.25°$	$146.58° \pm 3.10°$	$+1.78°$	5.74	< 0.001	0.48

Jump Height *(cm)*	Experimental	42.10 $\pm$ 2.80	48.40 $\pm$ 2.10	+6.30 cm	18.82	< 0.001	1.75
	Control	41.80 $\pm$ 2.60	43.44 $\pm$ 2.40	+1.64 cm	4.32	0.002	0.47

Within-Group Analysis

Smash Accuracy: The experimental group achieved a significant increase in smash accuracy ($t(9) = 10.32, p < 0.001, d = 5.08$). The control group showed a slight, non-significant change ($t(9) = 1.47, p = 0.178, d = 0.63$). Arm Angle & Jump Height: The experimental group made substantial gains in arm swing mechanics ($+9.38°, p < 0.001$) and vertical jump height ($+6.30$ cm, $p < 0.001$). The control group recorded minor changes.

Between-Group Comparison.

An independent-sample t-test conducted on post-test scores revealed significant superiority of the experimental group over the control group across all evaluated parameters:
Smash Accuracy: $t(18) = 7.54, p < 0.001$.

Arm Angle: $t(18) = 6.42, p < 0.001$.

Vertical Jump Height: $t(18) = 4.90, p < 0.001$.

Discussion

The main finding of this study is that KINOVEA-based biomechanical feedback training yields significantly superior improvements in volleyball smash accuracy, arm mechanics, and vertical jump height compared to conventional training (Shishov et al., 2026).

Mechanisms of Skill Enhancement.

The substantial increase in smash accuracy ($+4.80$ points) observed in the experimental group highlights the critical role of augmented visual feedback in motor learning. Unlike verbal instructions which depend on subjective interpretation visual movement analysis allows athletes to map internal proprioceptive sensations against objective visual evidence. This closed-loop learning mechanism accelerates error detection and technical adjustment (Mersin & Agopyan, 2025).

Biomechanical Adaptations.

The improvement in arm angle ($+9.38°$) signifies optimized shoulder rotation and extension at ball impact, which directly enhances power transmission and directional accuracy. Concurrently, gains in vertical jump height ($+6.30$ cm) indicate that visual feedback on take-off mechanics helped athletes improve lower-body coordination and kinetic chain sequencing during the approach phase (Karakaş et al., 2025).

Practical Implications.

These results hold significant practical value for physical education teachers and sports coaches in resource-limited settings. Because KINOVEA is open-source and compatible with standard camera equipment, high-quality biomechanical feedback can be effectively implemented in high school sports programs without high costs (Sharan et al., 2025).

Limitations.

Several limitations should be noted. The sample size was relatively small ($N = 20$) and derived from a single institution. Additionally, long-term retention of skill improvements was

not evaluated post-intervention. Future research should utilize larger samples and longitudinal retention designs.

Conclusions

KINOVEA-based biomechanical feedback training is an effective method for improving smash accuracy, arm swing mechanics, and vertical jump height in high school volleyball athletes. Integrating video-based motion analysis into training offers a practical, low-cost solution for enhancing technical skill development in school sports programs.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article. This research was conducted independently, and the use of KINOVEA software (version 0.8.27) was purely for academic and sports-performance analysis purposes. The authors have no financial, personal, or professional relationships with the developers of the software or any party that could inappropriately influence or bias the findings presented in this study.

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