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REAL-TIME VIDEO FEEDBACK TRAINING TO IMPROVE TENNIS SERVE ACCURACY AND BIOMECHANICS IN JUNIOR PLAYERS

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Abstract. This study aims to analyze the effect of real-time video feedback on improving serve accuracy and movement biomechanics in junior tennis athletes. The study used a quantitative approach with a pre-test–post-test control group design. The study sample consisted of 20 junior tennis athletes aged 14–16 years in Makassar City who were divided into an experimental group and a control group. Data were collected through the Hewitt Serve Test, biomechanical observations, and video documentation analyzed using Kinovea software. The experimental group was given real-time video feedback-based training for 8 weeks, while the control group underwent conventional training. Data analysis used a paired sample t-test and Cohen's d at a significance level of $\alpha = 0.05$. The results showed a significant increase in serve accuracy from 62.4% to 81.7%. In addition, trunk rotation increased by 18%, elbow angle by 12%, and movement timing coordination by 15%. A t-value of 9.21 and Cohen's d of 3.22 indicate that the use of real-time video feedback significantly impacts the quality of junior tennis athletes' service techniques. The implications of this study suggest that the use of real-time video technology can be an effective training strategy to improve technical performance, biomechanical evaluation, and coaching efficiency of young tennis athletes.

Keywords: Real-Time Video Feedback, Tennis, Serve, Biomechanics, Kinovea

Abstrak. Penelitian ini bertujuan untuk menganalisis pengaruh umpan balik video *real-time* terhadap peningkatan akurasi servis dan biomekanik gerakan pada atlet tenis junior. Penelitian menggunakan pendekatan kuantitatif dengan desain eksperimen *pre-test–post-test control group design*. Sampel penelitian terdiri atas 20 atlet tenis junior berusia 14–16 tahun di Kota Makassar yang dibagi ke dalam kelompok eksperimen dan kelompok kontrol. Data dikumpulkan melalui Tes Servis Hewitt, observasi biomekanik, dan dokumentasi video yang dianalisis menggunakan perangkat lunak Kinovea. Kelompok eksperimen diberikan latihan berbasis umpan balik video *real-time* selama 8 minggu, sedangkan kelompok kontrol menjalani latihan konvensional. Analisis data menggunakan uji *paired sample t-test* dan *Cohen's d* pada taraf signifikansi $\alpha = 0{,}05$. Hasil penelitian menunjukkan adanya peningkatan signifikan pada akurasi servis dari 62,4% menjadi 81,7%. Selain itu, rotasi batang tubuh meningkat sebesar 18%, sudut siku sebesar 12%, dan koordinasi waktu gerakan sebesar 15%. Nilai t sebesar 9,21 dan Cohen's d sebesar 3,22 menunjukkan bahwa penggunaan umpan balik video real-time memberikan pengaruh yang sangat besar terhadap kualitas teknik servis atlet tenis junior. Implikasi penelitian ini menunjukkan bahwa pemanfaatan teknologi video *real-time* dapat menjadi strategi pelatihan yang efektif untuk meningkatkan performa teknik, evaluasi biomekanik, dan efisiensi pembinaan atlet usia muda dalam olahraga tenis.

Kata Kunci: Umpan Balik Video *Real-time*, Tenis, Servis, Biomekanik, Kinovea

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INTRODUCTION

The serve is one of the most essential techniques in tennis because it determines the beginning of play and provides an opportunity to gain an immediate advantage during a match. A successful serve requires not only power, but also accuracy, timing, coordination, balance, and efficient biomechanical movement patterns. For junior athletes, mastering proper serve mechanics is particularly important because this developmental stage strongly influences the formation of long-term technical habits and motor coordination. However, many junior tennis athletes still experience difficulties in performing effective and consistent serves during training and competition.

Preliminary observations were conducted during junior tennis training sessions in Makassar involving athletes aged 14–16 years. The observations showed that several athletes frequently demonstrated biomechanical errors during the serving motion, particularly in trunk rotation, elbow positioning, ball-contact timing, and body balance at the follow-through phase. Inconsistent trunk rotation often reduced serve power, while improper elbow angles and delayed ball contact contributed to poor serve accuracy. In addition, some athletes showed unstable lower-body balance during landing, which affected movement coordination and shot consistency. These findings indicate that junior athletes still require more effective, objective, and technology-supported training methods to improve both technical accuracy and biomechanical efficiency (Vacek et al., 2025; Fett et al., 2021).

In current practice, conventional coaching methods still predominantly rely on verbal instructions and direct demonstrations from coaches. Although these approaches remain important, they often do not provide immediate and detailed visual feedback regarding specific movement errors. As a result, athletes may struggle to fully understand the corrections suggested by coaches, causing slower motor adaptation and less efficient technical improvement (Corbett et al., 2024; Zhou et al., 2021). According to motor learning theory, effective skill acquisition depends heavily on immediate, clear, and specific feedback. Therefore, integrating technology-based feedback systems into sports training has become increasingly relevant in improving movement learning and technical correction.

One technological innovation widely applied in modern sports training is real-time video feedback. This technology allows athletes to directly observe their own movements immediately after execution, enabling them to identify errors visually and objectively within the same training session. Real-time video feedback combines visual learning, self-evaluation, and immediate correction, which can accelerate motor learning and improve movement awareness. Previous studies have shown that video-assisted feedback contributes positively to

movement understanding, coordination, and technical performance in various sports contexts (Geisen et al., 2026; Hribernik et al., 2022). However, most previous studies focused mainly on general skill improvement or adult athletes, while research specifically examining serve biomechanics and serve accuracy among junior tennis athletes remains limited.

In addition, earlier studies generally analyzed technical performance outcomes separately from biomechanical indicators. Research examining serve accuracy often did not include detailed biomechanical analysis, whereas biomechanical studies tended to focus only on movement patterns without evaluating serve performance simultaneously. This condition highlights an important research gap because serve effectiveness is strongly influenced by biomechanical quality, including trunk rotation, elbow angle, timing coordination, and body balance. Therefore, studies integrating both serve accuracy and biomechanical analysis simultaneously in junior tennis athletes are still limited.

The novelty of this study lies in the integration of real-time video feedback with biomechanical motion analysis using Kinovea software to evaluate both serve accuracy and specific biomechanical components simultaneously. Unlike previous studies that examined these aspects separately, this research combines performance outcomes and biomechanical evaluation within one intervention framework. Furthermore, this study specifically focuses on junior athletes aged 14–16 years, a developmental stage in which motor coordination and technical habits are still highly adaptable through corrective feedback interventions. Based on these conditions, this study aims to analyze the effect of real-time video feedback on serve accuracy and movement biomechanics in junior tennis athletes. The findings are expected to provide empirical evidence regarding the effectiveness of technology-assisted feedback in sports training and contribute to the development of more objective, efficient, and biomechanically oriented coaching methods for junior tennis development.

METHOD

This study used a quantitative approach with a pre-test–post-test control group design. This design was chosen to objectively identify the effect of Kinovea software on improving tennis serve performance. The sample consisted of 20 junior tennis athletes from Makassar aged 14–16 years who were purposively selected based on inclusion criteria: having at least 1 year of training experience, actively participating in regular training, and not experiencing any injuries during the study. The training program lasted for 8 weeks (3 times per week, with a duration of 90 minutes per session). Each service practice session was recorded using a camera and analyzed directly using Kinovea. Athletes received real-time visual feedback, including

corrections to body position, arm angle, and timing at ball contact. Coaches provided instructions based on the results of the video analysis. The accuracy test uses a service accuracy test with a target area in the service box, using the Hewitt Service Test. Each athlete makes 10 service attempts, and a total score is calculated based on the number of successful hits. The test's validity refers to the ability to measure the accuracy of the serve direction.

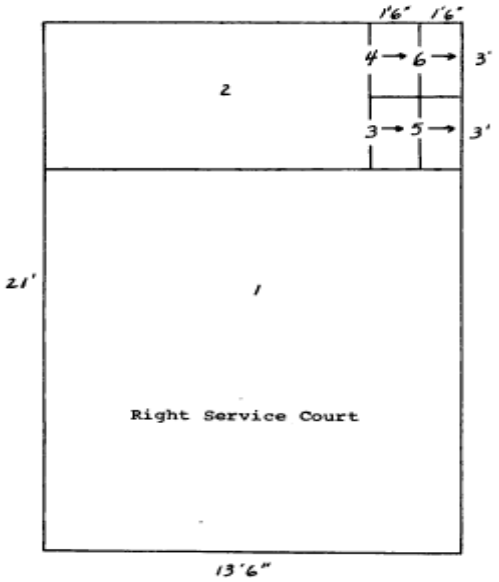

Figure 1. Hewit service test

The analysis was conducted using Kinovea software with several biomechanical parameters, including trunk rotation, body rotation angle during the coiling phase, ball toss, backswing, uncoiling, strike zone, follow-through, and fall-in movement. Measurements were carried out through video digitization techniques to obtain accurate angle and timing values during the serving motion. Data collection utilized a DSLR camera with a resolution of 720p–1080p and a frame rate of 60 fps to capture detailed movement sequences. Camera placement consisted of a lateral view to analyze trunk rotation and elbow angle, and a posterior view to observe ball direction, coordination, and body balance. The camera was positioned approximately 5–7 meters from the athletes using a tripod to ensure recording stability and supported by adequate lighting to minimize motion blur during fast movements.

The data analysis technique used in this study was a paired sample t-test to examine differences between pre-test and post-test results within each group. The significance level was set at $\alpha = 0.05$, and all statistical analyses were performed using SPSS software. In addition, effect size analysis using Cohen's d was conducted to determine the magnitude of the intervention effect. Overall, this experimental design was specifically employed to evaluate the

effectiveness of real-time video feedback in improving both serve accuracy and biomechanical movement quality among junior tennis athletes.

RESULTS

Descriptive statistical analysis of tennis serve accuracy in the pre-test and post-test stages involving 20 research samples. Parameters displayed include minimum, maximum, mean, median, mode, standard deviation, and variance. This data aims to provide a general overview of the distribution and characteristics of serve accuracy values before and after the treatment was administered.

Table 1. Descriptive statistics of service accuracy

Variables	N	Min	Max	Mean	Median	Mode	Elementary School	Variance
Pre-test	20	52	72	62.4	62	60	5.8	33.64
Post-test	20	70	92	81.7	82	80	6.2	38.44

Descriptively, Table 1 shows that the athletes' serve accuracy improved considerably after the implementation of real-time video feedback training. In the pre-test stage, the minimum score was 52% and the maximum score was 72%, with an average score of 62.4%. These results indicate that, before the treatment, most athletes still demonstrated relatively low and inconsistent serving performance. This condition reflects limitations in technical mastery and biomechanical coordination during the serving motion, particularly in aspects such as timing, body rotation, and ball contact accuracy. The standard deviation of 5.8 also suggests that the athletes' performance levels varied considerably, indicating differences in initial technical ability among participants.

After the treatment, the post-test results showed a substantial improvement, with scores ranging from 70% to 92% and an average score increasing to 81.7%. This increase demonstrates that the use of real-time video feedback contributed positively to improving serve accuracy and movement consistency among junior athletes. The higher median and mode values in the post-test further indicate that most athletes experienced performance improvements, not only a few individuals. Although the standard deviation slightly increased to 6.2, the overall distribution of scores shifted toward higher performance levels, suggesting that athletes became more capable of correcting movement errors through direct visual feedback. These findings indicate that real-time video feedback helps athletes better understand their biomechanical movements, leading to more effective motor learning and improved technical execution during serves.

Then, the biomechanical aspects of the tennis serve, including trunk rotation, elbow angle at ball contact, and timing of movement coordination, were examined in 20 study samples.

Table 2. Improvement of biomechanical aspects

Biomechanical Aspects	Pre-test	Post-test	Delta
Trunk rotation	65	83	18
Rotation angle	70	82	12
Timing coordination of movements	68	83	15

Descriptively, Table 2 shows quite clear improvements. In the aspect of trunk rotation, the value increased from 65% in the pre-test to 83% in the post-test, with a delta of 18%. In the elbow angle at ball contact, there was an increase from 70% to 82%, with a delta of 12%. Meanwhile, the timing of movement coordination increased from 68% to 83%, with a delta of 15%. These improvements indicate that the treatment provided contributed positively to the improvement of biomechanical techniques of serving, particularly in terms of movement coordination and the efficiency of body mechanics during serving. This study aimed to determine the difference in service accuracy between pre-test and post-test scores in 20 research samples. This test was used to assess the effectiveness of the treatment by comparing the average of two paired measurements. The significance level used in this study was $\alpha = 0.05$.

Table 3. Paired sample t-test results

Variables	t-count	p-value	Information
Service accuracy	9.21	< 0.05	Significant

Table 3 shows the results of the paired sample t-test analysis, with a t-value of 9.21 and a significance value (p) of <0.05. These results indicate a statistically significant difference between the pre-test and post-test scores of serve accuracy among junior tennis athletes. The significant increase in post-test scores demonstrates that the training program using real-time video feedback had a positive effect on improving athletes' serving performance. The high t-value reflects a strong difference between athletes' abilities before and after the intervention, indicating that the improvement did not occur by chance. Through direct visual feedback, athletes were able to identify technical errors more clearly, particularly in body positioning, timing of ball contact, and movement coordination during the serve. This finding suggests that real-time video feedback not only improves technical understanding but also accelerates the motor correction process, resulting in more accurate and consistent serving performance.

Effect size analysis using Cohen's d aims to determine the magnitude of the treatment's influence on improving service accuracy. This analysis complements the significance test by providing practical information about the strength of the effect.

Table 4. Cohen's d results

Variables	Cohen's d	Interpretation
Service Accuracy	3.22	Very large

The calculation results in Table 4 show a Cohen's d value of 3.22, which is in the very large category. This indicates that the treatment given has a very strong influence on improving service accuracy

DISCUSSION

The discussion of the results of this study shows that the use of real-time video feedback has a significant impact on improving tennis serve performance, both in terms of accuracy and biomechanics of the movement. The increase in the average value of serve accuracy from 62.4% to 81.7%, as well as the results of the paired sample t-test which showed a t-value of 9.21 with a p-value <0.05, indicates that the intervention provided is effective in improving athletes' serving abilities. This strengthens the assumption that technology-based approaches, especially direct visual feedback, are able to provide a more optimal learning stimulus than conventional methods. From a motor learning perspective, real-time video feedback acts as a form of augmented feedback that allows athletes to obtain external information about their movement performance in real-time. Athletes not only rely on internal perception (intrinsic feedback) but also receive an objective visual representation of both errors and successes in their technique. This allows for faster and more targeted movement correction. This aligns with Richard Schmidt's Schema Theory, a motor learning theory that emphasizes the importance of feedback in strengthening the relationship between movement parameters and outcomes (Yu et al., 2020; Meer et al., 2024).

Biomechanically, an 18% increase in trunk rotation, a 12% improvement in elbow angle, and a 15% improvement in movement coordination timing indicate an optimized kinetic chain in serving. An efficient kinetic chain allows for maximum energy transfer from the lower to upper body segments, resulting in a more powerful and accurate stroke. Increased trunk rotation, for example, contributes significantly to the development of rotational power, the primary source of ball speed in a tennis serve. This aligns with Bruce Elliott's findings that trunk rotation is a key component in producing an effective and powerful serve (Mödinger et al., 2022; Han et al., 2022).

In addition, improvements in movement timing and coordination indicate that athletes can coordinate movement sequences more efficiently, from the backswing phase to acceleration and follow-through. Good coordination reduces energy loss during movement transfer, which directly affects shot accuracy and consistency. Visual feedback also plays an important role in increasing athletes' awareness of body position and movement patterns. By observing recordings of their own performance, athletes can identify technical errors that were previously difficult to recognize internally (Aprilo et al., 2025; Caprioli et al., 2025).

The findings of this study also align with various previous studies demonstrating the effectiveness of technology use in sports skills learning. Studies show that visual feedback can improve movement accuracy through visual perception-based correction mechanisms. Furthermore, providing timely information, such as through real-time feedback, can enhance the effectiveness of motor learning, especially in beginner to intermediate athletes (Meer et al., 2024; Cairney et al., 2019). In the context of tennis, the use of video analysis has also been extensively studied. Previous studies have shown that athletes who receive video feedback improve their technique more quickly than those who only receive verbal instruction. This is due to the visualization of movements, which provides a more concrete and easily interpreted understanding. In fact, motion analysis-based studies using software like Kinovea have found that athletes are able to refine joint angles and movement patterns more precisely after viewing recordings of their performances (Yu et al., 2020; Aprilo et al., 2022).

Furthermore, integrating technology into sports training also has a positive psychological impact, particularly in increasing athlete motivation and engagement. Athletes tend to be more engaged and focused when using visual-based media and interactive technology. This indirectly accelerates the learning process due to increased engagement during training. Thus, the use of real-time video feedback impacts not only the technical and biomechanical aspects, but also the cognitive and affective aspects of sports learning (Soni & Wijeratne, 2021; Soni & Wijeratne, 2022). However, despite its advantages, the implementation of real-time video feedback also has several limitations that should be considered. The effectiveness of this method is highly dependent on the availability of adequate recording devices, camera positioning, lighting quality, and video resolution. Poor-quality recordings may reduce the accuracy of biomechanical analysis and make movement errors more difficult to identify. In addition, the use of video analysis software requires technical understanding from coaches and sufficient training time during implementation. Another potential limitation is that athletes may become overly dependent on visual feedback if it is provided too frequently, reducing their ability to develop intrinsic movement awareness. Therefore, feedback should be delivered

selectively, consistently, and accompanied by coach guidance so that athletes can gradually internalize correct movement patterns (Weakley et al., 2023; Mödinger et al., 2022).

Overall, the results of this study confirm that the use of real-time video feedback is an effective strategy for improving tennis serve performance. The significant increase in serve accuracy and improvements in biomechanics demonstrate that technology can be a highly effective training tool. These findings also reinforce previous research and motor learning theory, which emphasizes the importance of feedback in improving movement quality. Therefore, the integration of technology into tennis training programs is highly recommended, particularly for the sustainable improvement of athlete technique and performance.

CONCLUSION

Based on the research results, it can be concluded that the use of real-time video feedback significantly improves the serve accuracy and biomechanical movements of junior tennis athletes. Direct visual feedback helps athletes understand and correct technical errors more concretely than verbal instructions alone. Improvements in trunk rotation, elbow angle, and movement timing coordination indicate that video feedback technology supports the optimization of the kinetic chain during the serve. The use of Kinovea software allows for objective and detailed movement analysis, allowing for faster and more precise technique corrections. In addition to improving technical and biomechanical aspects, technology integration also increases athletes' focus, engagement, and understanding in the motor learning process. Therefore, real-time video feedback is recommended as an effective, innovative training method to improve the quality of serve technique in junior tennis athletes.

REFERENCES

Aprilo, I., Arfanda, PE, Mappaompo, MA, Asyhari, H., & Imran, M. (2025). Development of Tennis Spin Serve Technique Observation Instrument: The Quality Tennis Learning in Higher Education. 4(3), 509–516.

Aprilo, I., Asmawi, M., & Tangkudung, J. (2022). Kinovea-Based : Tennis Spin Serve Analysis. Journal of Physical Education, Sport, Health and Recreations, 11(2), 7985. https://doi.org/https://doi.org/10.15294/active.v11i2.55643

Cairney, J., Dudley, D., Kwan, M., Bulten, R., & Kriellaars, D. (2019). Physical Literacy, Physical Activity and Health: Toward an Evidence-Informed Conceptual Model. Sports Medicine, 49(3), 371–383. https://doi.org/10.1007/s40279-019-01063-3

Caprioli, L., Romagnoli, C., Campoli, F., Edriss, S., Padua, E., Bonaiuto, V., & Annino, G. (2025). Reliability of an Inertial Measurement System Applied to the Technical Assessment of Forehand and Serve in Amateur Tennis Players. Bioengineering, 12(1), 1–31. https://doi.org/10.3390/bioengineering12010030

Corbett, R., Partington, M., Ryan, L., & Cope, E. (2024). A systematic review of coach augmented verbal feedback during practice and competition in team sports. International Journal of Sport Science & Coaching. https://doi.org/10.1177/17479541231218665

Fett, J., Oberschelp, N., Vuong, J. L., Wiewelhove, T., & Ferrauti, A. (2021). Kinematic characteristics of the tennis serve from the ad and deuce court service positions in elite junior players. PLOS ONE, 16(7 July), 1–14. https://doi.org/10.1371/journal.pone.0252650

Geisen, M., Baumgartner, T., Riedl, N., & Klatt, S. (2026). Real-time feedback in video-based motor learning : A pilot study exploring innovative training methods. Research and Practice in Technology Enhanced Learning.

Han, Y., Kamaruzaman, S., Syed, B., & Ji, L. (2022). Use of Observational Learning to Promote Motor Skill Learning in Physical Education: A Systematic Review. International Journal of Environmental Research and Public Health.

Hribernik, M., Umek, A., Tomaži˘c, S., & Kos, A. (2022). Review of Real-Time Biomechanical Feedback Systems in Sport and Rehabilitation. Censorship.

Meer, BR Van Der, Hoven, MAC Van Den, Kamp, J. Van Der, Savelsbergh, GJP, & Meer, BR Van Der. (2024). Self-Controlled Video Feedback Facilitates the Learning of Tactical Skills in Tennis Self-Controlled Video Feedback Facilitates the Learning of Tactical Skills in Tennis. Research Quarterly for Exercise and Sport, 95(2), 537–545. https://doi.org/10.1080/02701367.2023.2275801

Mödinger, M., Woll, A., & Wagner, I. (2022). Video-based visual feedback to enhance motor learning in physical education — a systematic review. Review, April 2021, 447–460. https://doi.org/10.1007/s12662-021-00782-y

Soni, M., & Wijeratne, T. (2021). The Effect of Real-Time Video-Based Engagement and Feedback during Pedaling on Cadence Control and Exercise Motivation : A Proof-of-Concept Study. Bioengineering.

Soni, M., & Wijeratne, T. (2022). Cadence Feedback and Video-Based Engagement Improve Motivation and Performance during Pedaling in Stroke Patients. Applied Sciences, 1–10.

Vacek, J., Vagner, M., Malecek, J., & Stastny, P. (2025). Tennis Serve Speed in Relation to Isokinetic Shoulder Strength, Height, and Segmental Body Mass in Junior Players. Journal of Functional Morphology and Kinesiology, 10(1), 9–11.

Weakley, J., Cowley, N., Schoenfeld, B.J., Read, D.B., Timmins, R.G., Ramos, A.G., & Mcguckian, T.B. (2023). The Effect of Feedback on Resistance Training Performance and Adaptations: A Systematic Review and Meta-analysis. Sports Medicine, 53(9), 1789–1803. https://doi.org/10.1007/s40279-023-01877-2

Yu, C., Wu, C., Wang, J., & Chen, H. (2020). Learning Tennis through Video-based Reflective Learning by Using Motion-Tracking Sensors. Educational Technology & Society, 23, 64–77.

Zhou, Y., Shao, W. De, & Wang, L. (2021). Effects of Feedback on Students' Motor Skill Learning in Physical Education: A Systematic Review. International Journal of Environmental Research and Public Health