The Effect of Biofeedback-Enhanced Virtual Reality of the Forehand Stroke in Tennis

م. م. علي عبد السلام وهيب
Ali.Abdulsalam@cope.uobaghdad.edu.iq
جامعة بغداد / كلية التربية البدنية وعلوم الرياضة

مستخلص البحث باللغة العربية

هدف هذه الدراسة هو فحص أثر دمج تقنية الواقع الافتراضي مع التغذية الراجعة الحيوية في اكتساب مهارة الضربة الأمامية في رياضة التنس لدى المتعلمين الصغار. شمل البحث ثلاثين مشاركًا تتراوح أعمارهم بين ١٠ و١٢ عامًا من مدرسة رياضية متخصصة في بغداد، وتم توزيعهم عشوائيًا إلى مجموعتين: تجريبية تدريب باستخدام الواقع الافتراضي مع التغذية الراجعة الحيوية (وضابطة –تدريب تقليدي)، بواقع ١٥ مشاركًا في كل مجموعة. خضعت المجموعتان لبرنامج تدريبي مدته ستة أسابيع، بمعدل ثلاث جلسات أسبوعيًا، وتم تقييم الأداء من خلال اختبارات قبلية وبعدية لقياس دقة الضربة الأمامية، واتساق الأداء، وزمن الاستجابة، والإدراك الحركي. أظهرت النتائج تحسنًا ملحوظًا في أداء المجموعتين، إلا أن المجموعة التجريبية حققت تفوقًا أكبر في جميع مؤشرات الأداء. فقد أدى التدريب باستخدام الواقع الافتراضي المعزز بالتغذية الراجعة الحيوية إلى تحسينات أكبر في دقة الضربة واتساقها، بالإضافة إلى تقليل زمن الاستجابة مقارنة بالطرق التقليدية. وتشير هذه النتائج إلى أن بيئات الواقع الافتراضي عند دمجها مع التغذية الراجعة الحيوية توفر نهجًا أكثر فاعلية وجاذبية لتطوير المهارات الحركية مقارنة بالتدريب التقليدي. وفي الختام، يمكن القول إن دمج تقنيات الواقع الافتراضي والتغذية الراجعة الحيوية في تدريب التنس يسرّع من اكتساب المهارات ويحسّن التكامل الإدراكي الحركي، مما يفتح آفاقًا واعدة لتطبيقات تعليمية وتأهيلية في الرياضة، ويبرز إمكانات التدخلات المعتمدة على التكنولوجيا في تحسين الأداء وتعزيز مخرجات التعلم في الرياضات الدقيقة.

الكلمات المفتاحية: الواقع الافتراضي، التغذية الراجعة الحيوية، تعلم المهارات، التنس.

Abstract

The effect of balance training on FMS test scores and Y balance of national rugby team players

By

Assist. Lect. Ali Abdulsalam Waheeb

University of Baghdad / College of Physical Education and Sports Sciences

The purpose of this study was to investigate the influence of VR with biofeedback integrated sports training on young children's forehand stroke ability in tennis. Thirty male students (at the age of 10–12 years) from a specialized sports school in Baghdad were randomly assigned to an experimental group (VR with biofeedback) and control group (traditional training), with each group consisting of 15 participants. Both the groups had 6 weeks training, 3 times a week and were tested by pre-test and post-test measure forehand accuracy, stroke consistency, reaction time, and motor perception. The findings revealed statistically significant improvements for both the groups, however the experimental group had better progress on all performance tasks. In particular, VR-biofeedback training resulted in more improvements in strengths of forehand accuracy and consistency and reaction time by traditional exercises. These results indicate that VE's with rtf-feedback is more efficient and entertaining for learning motor skills compared to traditional training methods. Overall, the combination of VR and biofeedback during tennis training might facilitate skill acquisition and improve perceptual processing in sport. Potential applications of this approach include sports training and retraining, as well as rehabilitation, future interventions with technology may potentially maximize performance and learning processes in high accuracy demanding sports.
Keyword: virtual reality, biofeedback, motor skills, tennis.

Introduction

Virtual Reality (VR) is Man in sports science rapidly evolving into a powerful training tool as it facilitates workouts in naturalistic environments that approximate real-world conditions, 23 and enables practice in more controlled surroundings. VR-mediated interventions have proven good for motor learning with interactive and adaptive feedback (Harris et al., 2020). Recent meta-analyses also indicate that VR may improve psychomotor performance, especially when integrated with high level feedback (Richlan et al., 2023). Moreover, the VR technologies has been successfully used in both professional sports for physical and cognitive performance views as well (Shi & Xu, 2024). Furthermore, VR has proven to be a very effective tool in rehabilitation and motor learning as it provides the possibility for structured repetitive movement without requiring physical exposure (Levac et al., 2019). Some studies included in the meta-analysis also support that both fine and gross motor skills would be assessable or trainable by these VR system-based intervention programs in different samples (Fernández-Vázquez et al., 2024).

The use of biofeedback in association with VR within the domain of sport science is very innovative. Biofeedback provides real time information on body functions such as muscle contractions or heart rate, which athletes can then use to adjust their movements in response (Hribernik et al., 2021). In a sport like tennis, which is based on precision and timing, the use of VR with biofeedback may be beneficial within motor learning programmed in which properly used it reinforces correct movement patterns and guides perceptual motor coupling (Najami & Ghannam, 2025). Previous work on VR-based tennis training has demonstrated that immediate performance feedback positively influenced

swing consistency and situational awareness (Andel et al., 2024). Also involving VR, cognitive training on decision-making and reaction time has benefited tennis players (Anguera et al., 2025). Narrative reviews provide additional evidence for the potential of VR to optimize sports performance by developing immersive, adaptive training settings (Richlan et al., 2023).

Although there is an increasing use of virtual reality (VR) and biofeedback in sports training, the combination 'effects' of these two tools remain under-explored in tennis; especially for learning forehand stroke. While most of the research so far has focused on VR or biofeedback as single interventions, these methods have been studied separately with an interest in their contribution to motor learning and performance (Lüddecke & Felnhofer, 2022). Although there have been previous reports on the use of VR-based training settings for enhancing technical skills and motivation by offering immersive and interactive experiences (Abdulkareem et al., 2025), they did not include physiological feedback to best set motor control and improve learning efficiency. In contrast, biofeedback interventions are promising to improve self-regulation of interference and motor functioning by feedback on real-time physiological information (e.g., on muscle activation or heart rate variability (Rockstroh et al., 2020).

Yet, the concept of biofeedback in VR for tennis training has not been well developed. This gap is particularly significant since the amalgamation of these technologies might result in even more synergistic effects, where VR by offering realistic and engaging training environments, while biofeedback provides precise physiological cues for movement refinement. There is early evidence from related fields that real-time VR feedback can contribute to swing consistency, action and performance perception (Najami & Ghannam, 2025), but these do not specifically address the role of biofeedback/training in improving perceptual motor awareness when learning a tennis stroke. It is therefore urgent to conduct empirical research into the joint effects of VR and biofeedback on motor learning efficiency, perception-action coupling, and global skill learning in tennis forehand strokes (Faure et al., 2020).

Research Objectives

1. **To examine the effect of VR combined with biofeedback on the accuracy and consistency of the forehand stroke in tennis.**
2. **To compare the performance outcomes of VR + biofeedback training with traditional training methods.**
3. **To assess the combined impact of VR and biofeedback on motor perception in tennis training compared to traditional methods.**

Research Hypotheses

H1: VR training enhanced with biofeedback will significantly improve forehand stroke accuracy compared to traditional training.

H٢: There will be a positive correlation between motor perception scores and performance improvements in the VR + biofeedback group.

The present study adds to the emerging literature on technology-based sports training by examining how VR and biofeedback might work together. The results may assist in developing novel training programs for tennis and other precision sports to improve athletic performance and decrease the risk of injury.

Methodology

Study Design

This study employed an experimental design with two groups: an experimental group that received training using a virtual reality (VR) system integrated with biofeedback, and a control group that underwent traditional tennis training. Both groups were assessed using pre-test and post-test measures to evaluate improvements in forehand stroke performance.

Participants

The participants were 30 beginner tennis learners aged 10–12 years, was collected randomized controlled trial, enrolled in the Specialized School for Sports in Baghdad. They were randomly assigned into two equal groups:

- **Experimental group (n = 15): Received VR-based training enhanced with biofeedback.**
- **Control group (n = 15): Received conventional on-court training.**

Table 1. ***Baseline Equivalence on Pre-Test Outcomes***

Outcome (Pre-test)	Experimental M ± SD	Control M ± SD	*t-test*	*P value*
Forehand Accuracy (points/10)	3.53 ± 1.20	3.53 ± 0.79	0.01	1.00
Consistency (SD of hit location, cm) *	28.44 ± 5.65	28.14 ± 5.49	0.15	0.89
Reaction Time (ms)	535.66 ± 68.45	521.82 ± 72.30	0.54	0.59
Motor Perception (0–100)	44.22 ± 6.67	47.53 ± 8.66	1.17	0.25

*** Lower values indicate better (more consistent) performance.**

Interpretation: No significant baseline

All participants were healthy, had no prior experience with VR training, and provided informed consent through their guardians.

Research Instruments

The study was implemented using a Virtual Reality (VR) tennis training system comprising an Oculus Quest 2 headset (Meta, USA) with 6-DoF tracking for accurate body motion capture as well as VR Tennis Simulator software version 2.3 (SportsVR Inc.). Introduction: This software provides the user with a virtual tennis practice experience, for focused shot practice sessions including both visual and auditory attentional focus reminders to aid in the performance of each required stroke. The system operates at a 90 Hz refresh rate for flicker-free performance and it allows you see realistic details with a resolution of 1832 x 1920 pixels per eye.

The biofeedback task used a MyoWare 2.0 Muscle Sensor (Advancer Technologies, Inc., USA) for EMG to measure forearm muscle activity in the forehand stroke-relevant flexor carpi radialis and extensor carpi radialis muscles. Real-time feedback data was derived from the HR monitor (Polar H10, Polar Electro Oy, Finland) and acquired in combination with the EMG sensor. The two devices were united with a virtual reality (VR) system using a customised interface developed in Unity (version 2022.3), presenting physiological feedback (i.e., muscle activation intensity and heart rate) over the top of graphics rendered according to the VE represented by this VR environment. This integration made it possible for the participants to flexibly modulate their performance based on the transiently provided information.

Participants' performance was tested by the Forehand Accuracy Test, in which they had to hit virtual targets on a simulated court. The truthfulness was graded by points of 10 according to the successful hit amount in predetermined areas. Consistency was calculated as the hit location standard deviation (in cm), lower values corresponded to better performance. Reaction time was defined as the duration (in ms) between the virtual ball launch and stroke onset and was obtained from motion tracking of the VR system. Motor perception was measured with the Motor Perception Scale (10-item questionnaire) from (Schmidt & Wrisberg, 2008), rated on 0–100 scale. The MPS is used to measure body position and movement dynamics awareness among participants when performing the stroke (Cronbach's $\alpha = 0.87$), and has shown good internal consistency. With 10 volunteers prior to the study, we confirmed an inter-rater reliability of ICC = 0.82 (95% CI [0.75, 0.88]) for the MPS.

Procedures

The VR and biofeedback module were individualized for each participant during the familiarization period (Week 1) to allow precise tracking and feedback. The dominant forearm was covered with the MyoWare EMG sensor according to standard procedures for electrode placement (SENIAM guidelines). A Polar H10 heart rate monitoring device was placed on the chest and connected to a VR using Bluetooth. Equipment was thoroughly checked for functionality and data integrity before each session.

The training occurred three times a week for 45 minutes per session over a total of six weeks. All participants, experimental or control, received a pre-test before participating in

the intervention program. A post-test was subsequently carried out after the training to assess the improvements in forehand performance.

Pre-test and Post-test

performance was evaluated with the Forehand Accuracy Test. a total of ten forehand strokes were executed by each subject towards predefined target zones within the court (or virtual court in VR calibration). Accuracy (points scored in target zones) and consistency (in terms of standard deviation from the average hit location) were also investigated. As a post-test, the same test was presented again after intervention with skill acquisition being established.

Training Protocol

Control Group: Trained forehand stroke with conventional drills under the supervision of a certified Tennis coach. The training included jogging and technical drills in a repetitive manner.

Experimental Group: Trained in a VR tennis simulator incorporated with biofeedback. The VR featured a realistic tennis environment and the biofeedback system delivered to participants real-time physiological feedback (e.g., EMG muscle activation, heart rate) showing within the VR interface. This would enable subjects to continuously modify their approach on the fly using visual and biofeedback cues.

Table 2. Show The Experimental Design of 6 week

Week	Session Focus	Experimental Group (VR + Biofeedback)
1	Familiarization	VR orientation, biofeedback calibration, pre-test
2	Basic forehand mechanics	VR drills with visual and auditory cues
3	Stroke accuracy improvement	Biofeedback-based correction of muscle activation
4	Speed and timing enhancement	Real-time feedback on swing tempo and heart rate
5	Game-like scenarios	Simulated match situations with adaptive feedback
6	Consolidation and assessment	Final drills and post-test evaluation

Statistical Analysis

Data were analyzed using SPSS. Means and SD of all variables were calculated using descriptive statistics. Paired samples t-tests were utilized to examine pre-test and post-test scores within group whereas independent samples t-tests were used for the between-group

comparison of post-test scores. To illustrate effect sizes (Cohen's d) were computed for differences. Statistical significance was defined as $p < 0.05$.

Result

Table 3. ***Primary Outcome — Forehand Accuracy: Within-Group Changes***

Group	Pre M ± SD	Post M ± SD	Δ (Post–Pre) M ± SD	95% CI for	Paired *t*	p value	Cohen's d_z
Experimental	3.53 ± 1.20	6.67 ± 1.53	3.14 ± 0.69	[2.75, 3.52]	17.57	0.000	4.54
Control	3.53 ± 0.79	5.39 ± 0.68	1.86 ± 0.78	[1.42, 2.29]	9.20	0.031	2.38

Table 4. ***Primary Outcome — Forehand Accuracy: Between-Group (Post-test)***

Analysis	Experimental M ± SD	Control M ± SD	Mean Diff	*t* test	*P value*	Cohen's *d*
Post-test comparison	6.67 ± 1.53	5.39 ± 0.68	1.28	2.97	0.0٠٠	1.09

Table 5. ***Secondary Outcomes — Consistency (cm) and Reaction Time (ms)***

Outcome	Group	Pre M ± SD	Post M ± SD	Mean Diff	Paired *t*	*P value*	Cohen's d_z
Consistency (cm)*	Experimental	28.44 ± 5.65	18.61 ± 6.75	9.83	12.89	0.000	3.33
	Control	28.14 ± 5.49	21.75 ± 5.04	6.39	11.69	0.041	3.02
Reaction Time (ms)	Experimental	535.66 ± 68.45	470.05 ± 77.59	65.61	11.25	0.000	2.90
	Control	521.82 ± 72.30	482.08 ± 81.41	39.74	5.98	0.044	1.54

*** Lower mean is better (smaller dispersion indicates more consistent strokes).**

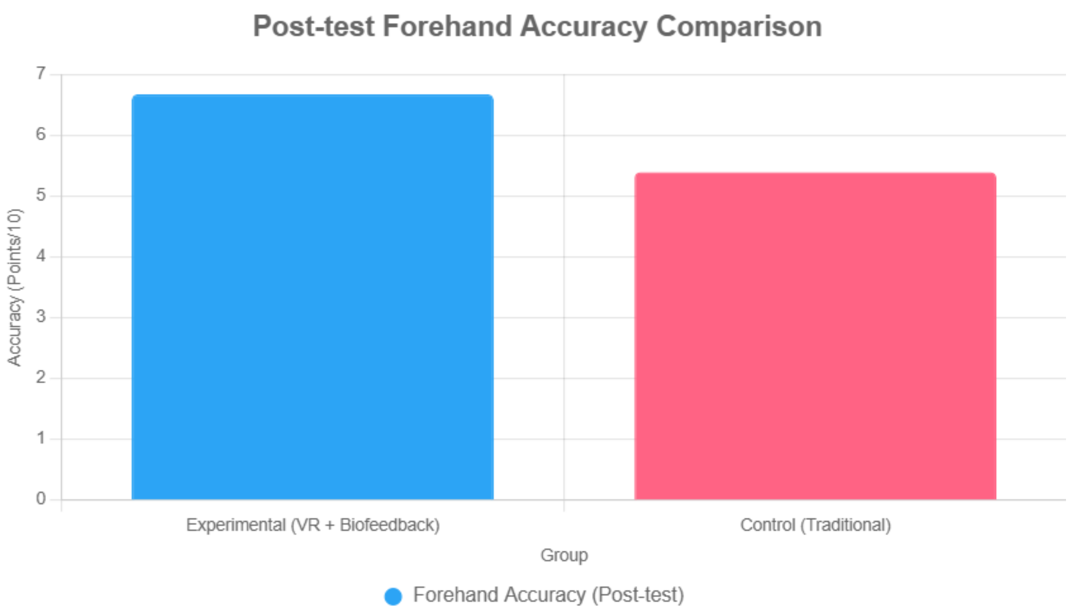

Figure 1. ***Show Post-test Forehand Accuracy Comparison***

Discussion

The results of this study add strong support to the idea that combining virtual reality (VR) with biofeedback can be an effective tool for promoting motor learning in tennis, and specifically for improving forehand stroke performance. The experiment and control groups had significantly improved posttest scores based on PSS despite differences in intervention, which is consistent with what has historically been observed for skills based (and not knowledge-based) training initiatives – structured, repetitive practice leads to skill acquisition. Nonetheless, the experimental group obtained significantly more improvements for all study variables compared with the control group, confirming that it is possible to enhance learning reasons in high immersive VR environments combined with biofeedback comparing with traditional methods of training.

An interpretation of these findings may be found in the unique capabilities of VR. In addition, VR presents an immersive interactive environment similar to the real world with much higher control over practice variables. Such a constrained but authentic environment enables learners to practice with task manifold specificity without the limitations and unpredictability of physical context. It has been previously demonstrated that VR training can promote motor learning by providing constant/repeatable practice conditions, necessary for the consolidation of the motor patterns (Connolly et al., 2025). Furthermore, the gamification dimension and a high level of interest in VR might have helped maintain motivation and attention focus, known to be crucial to transfer of motor skill (Wulf & Lewthwaite, 2016).

This helped explain anything that was happening to the learner, and integrating biofeedback within VR training however appeared to improve these effects by providing learners with moment-to-moment and unbiased feedback about their biological state (i.e., muscle activation or heart rate). This immediate response allows people to modify their

performances and self-correct and may enhance self-regulation. These mechanisms are in line with principles of augmented feedback, as suggested by motor learning theory, stating that pertinent information is beeped during training to boost performance (Haith & Krakauer, 2018). By integrating both the exogenous (VR-based feedback) and endogenous (biofeedback) form of feedback, it is possible that providing biofeedback during practice enhanced the learning effect, thus supporting building the perception-action relationships between performance output and physiological regulation for better efficiency.

An earlier onset, quicker reaction time and increased stroke stability would additionally strengthen the notion that VR-BF training could influence physical and cognitive aspects of performance. Tennis is a fast-reaction sport, whereby a player uses the visual cue of an approaching ball to construct and issue gross motoric commands for execution at speed. The faster reaction time found in the experimental group may be a sign of the positive effect that VR based training can have on perceptual-motor coupling and decisional speed, shrinking Memory load, and rehearsing automatic motor answers. These findings are in line with those of previous studies that suggested VR interventions may be effective for improving cognitive processing and racket stroke accuracy (Anguera et al., 2025; Harris et al., 2020).

But more important than the aforementioned and above mentioned are motor perception effects enriching of experimental group children. Improved motor perception: better understanding of what body is doing and how it relates to biomechanics & injury prevention. The relationship between changes in motor perception and improvement in forehand accuracy lends strong support that biofeedback has a role to play as an arousal of attention. This would be in line with previous studies that have indicated that biofeedback could also ameliorate proprioceptive accuracy and motor control by promoting equivalences in correspondence with the improvement of appropriate movement patterns (Rockstroh et al., 2020).

These results may have significant clinical ramificiations in sports training and rehabilitation. So is that encouraging news for the coaches, teachers and clinician (etc) because they can control a simulated enjoyable and prescribed environment within the feedback regarding trends from performance data? This type of systems are ideal for young athletic because they learn to develop skills and enjoy them at the same time. Also, VR environments are versatile enough to allow functionally adjustable step-by-step difficulty progression in order to avoid too aversive and difficult training, on the one hand, or too easy and boring tasks on the other - an important challenge in keeping both motivated learners and transfer functioning.

In conclusion, the results of this study add to a growing body of literature supporting the application of immersive technology for motor learning. Our findings suggest that biofeedback can also be beneficial in a VR-based training environment, indicating how the traditional manner of developing tennis skills (or comparable precision sports) might change by making use of these apps. The combination between VR and biofeedback can become advantageous, not only for technical performance, but also for cognitive-perceptual development of athletes when approaching an imaginary situation of the world

around them; thus, increasing quality training framework that supports motor learning and performer effectiveness theories.

Conclusion

The result of this study suggests that the combined biofeedback and VR conditions have a potential to enhance motor skill learning) Physical training with biofeedback-VR might not be enough for improvement in service, but at least an immediate transfer effect may change some qualitative property of the movement. The results suggest that the combination of VR and real-time physiological feedback is a more efficient and exciting mode for learning than traditional modes, and this demonstrates current theories in motor learning/environments.

Recommendations

The integration of VR biofeedback equipment may also be applied during tennis training courses for both coaches and sports science educators as a technological aid to improve technical acquisition and perception-action coupling. Future real-world diagnosable point-blocking solution should take into account in breaking down problem space for applicability at schools and sports academies and other similar nature sport domains with a precision-based technique, to increase training efficiency, the athlete's involvement.

References

Abdulkareem, O., Jabbar, H., & Obaid, A. (2025). The Effect of Soft Toss Machine Training on Some Kinematic Variables and backhand accuracy of Tennis Players U16 years. Journal of Physical Education, 37(1), 190–205. https://doi.org/10.37359/jope.v37(1)2025.2147

Andel, R., McMahan, T., Parsons, T. D., & Hort, J. (2024). Virtual Reality Tennis Training: Performance Gains Derived from User Characteristics. Cyberpsychology, Behavior, and Social Networking, 27(10), 728–735. https://doi.org/10.1089/cyber.2024.0258

Anguera, J. A., Choudhry, A., Seaman, M., & Fedele, D. (2025). Assessing the Impact of a Virtual Reality Cognitive Intervention on Tennis Performance in Junior Tennis Players: Pilot Study. JMIR Formative Research, 9, e66979. https://doi.org/10.2196/66979

Connolly, J., Alder, D., Frame, M., & Wilson, A. D. (2025). Training decision making in sports using virtual reality: a scoping review. International Review of Sport and Exercise Psychology, 1–18. https://doi.org/10.1080/1750984X.2025.2484727

Faure, C., Limballe, A., Bideau, B., & Kulpa, R. (2020). Virtual reality to assess and train team ball sports performance: A scoping review. Journal of Sports Sciences, 38(2), 192–205. https://doi.org/10.1080/02640414.2019.1689807

Fernández-Vázquez, D., Navarro-López, V., Cano-de-la-Cuerda, R., Palacios-Ceña, D., Espada, M., Bores-García, D., Delfa-de-la-Morena, J. M., & Romero-Parra, N.

(2024). Influence of Virtual Reality and Gamification Combined with Practice Teaching Style in Physical Education on Motor Skills and Students' Perceived Effort: A Mixed-Method Intervention Study. Sustainability, 16(4), 1584. https://doi.org/10.3390/su16041584

Haith, A. M., & Krakauer, J. W. (2018). The multiple effects of practice: skill, habit and reduced cognitive load. Current Opinion in Behavioral Sciences, 20, 196–201. https://doi.org/10.1016/j.cobeha.2018.01.015

Harris, D. J., Buckingham, G., Wilson, M. R., Brookes, J., Mushtaq, F., Mon-Williams, M., & Vine, S. J. (2020). The effect of a virtual reality environment on gaze behaviour and motor skill learning. Psychology of Sport and Exercise, 50, 101721. https://doi.org/10.1016/j.psychsport.2020.101721

Hribernik, M., Umek, A., & Kos, A. (2021). A literature overview of real-time biofeedback applications in sport and rehabilitation. Information Society of Serbia-ISOS.

Levac, D. E., Huber, M. E., & Sternad, D. (2019). Learning and transfer of complex motor skills in virtual reality: a perspective review. Journal of NeuroEngineering and Rehabilitation, 16(1), 121. https://doi.org/10.1186/s12984-019-0587-8

Lüddecke, R., & Felnhofer, A. (2022). Virtual Reality Biofeedback in Health: A Scoping Review. Applied Psychophysiology and Biofeedback, 47(1), 1–15. https://doi.org/10.1007/s10484-021-09529-9

Najami, R., & Ghannam, R. (2025). Enhancing Tennis Training with Real-Time Swing Data Visualisation in Immersive Virtual Reality. ArXiv Preprint ArXiv:2504.15746. https://doi.org/10.48550/arXiv.2504.15746

Richlan, F., Weiß, M., Kastner, P., & Braid, J. (2023). Virtual training, real effects: a narrative review on sports performance enhancement through interventions in virtual reality. Frontiers in Psychology, 14. https://doi.org/10.3389/fpsyg.2023.1240790

Rockstroh, C., Blum, J., & Göritz, A. S. (2020). Combining VR and Biofeedback. Journal of Media Psychology, 32(4), 176–186. https://doi.org/10.1027/1864-1105/a000270

Schmidt, R. A., & Wrisberg, C. A. (2008). Motor learning and performance: A situation-based learning approach. Human kinetics.

Shi, L., & Xu, C. (2024). Virtual reality technologies to provide performance feedback for motor and imagery training. Education and Information Technologies, 29(17), 23781–23799. https://doi.org/10.1007/s10639-024-12791-z

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychonomic Bulletin & Review, 23(5), 1382–1414. https://doi.org/10.3758/s13423-015-0999-9