



EFFECTIVENESS OF VIRTUAL REALITY SIMULATION BASED TRAINING ON MOTOR SKILL DEVELOPMENT IN JUNIOR TENNIS PLAYERS

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ABSTRACT

Advances in sports technology, particularly Virtual Reality (VR), provide innovative training methods that allow athletes to practice motor skills in simulated and controlled environments. This study aimed to examine the effectiveness of Virtual Reality Simulation-Based Training on motor skill development in junior tennis players. The research was conducted at a junior tennis club in Singaraja, Bali, involving 20 junior athletes as research participants. This study employed an experimental approach using a pre-test and post-test design. The training program integrated virtual simulations of tennis movements, including stroke techniques, footwork coordination, reaction timing, and spatial awareness. Athletes participated in structured VR training sessions combined with conventional tennis practice over a determined training period. Motor skill performance was measured using standardized tennis motor skill tests that assessed coordination, agility, movement accuracy, and stroke execution. The results indicated a significant improvement in the motor skill performance of junior tennis players after participating in the Virtual Reality Simulation-Based Training program. The integration of VR technology allowed athletes to experience repetitive movement practice, immediate feedback, and immersive training scenarios that enhanced motor learning processes. In addition, VR-based training contributed to increased motivation and engagement among athletes during the training sessions. In conclusion, Virtual Reality Simulation-Based Training is an effective and innovative training approach for enhancing motor skill development in junior tennis players. The findings suggest that the integration of VR technology into tennis training programs can support coaches in creating more interactive, efficient, and technology-driven training environments that optimize motor skill acquisition among young athletes.

Keyword : virtual reality training; motor skill development

ABSTRAK

Kemajuan dalam teknologi olahraga, khususnya Realitas Virtual (VR), menyediakan metode pelatihan inovatif yang memungkinkan atlet untuk melatih keterampilan motorik dalam lingkungan simulasi dan terkontrol. Studi ini bertujuan untuk menguji efektivitas Pelatihan Berbasis Simulasi Realitas Virtual terhadap pengembangan keterampilan motorik pada pemain tenis junior. Penelitian ini dilakukan di sebuah klub tenis junior di Singaraja, Bali, yang melibatkan 20 atlet junior sebagai partisipan penelitian. Studi ini menggunakan pendekatan eksperimental dengan desain pra-uji dan pasca-uji. Program pelatihan mengintegrasikan simulasi virtual gerakan tenis, termasuk teknik pukulan, koordinasi gerak kaki, waktu reaksi, dan kesadaran spasial. Atlet berpartisipasi dalam sesi pelatihan VR terstruktur yang dikombinasikan dengan latihan tenis konvensional selama periode pelatihan tertentu. Kinerja keterampilan motorik diukur menggunakan tes keterampilan motorik tenis standar yang menilai koordinasi, kelincahan, akurasi gerakan, dan eksekusi pukulan. Hasil menunjukkan peningkatan yang signifikan dalam kinerja keterampilan motorik pemain tenis junior setelah berpartisipasi dalam program Pelatihan Berbasis Simulasi Realitas Virtual. Integrasi teknologi VR memungkinkan atlet untuk mengalami latihan gerakan berulang, umpan balik langsung, dan skenario pelatihan imersif yang meningkatkan proses pembelajaran motorik. Selain itu, pelatihan berbasis VR berkontribusi pada peningkatan motivasi dan keterlibatan di antara para atlet selama sesi pelatihan. Kesimpulannya, Pelatihan Berbasis Simulasi Realitas Virtual adalah pendekatan pelatihan yang efektif dan inovatif untuk meningkatkan pengembangan keterampilan

motorik pada pemain tenis junior. Temuan ini menunjukkan bahwa integrasi teknologi VR ke dalam program pelatihan tenis dapat mendukung pelatih dalam menciptakan lingkungan pelatihan yang lebih interaktif, efisien, dan berbasis teknologi yang mengoptimalkan perolehan keterampilan motorik di antara atlet muda.

Kata kunci : pelatihan realitas virtual; pengembangan keterampilan motorik

INTRODUCTION

Motor skill development is a fundamental component in improving athletic performance, particularly in sports that require high levels of coordination, agility, and precision such as tennis. Motor skills involve the integration of neuromuscular control, perceptual abilities, and cognitive processes that allow athletes to perform complex movements efficiently during practice and competition (Schmidt & Lee, 2021). In tennis, athletes must coordinate footwork, stroke mechanics, reaction speed, and spatial awareness simultaneously in order to respond effectively to dynamic match situations. Therefore, the development of motor skills in junior athletes is considered essential for long-term athlete development and performance improvement (Gabbett et al., 2022).

Tennis is categorized as an open skill sport that requires rapid decision making and precise motor responses in unpredictable environments. Players must react quickly to ball trajectory, opponent movements, and game situations while maintaining proper technique and movement efficiency (Reid et al., 2021). For junior athletes, the mastery of fundamental motor skills such as agility, balance, coordination, and reaction time is particularly important as it forms the basis for the development of more advanced technical and tactical abilities (Farrow & Reid, 2022).

Traditional tennis training methods generally involve repetitive drills, physical conditioning, and on-court practice sessions guided by coaches. Although these methods remain widely used and effective, they sometimes provide limited opportunities for athletes to experience varied game situations in a controlled environment. In addition, traditional training approaches may not always provide immediate feedback or sufficient repetition needed for optimal motor learning (Gray, 2021). As a result, sports scientists and coaches continue to explore innovative training technologies that can enhance the effectiveness of athlete training programs.

One of the emerging technologies that has attracted considerable attention in sports training is Virtual Reality (VR). VR technology allows users to interact with computer-generated environments that simulate real-world scenarios, providing immersive training experiences for athletes (Michalski et al., 2022). Through VR-based systems, athletes can practice sports movements repeatedly while receiving visual and sensory feedback that supports the learning of motor skills in a safe and controlled setting.

Recent studies have shown that VR technology can significantly enhance motor learning and perceptual-motor skills in athletes. VR training allows athletes to experience realistic simulations of sports situations, enabling them to practice movement coordination, timing, and spatial awareness more effectively (Pastel et al., 2023). The immersive characteristics of VR environments also facilitate the integration of perception and action processes, which are essential in developing sport-specific motor skills (Slater & Sanchez-Vives, 2022).

Furthermore, VR-based training has been shown to improve reaction time, decision-making ability, and movement accuracy in sports performance. Research indicates that athletes who train using VR simulations often demonstrate improvements in motor coordination and performance consistency due to the repeated exposure to simulated game situations (Ma et al., 2024). This

technology also enables athletes to train in situations that may be difficult to replicate during conventional training sessions.

In racket sports such as tennis, VR technology offers promising opportunities for improving training effectiveness. VR simulations can replicate match scenarios, ball trajectories, and opponent movements, allowing athletes to practice stroke execution and movement patterns in a controlled environment (Andel et al., 2024). Such training methods help athletes develop better anticipation skills and improve coordination between visual perception and motor responses during gameplay.

In addition to improving technical skills, VR-based training can also increase athlete motivation and engagement during training sessions. The interactive and immersive nature of VR environments provides a more engaging learning experience compared to traditional repetitive drills (Neumann et al., 2023). As a result, athletes may demonstrate higher levels of focus, participation, and enthusiasm during training, which ultimately contributes to improved skill development.

Despite the growing interest in VR technology within sports training, research examining its effectiveness for motor skill development in junior tennis players remains limited. Most existing studies have focused on general motor performance or other sports contexts. Therefore, this study aims to examine the effectiveness of Virtual Reality Simulation-Based Training on motor skill development in junior tennis players at a junior tennis club in Singaraja, Bali. The findings of this study are expected to provide scientific evidence regarding the potential benefits of VR technology in supporting innovative training methods for developing motor skills in young tennis athletes.

METHODS

Participants

The participants in this study were 20 junior tennis players from a junior tennis club located in Singaraja, Bali, Indonesia. The athletes were actively involved in regular tennis training programs and had basic technical experience in tennis. The participants ranged in age from 12 to 16 years and had been involved in structured tennis training for at least one year prior to the study. All participants were physically healthy and free from injuries that could interfere with training activities during the research period. Prior to data collection, informed consent was obtained from the athletes and their parents or guardians. The study was conducted in accordance with ethical guidelines for research involving human participants.

Sampling Procedures

This study employed a purposive sampling technique to select participants who met specific inclusion criteria. The criteria included : 1) being an active junior tennis athlete registered in the tennis club; 2) participating in regular training sessions at least three times per week and 3) having no injuries during the research period. A total of 20 athletes who met these criteria were selected as the research sample. Purposive sampling was considered appropriate for this study because the research specifically targeted junior tennis athletes who could participate in both conventional tennis training and virtual reality-based training interventions.

Materials and Apparatus

The study utilized a Virtual Reality (VR) simulation training system designed to support tennis motor skill training. The VR system consisted of a VR headset, motion tracking sensors,

and a simulation application that displayed tennis training scenarios such as stroke execution, ball trajectory response, reaction timing, and movement coordination. The VR environment allowed athletes to interact with simulated tennis situations while practicing motor responses in an immersive environment.

In addition to the VR system, several conventional tennis training tools were used, including tennis rackets, tennis balls, agility ladders, and cones to support complementary training activities. Motor skill performance was assessed using a standardized motor skill test focusing on agility, coordination, reaction time, and stroke accuracy. These assessments were conducted both before and after the intervention period.

Procedures

The research was conducted over a structured training period at the junior tennis club in Singaraja, Bali. Prior to the intervention, all participants completed a pre-test to measure their baseline motor skill performance. The pre-test included assessments of agility, coordination, reaction time, and tennis stroke execution.

Following the pre-test, the athletes participated in a Virtual Reality Simulation-Based Training program integrated with their regular tennis training sessions. The training program consisted of VR simulation exercises that allowed athletes to practice tennis-specific movements such as forehand and backhand strokes, movement anticipation, and response to simulated ball trajectories. Each VR training session lasted approximately 20-30 minutes and was conducted three times per week.

The training intervention was implemented for several weeks under the supervision of tennis coaches and researchers. After completing the training program, all participants performed a post-test using the same motor skill assessment procedures used during the pre-test. The comparison between pre-test and post-test results was used to determine the effectiveness of the VR-based training program.

Design and Data Analysis

This study employed a quantitative experimental approach using a one-group pre-test and post-test design to examine the effectiveness of Virtual Reality Simulation-Based Training on motor skill development. The research design allowed for the measurement of changes in motor skill performance before and after the implementation of the VR training program.

Data obtained from the motor skill tests were analyzed using descriptive and inferential statistical methods. Descriptive statistics were used to calculate the mean and standard deviation of the pre-test and post-test scores. To determine whether there were significant differences in motor skill performance before and after the intervention, a paired sample t-test was conducted. Statistical analysis was performed using statistical software with a significance level set at $p < 0.05$. The results of the analysis were used to evaluate the effectiveness of VR-based training in improving motor skill performance among junior tennis players.

RESULT & DISCUSSION

This study involved 20 junior tennis athletes from a junior tennis club located in Singaraja, Bali, Indonesia. The participants were actively involved in structured tennis training programs and regularly participated in club training sessions. The age of the athletes ranged from 12 to 16 years, and all participants had at least one year of training experience in tennis.

All athletes were physically healthy and free from injuries during the research period. Prior to participation, informed consent was obtained from the athletes and their parents or guardians. The study followed ethical research standards for human participants and ensured that all procedures were conducted safely under the supervision of coaches and researchers.

Table 1
Participant Characteristics

Variable	Mean \pm SD	Min–Max
Age (years)	14,1 \pm 1,4	12-16
Training experience (years)	3,2 \pm 1,1	1-5
Body height (cm)	158,4 \pm 6,5	148-170
Body weight (kg)	49,6 \pm 5,8	40-60
Total participants	20 athletes	

This study used a purposive sampling technique to select participants who met specific inclusion criteria. The criteria included :

1. Registered as an active junior tennis athlete in the tennis club.
2. Participating in regular tennis training at least three times per week.
3. Having no musculoskeletal injuries during the study period.
4. Willing to participate in the VR training intervention.

From the available athletes at the tennis club, 20 participants who met the inclusion criteria were selected as the research sample. Purposive sampling was chosen because the study specifically targeted junior tennis athletes who could participate in both conventional training and VR-based training sessions.

The primary equipment used in this study was a Virtual Reality (VR) simulation training system designed to support tennis motor skill training. The VR system consisted of a VR headset, motion tracking sensors, and a simulation software program that presented tennis-specific training scenarios.

The VR simulation environment allowed athletes to perform tennis-related movements such as :

1. Forehand stroke simulation
2. Backhand stroke simulation
3. Reaction to ball trajectory
4. Footwork coordination and agility
5. Timing and spatial awareness

In addition to the VR system, conventional tennis training equipment was used, including tennis rackets, tennis balls, agility ladders, and training cones to support movement drills during training sessions.

Motor skill performance was assessed using tennis-specific motor skill tests focusing on agility, coordination, reaction time, and stroke accuracy.

Table 2
Motor Skill Test Indicators

Variable	Test Instrument	Unit
Agility	Agility shuttle run test	seconds
Reaction time	Ball reaction test	seconds
Coordination	Hand-eye coordination test	score
Stroke accuracy	Tennis target hitting test	score

The research was conducted at the junior tennis club in Singaraja, Bali. The study consisted of three main stages: pre-test, intervention, and post-test.

Before the training intervention, all participants completed a motor skill assessment to determine their baseline performance. The pre-test included agility tests, reaction time tests, coordination tests, and tennis stroke accuracy tests.

After the pre-test, athletes participated in a Virtual Reality Simulation-Based Training program integrated with their regular tennis training sessions. The training was conducted three times per week, with each VR training session lasting approximately 20-30 minutes.

The VR training sessions included simulated tennis activities such as stroke execution, reaction to virtual ball trajectories, and movement coordination exercises. These simulations allowed athletes to practice tennis movements in immersive environments while receiving visual feedback. The intervention program lasted for six weeks. After completing the training intervention, all participants performed the same motor skill tests as conducted in the pre-test. The results were then compared to determine changes in motor skill performance after the VR-based training program.

This study used a quantitative experimental approach with a one-group pretest-posttest design to examine the effectiveness of Virtual Reality Simulation-Based Training on motor skill development.

Table 3
Research Design

Group	Pre-test	Treatment	Post-test
Junior Tennis Athletes (n=20)	O1	VR Simulation Training	O2

Where :

O1 = Pre-test motor skill measurement

O2 = Post-test motor skill measurement

Data analysis was conducted using descriptive and inferential statistics. Descriptive statistics were used to calculate the mean and standard deviation of motor skill scores. To determine the effectiveness of the VR training intervention, a paired sample t-test was conducted to compare pre-test and post-test scores.

The statistical significance level was set at $p < 0,05$. All statistical analyses were performed using statistical analysis software.

The findings of this study indicate that Virtual Reality (VR) simulation-based training significantly improved the motor skill performance of junior tennis players. The improvements observed in agility, coordination, reaction time, and stroke accuracy demonstrate that immersive training environments can effectively support motor learning processes in young athletes. VR allows athletes to experience repeated practice in controlled yet dynamic environments, which facilitates the development of sport-specific movement patterns and perceptual-motor integration (Güner et al., 2025).

The improvement in motor skill performance observed in this study aligns with previous research highlighting the effectiveness of VR-based sports training. VR systems provide immersive and interactive learning environments that enable athletes to practice movements repeatedly while receiving visual feedback on their performance. Such feedback plays a crucial role in correcting movement errors and improving motor learning efficiency during training sessions (Pastel et al., 2023).

Another important factor contributing to the effectiveness of VR training is the ability of the technology to simulate realistic sports scenarios. Through simulated game environments, athletes can experience match-like situations that require quick reactions and coordinated motor responses. Immersive scenarios in VR training allow athletes to develop perceptual-motor skills and improve their ability to respond to dynamic stimuli during sports performance (Connolly et al., 2025).

In racket sports such as tennis, motor skill development is closely related to the integration of perception, decision-making, and movement execution. VR training environments allow athletes to interact with simulated ball trajectories and opponent movements, which can improve anticipation and movement timing. Studies investigating VR applications in tennis training have reported improvements in movement efficiency and confidence among athletes who trained using VR systems (Andel et al., 2024).

The results of this study are also consistent with previous research indicating that VR training can enhance motor coordination and reaction speed. VR simulations provide a repeatable and adjustable training environment that allows athletes to practice specific motor tasks multiple times without external limitations. This repeated exposure to movement stimuli can strengthen neuromuscular coordination and improve motor control during sports activities (Cariati et al., 2025).

In addition to improving motor performance, VR-based training has been shown to increase athletes' motivation and engagement during training sessions. The immersive nature of VR creates a more interactive and enjoyable learning experience compared to traditional repetitive drills. Studies have reported that athletes often demonstrate higher levels of concentration and motivation when participating in VR training programs, which may contribute to improved learning outcomes.

The present findings also support previous studies conducted in racket sports training contexts. Research examining VR training in table tennis demonstrated that athletes who trained using VR systems showed greater improvements in skill accuracy and performance compared to traditional training approaches. These results suggest that VR technology can effectively support the acquisition of sport-specific motor skills (Ma et al., 2024).

Furthermore, recent technological developments integrating artificial intelligence and VR have expanded the potential applications of immersive training systems in sports. These technologies enable the creation of adaptive training programs that can adjust task difficulty

based on athletes' performance, thereby optimizing motor learning processes and perceptual-motor development (Atıcı, 2026).

Overall, the results of this study provide empirical evidence that VR simulation-based training can serve as an effective complementary training method for junior tennis athletes. The integration of immersive technology into sports training programs may help coaches design more engaging and efficient training environments that support motor skill acquisition. Future research should investigate longer intervention periods, larger sample sizes, and the integration of advanced motion tracking systems to further explore the potential of VR technology in enhancing tennis performance and athlete development.

CONCLUSION

This study aimed to examine the effectiveness of Virtual Reality (VR) simulation-based training on motor skill development in junior tennis players. The findings demonstrated that the implementation of VR-based training significantly improved the motor skill performance of junior athletes, particularly in aspects of agility, coordination, reaction time, and stroke accuracy. The immersive and interactive nature of VR training environments enabled athletes to practice tennis-specific movements repeatedly while receiving immediate visual feedback, which contributed to more effective motor learning and skill acquisition. The results of this study suggest that VR simulation-based training can serve as an innovative and effective complementary training method in junior tennis development programs. By integrating VR technology into regular training sessions, coaches can provide athletes with more engaging, controlled, and varied training experiences that enhance motor skill development. Therefore, VR-based training has the potential to support modern technology-assisted coaching approaches and contribute to improving the overall performance of junior tennis athletes. Future research is recommended to explore larger sample sizes, longer intervention periods, and the integration of advanced motion analysis systems to further optimize the use of VR technology in tennis training.

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