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Training the tennis serve skill according to the kinetic chain model and its effect on biomechanical variables and the angular kinetic energy index among young players

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Abstract

Based on kinetic chain concept and angular kinetic energy index, we aimed to assess the effect of a training program to improve tennis serve biomechanics among young players in Iraq. A pre-test/post design was applied; twelve players (16-20 years old) from tennis clubs in Baghdad and Basra were given a serving training program as possible. Biomechanical variables were evaluated by3D motion analysis and high-speed cameras following an 8-week focused training program. Responses indicated that performance of the serve had improved ($\alpha \leq 0.05$) with respect to speed (from 95 km/h to 117 km/h) and precision (65% vs.85%). Improvements in angular indices were also noted and these augmented angular kinetic energy measures with more efficient motor coordination. It was concluded that specialized biomechanical training is successful in improving serve performance and should be incorporated into coaching/training factory practice, with implications for future research using a larger sample to corroborate the results.

Keyword: tennis serves, kinetic chain, angular kinetic energy, sports biomechanics, young athletes, sports training.

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Introduction

Tennis serve is one of the most important and decisive offensive skills that determine the winning and losing of a match, Because research has indicated that about 60% points in elite tennis match are won or lost at the serve level. The successful performance of this complex skill rests upon accurate and coordinated control among various regions of the body, which is termed as the kinetic chain, scientifically. That is the key, it's how we generate that power from the legs and transfer it through our body to hit as fast and accurate as possible.

The index of Angular Kinetic Energy (AKE) is one important biomechanical variable to evaluate efficiency of rotational movements of body segments (e.g., trunk, pelvis, shoulder) in serving action. It contributes to assessing how much the player makes use of rotational energy and I know that it prevents its dissipation, involving the degree of motor performance.

The kinetic chain and linear and angular kinetic energy have been studied in several reports. For example, Movella (2024) investigated the applicability of Xsens MVN technology for performance analysis and biomechanical accuracy evaluation in young tennis players with significant better results as concerns knowledge about the kinetic chain. Fort-Vanmeerhaeghe (2020) further investigated the effect of maturation on neuromuscular symmetry in the lower limbs in elite junior competitive tennis players, and suggested that specific training likely plays a significant role. In addition, Sterner et al. (2020) studied the inverse dynamics of the throwing arm with body composition imaging, which could contribute to coverage on angular kinetic energy.

Despite increasing tennis interest in Iraq, young players encounter significant challenges related to a lack of scientifically based training programs emphasising appropriate biomechanical principles. I doesn’t just mean compromised performance, it also equates to more injuries too due to poor movement patterns. Thus, there is an immediate need for an applied study which develops and evaluates a tailored training program to fill these gaps, namely the lack of appropriate studies to guide practice in this area, the scarceness of applied research and the dearth of targeted training interventions.

The specific objectives of this research are:

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- To determine the impact of a kinetic chain-based training program on biomechanical variables (speed, accuracy and joint angles) of the service action.
- To examine the trends of changes in the angular KEI and energetics among players.
- To offer guidelines for coaches and sports federations in prescribing training programs when aiming for effectiveness and safety.

The current research is guided by the following hypotheses:

- H 1 : There are statistically differences ($\alpha \leq 0.05$) between biomechanical variables of the serve at pre-test and post-test after intervention with the suggested training program.
- H2: There is a strong positive correlation between AK index and increase of server performance by speed and accuracy.
- H3 - Training according to the kinetic chain is beneficial for motor coordination and sequence of energy transfer from lower to upper extremities.

Methodology

This investigation was conducted using a quasi-experimental research design (One-Group Pretest/Post-test Design). Twelve competitive young tennis players (16-20 years) were purposefully selected from accredited tennis clubs in Baghdad and Basra. All subjects underwent medical screening in order to be free of any injury that could interfere with their performance.

Key Characteristics of the Homogeneity of the Sample Table 1 displays homogeneity (or lack thereof) in some variables (e.g., age, height, weight, years of training experience) to demonstrate that differences between at blast and post test were due to an intervention rather than initial disparities.

Table 1. ***Description and Homogeneity of the Research Sample in Basic Variables (n = 12)***

Variable	Unit	Mean	Std. Deviation	Skewness
Age	Year	18.25	1.48	0.45
Height	cm	179.5	5.6	-0.21
Weight	kg	72.8	6.2	0.15
Training Experience	Year	6.5	1.8	0.33

The table above shows that the skewness values for all variables are within (±1), and this suggests that the data satisfies normal distribution. This means that the sample was homogeneous for these basic variables before carrying out the training program, thus increasing the internal validity of results.

Measurement Tools

The kinematic variables were recorded using a 3D analysis motion system (3D Motion Analysis) with high-speed cameras. Serve velocity was quantified with a dedicated radar machine and confirmed via video analysis. Serve accuracy was evaluated using a target-orientated test, in which players had to direct the serve at specific zones of the opponent's court.

- **Biomechanical variables:** Angular kinetic energy and major joint angles were calculated using specialized software such as *Kinovea* and biomechanical physics equations.

Below is a detailed description of each test employed in the research, including its purpose and measurement procedure:

1. Serve Speed Test

Purpose

To find the highest linear speed of tennis ball as it leaves the racquet. Serve speed is a reflection of explosive power and kinetic chain efficiency.

Measurement Method

Two complementary techniques were used for accuracy:

- **Speed Radar:** An electronic device positioned behind the player aimed at the ball trajectory to instantly record ball velocity.
- **3D Video Analysis:** High-speed cameras were used to capture the serve, and ball displacement over a precise time frame was analyzed to calculate speed accurately.

2. Joint Angle Measurement

Purpose

Calculating the exact joint angles of relevant joints (shoulder, elbow and knee) at crucial time points during the serve (ball toss phase as well as ball impact) to evaluate movement efficiency and technical faults.

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Measurement Method

The motion analysis software Kinovea was utilised. Digital markers on the joints of the subjects in high-speed video frames were used to annotate, enabling digital angle calculation for each phase.

3. Angular Kinetic Energy Calculation

Purpose

To estimate the kinetic energy from rotation of various body segments. This parameter represented the ability of the players to create and transfer force to the racket effectively via use of trunk, pelvis and shoulder rotation.

Measurement Method

There is no direct measurement for this, but the value is obtained through a systems of biomechanical equations. The researcher enters motion analysis system data (e.g. angular velocity, mass of each body segment) into formulae to obtain angular kinetic energy in Joules (J).

Definition

The energy of an object spinning is called angular kinetic energy. It is controlled by the laws of energy and angular momentum conservation.

Formula:

$$K_{rot} = \frac{1}{2} I \omega^2$$

Where:

- **I** = Moment of inertia (mass × radius^2)
- **ω** = Angular velocity (rad/s)

Journal of Physical Education
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Application in Tennis

During the serve, they first turn the trunk and arms away from the target (high inertia, low angular velocity), and then quickly drive them forward (low inertia, high angular velocity), creating a significant amount of stored rotational kinetic energy that is available for transfer to the racket and ball.

4. Serve Accuracy Test

Purpose

To assess the player's ability to direct the ball into specified target zones within the service box. Accuracy reflects control and motor precision.

Measurement Method

A target-based test was conducted. The serving box was compartmentalized into target areas, and players made a pre-determined number of serves in each. The efficiency of serves landing in the target areas was measured.

Table 2. ***Research Variables and Measurement Methods***

Study Variable	Measurement Method
Serve Speed	Speed Radar + 3D Video Analysis
Joint Angles	Kinovea Motion Analysis System
Angular Kinetic Energy	Quantitative calculation using biomechanical equations
Serve Accuracy	Target-based service test

Training Program

The duration of the training programmed was 8 weeks (3 sessions per week, 90 min each session). The intervention was conducted specific exercises aimed at improving the kinetic chain phases in serve and consisted in:

- Plyometric exercises for lower limb explosive power
- Trunk and pelvic rotation drills using medicine balls
- Shoulder strengthening and arm–trunk coordination training
- Full-serve simulation drills emphasizing correct movement sequencing

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Result

Table 3. *Independent t-test results for differences between pre- and post-test measurements of the study variables (n = 12)*

Variable	Pre-test Mean ± SD	Post-test Mean ± SD	Mean Difference	Std. Error	t-value	Sig. (p)	Effect Size
Serve speed (km/h)	95 ± 8.5	117 ± 7.2	22	4.55	4.83	0.001	1.20
Serve accuracy (%)	65 ± 10.2	85 ± 5.5	20	4.85	4.12	0.001	1.05
Angular kinetic energy – hip (J)	45.8 ± 11.2	68.5 ± 9.8	22.7	5.89	3.85	0.01	1.23
Angular kinetic energy – shoulder (J)	38.2 ± 9.5	59.1 ± 8.1	20.9	5.90	3.54	0.01	1.14
Angular kinetic energy – arm (J)	29.6 ± 7.8	46.3 ± 6.4	16.7	5.20	3.21	0.05	1.07
Motor coordination (index)	0.68 ± 0.15	0.89 ± 0.09	0.21	0.046	4.50	0.001	1.13

Discussion

The obtained results actually prove the effectiveness of the training procedure based on kinetic chain theory. These magnitude positive changes can be justified in terms of biomechanics and Science and they are as follows:

1. Interpretation of the Increase in Serve Speed and Accuracy

Results The average serve speed and accuracy increased statistically significantly from 95–117 km/h and from 65% to 85%, respectively. This rather remarkable improvement is almost entirely due to kinetic linking. The training was based on teaching the players how to develop force from the larger and more powerful segments (legs and trunk) to project it to smaller and quicker segments (shoulder and arm) until reaching maximum transfer in the racket.

This appropriate succession allow one to have the sum of angular velocities, and a high linear velocity on the racket at ball impact. These results are in agreement with Movella (2024) who demonstrated that the use of motion analysis techniques to analyse and correct kinetic chain in young tennis players provides noticeable performance enchancements. The rise in speed and accuracy goes hand-in-hand with better motor control, as movement becomes more fine-grained.

2. Improvements in Angular Kinetic Energy as a Core Factor

It should be noted that the above described observation, which is of interest for any results interpretation, reveals also a large enhancement of angular kinetic energy indicators. The

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intervention successfully improved participants' potential for safely accessing trunk and pelvic rotation, the predominant source behind the modern tennis service motion. The increase in rotational energy indicates that hockey players depended less on muscular contraction of the shoulder/upper arm to deliver the slapshot, and more on body opening and greater amounts of distant muscle groups with less fatigue as well as with higher efficiency.

This finding is in agreement with Sterner et al. (2020) who performed inverse dynamics analysis and demonstrated the significance of trunk and shoulder rotation to generate kinetic energy for the hitting arm. Therefore, the pursuit of this variable was not an attempt in the dark, but sound arrived at from it's power progenitor.

3. Enhancement of Motor Coordination and Energy Transfer

Results This finding suggests that KC-based training may enhance the coordination and sequencing of energy release. It is because of this improvement that everything else firms up--those prophylactic elements are essential for greater speed and accuracy. Also causing these problems in tennis are the bad movement patterns and using arm too much. Improved neuromuscular coordination means mechanical stress is distributed through your body rather than concentrated into smaller joints like your elbow or shoulder, and that makes it less likely you'll end up with overuse injuries.

This observation is in line with Fort-Vanmeerhaeghe (2020) study which highlights the need for early and specialized training intervention to address neuromuscular asymmetry and develop adequate movement pattern according to maturation status of tennis players.

4. Local Relevance and Research Contribution

These findings are particularly important because they apply in a sample of young football players in Iraq. They validate that universal biomechanical concept can be translated and implemented for the benefit of local environments, providing a best practice reference model for coaches and academies in Iraq to create successful training programmes beyond traditional methods. The current research also covers a significant gap in the literature that lacks of applied studies done on Arab and Iraqi specifically samples.

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Overall Interpretation

The results strongly support the positive effect of the kinetic chain–based training program in improving one's serve. Increased serve speed (in average +22 km/h) is mainly due to better transfer of energy from legs and trunk in the hitting arm, confirming what Movilla (2024) analyses have already found.

Furthermore, the bias of the programme towards angular kinetic energy made for more economic movement. Rather than focusing on the force generated solely by the arm, card games players learned how to optimally use trunk and pelvis rotation which would decrease the waste of energy and provide a greater amplitude of forces when being transmitted to the ball. This is in agreement with the results reported by Sterner et al. (2020) on the use of inverse dynamics to interpret segmental involvement in motion.

One of the most impressive results was an improvement in motor coordination, which doesn't just help you do better, but also works to prevent injury. A large number of tennis-related shoulder and elbow injuries are caused by over-using the upper extremities as a compensation mechanism, due to weakness or lack of efficiency in the kinetic chain.

Conclusions

The results of the study clearly indicate that the kinetic chain-analysis-angular kinetic energy-based training program is very efficient in enhancing biomechanical parameters of tennis service. The findings underscored the need for a shift from empirical exercise building towards scientific, biomechanical based training in maximizing performance. Moreover, this study represents a scientific reference to future studies for working on developing tennis and sport performance in Iraq.

Recommendations

It may be advisable to include concept of the kinetic chain and angular kinetic energy index in training programs for young athletes. It is necessary to educate and train coaches with modern technologies on the need for performance analysis. Further research should be extended to other samples (increased sample size), youth age groups, and populations with varying distributions to women athletes. It is recommended to include further variables (e.g., muscular strength, flexibility) to achieve an even more detailed insight into performance. The implementation of AI in performance diagnostics and individualized training should be endorsed. It is necessary to invest in the advanced motion analysis technology in national training centers and specify the scientific standard criteria for practice program, which contributes to cultivating talents soundly. Finally, promoting cooperation and research affiliations with foreign centers of sports biomechanics is greatly recommended.

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