

Original Article

Eight-Week Shoulder Flexibility Program Improves Serve Accuracy and Select ROM in Youth Volleyball: A Randomized Controlled Trial

Aziz Enes Sahin¹, Selim Asan¹, Esedullah Akaras²¹Faculty of Sport Sciences, Erzurum Technical University, Türkiye;²Faculty of Health Sciences, Erzurum Technical University, Türkiye**Abstract**

Objective: This study investigated the effects of an eight-week shoulder flexibility exercise program on shoulder range of motion (ROM) and serve accuracy in youth volleyball players. **Methods:** Thirty-two adolescent players (12–13 years) were randomly assigned to an experimental group (EG, n=16) and a control group (CG, n=16). The EG performed structured flexibility exercises twice weekly in addition to regular training, while the CG continued routine volleyball practice only. Shoulder ROM was assessed with a goniometer, and serve accuracy was evaluated using a standardized scoring protocol (maximum 48 points). **Results:** Significant improvements were observed over time in both groups for most ROM variables ($p < 0.001$). However, significant group differences emerged for shoulder external rotation ($F_{1,29}=5.42$, $p=0.027$, $\eta^2=0.153$) and serve accuracy (Time×Group: $F=6.73$, $p=0.015$, $\eta^2=0.183$). The adjusted ANCOVA confirmed a significant group effect for external rotation ($F_{1,29}=4.28$, $p=0.048$, $\eta^2=0.128$). The experimental group improved serve accuracy by +17.2 points (95% CI: 15.6–18.8) versus +11.6 points (95% CI: 9.4–13.8) in the control group. **Conclusion:** The eight-week flexibility program significantly enhanced serve accuracy and select shoulder ROM parameters in youth volleyball players. Incorporating structured flexibility exercises into training routines may improve technical performance and support shoulder function development during early adolescence.

Keywords: Athlete Performance, Flexibility Training, Serve Accuracy, Shoulder Mobility, Young Athletes

Introduction

Volleyball is characterized by high tempo, short-duration, and repetitive explosive movements, where physical, technical, and tactical skills are comprehensively performed. In particular, due to the intensive involvement of upper extremity movements such as serving, spiking, and blocking, the shoulder joint is regarded as one of the key determinants of both performance and injury risk in this discipline¹. In addition to being a fundamental technique

that initiates play, the serve is considered a critical skill determining the effectiveness of offensive strategies². It has been shown that the force and speed applied to the ball during the serve and spike increase the chances of scoring by disrupting the opponent's defensive setup³. Furthermore, studies in beach volleyball have demonstrated that serve accuracy is closely related to speed and power parameters. That shoulder internal rotation is a significant factor in serve success⁴.

The range of motion of the shoulder joint has a decisive effect on volleyball players' performance and risk of injury. Studies conducted on adolescent volleyball players have indicated that the range of motion in internal and external rotation of the glenohumeral joint is closely associated with performance⁵. Similarly, research on adolescent female volleyball players has shown that differences in range of motion between dominant and non-dominant shoulders can influence performance⁶. Moreover, a tendency toward glenohumeral internal rotation deficit in adolescent female

The authors have no conflict of interest.

Corresponding author: Aziz Enes Şahin, Faculty of Sports Sciences, Erzurum Technical University, Erzurum, Turkey
E-mail: azizenes.sahin52@erzurum.edu.tr

Edited by: G. Lyritis

Accepted 16 October 2025



volleyball players has been reported to increase the risk of injury in both passive and dynamic movements⁷. In male volleyball and handball players, a decrease in total joint range of motion has been identified as a critical risk factor for shoulder pathologies⁸. Previous studies have indicated that flexibility-based training programs play an important role in injury prevention and improving movement efficiency among young athletes^{9,10}. In particular, stretching and mobility exercises targeting the shoulder region have produced notable improvements in rotational range of motion, thereby contributing to performance enhancement¹¹. However, only a limited number of studies have directly examined the effects of flexibility training on serve accuracy and similar performance parameters. The present study differs from strength- or proprioception-oriented approaches by aiming to improve shoulder joint mobility, particularly in the external rotation and horizontal abduction planes. These movement planes are crucial in controlling ball velocity and direction during the volleyball serve^{12,13}.

Studies examining the relationship between shoulder rotation, kinematic characteristics, and volleyball techniques have revealed important findings concerning serve accuracy. Research on adolescent male volleyball players has determined a direct relationship between shoulder rotational range of motion and serve ball speed¹⁴. Likewise, it has been shown that different spiking techniques produce varying effects on shoulder range of motion and humeral rotation, impacting both performance and injury risk¹⁵. Additionally, significant relationships have been identified between wrist and shoulder joint isokinetic strength and serve and spike speed in elite female volleyball players¹⁶. A study comparing professional and amateur volleyball players reported that shoulder kinematics and striking dynamics in the jump serve determined ball speed and accuracy¹⁷. Furthermore, another study on young volleyball players revealed that serve effectiveness is directly associated with shoulder and upper extremity movement patterns¹⁸.

The effects of interventions aimed at improving shoulder joint range of motion on performance and injury prevention have also attracted attention in the literature. It has been reported that shoulder exercises with TheraBand increase joint range of motion and positively influence throwing skills, particularly in volleyball players with internal rotation deficits¹⁹. Similarly, shoulder injury prevention programs applied to young volleyball players have been found to improve proprioception and dynamic stability²⁰. Upper extremity performance parameters are important for volleyball players and athletes in sports with similar movement demands. A study conducted on handball players examined the relationships between upper extremity neuromuscular control, grip strength, and shooting accuracy, and found that technical skills were also an important factor in shooting success²¹. This finding suggests that serve accuracy in volleyball is closely related to physical attributes, technical proficiency, and movement

coordination.

In conclusion, the existing literature demonstrates that shoulder joint range of motion, muscle strength, neuromuscular control, and kinematic characteristics are decisive factors in volleyball performance, particularly in upper extremity movements such as serving and spiking. Moreover, exercises aimed at maintaining and improving shoulder joint mobility have been reported to play an important role in enhancing performance and preventing possible injuries²². Serve accuracy depends on the efficient functioning of a kinetic chain that begins in the lower extremities and extends to the shoulder joint. Hip and knee extension form the basis of the force transmitted to the ball, while trunk rotation and forward flexion transfer this energy to the upper extremities⁴. Shoulder extension and internal rotation are the most critical components in generating maximum ball speed during the serve; in this process, the synchronized activation of the shoulder muscles ensures efficient energy transfer^{14,15}. Moreover, increased flexibility in these movements enhances mechanical efficiency and improves proprioceptive feedback and neuromuscular coordination, thereby optimizing timing and accuracy of ball contact²³⁻²⁵. In this context, the present study aimed to examine the effects of an eight-week flexibility exercise program targeting the shoulder joint on shoulder joint range of motion and serve accuracy in young volleyball players.

Materials and Methods

Research Design

This study used a pre-test-post-test experimental research design with a control group. The experimental research method involves testing the effects of changes caused by the researcher on the dependent variable. Experimental studies can be conducted on a single participant or group, but generally include two or more participant groups for comparison purposes^{26,27}.

Research Group

The study included volunteer athletes actively playing volleyball in different sports clubs registered in youth leagues. The G*Power 3.1.9.4 software was used to determine the sample size. Within the scope of the power analysis, the significance level was set at $\alpha = 0.05$, statistical power at $1 - \beta = 0.80$, and Cohen's $d = 0.50$. Based on these parameters, the calculation indicated that at least 28 participants were required to obtain reliable results. To prevent possible data loss and increase statistical power, the sample size was increased by 15%, and the study was completed with 32 participants, including 16 women and 16 men.

Inclusion criteria were defined as follows: having at least six months of volleyball training history, regularly participating in weekly training, not having sustained a serious sports injury in the past six months, and providing written voluntary participation consent with parental

Table 1. Descriptive characteristics of participants and comparison of pre-test differences between groups.

Variables	Group	n	\bar{X}	SD	t	p
Age (years)	EG	16	12.31	1.302	1.359	0.184
	CG	16	13.00	1.549		
	Σ	32	12.66	1.450		
Height (m)	EG	16	1.65	0.111	0.539	0.594
	CG	16	1.67	0.098		
	Σ	32	1.66	0.104		
Body Weight (kg)	EG	16	57.69	14.94	0.049	0.961
	CG	16	57.44	13.90		
	Σ	32	57.56	14.19		
Body Mass Index (kg/m ²)	EG	16	21.09	4.728	0.414	0.681
	CG	16	20.46	3.841		
	Σ	32	20.77	4.250		

Notes: n: Sample size; \bar{X} : Mean; SD: Standard deviation; Σ : Sigma; EG: Experimental Group; CG: Control Group.

approval. *Exclusion criteria were defined as:* having chronic neuromuscular or orthopedic conditions, a history of severe trauma or surgery affecting the upper extremities within the past six months, or currently undergoing medication or treatment that might affect flexibility or balance. All participants were informed about the research protocol, written consent was obtained from their parents, and voluntary participation forms were signed. Descriptive statistics of the participants are presented in Table 1.

According to Table 1, the experimental group (age: 12.31 ± 1.30 years; height: 1.65 ± 0.11 m; weight: 57.69 ± 14.94 kg; BMI: 21.09 ± 4.73 kg/m²) and control groups (age: 13.00 ± 1.55 years; height: 1.67 ± 0.09 m; weight: 57.44 ± 13.90 kg; BMI: 20.46 ± 3.84 kg/m²), no significant difference was found between the descriptive parameters.

Research Procedure

The research process was carried out in three stages: pre-test measurements, implementation of the exercise program, and post-test measurements. All applications were conducted in an indoor facility with controlled environmental conditions, between 15:00 and 17:00 in alignment with the participants' circadian rhythms, thereby minimizing the influence of biological variability. Thirty-two athletes were randomly assigned to the experimental group (n = 16) and the control group (n = 16) using a lot-drawing method that ensured balance in age and sex. The group assignments were carried out by an independent researcher who was not involved in the training or assessment procedures. In the pre-test stage, the shoulder joint range of motion was measured in both groups in accordance with standardized protocols. The experimental group participated in a structured flexibility training program conducted under the supervision of the research team, which was applied twice weekly for eight weeks. The same investigator conducted

goniometric measurements and serve accuracy tests. The assessor was not informed about group allocation. However, complete blinding was impossible because the sessions were carried out in the same training environment. This limitation was acknowledged as one of the constraints of the study. Participants in the exercise group attended an average of 92% of the eight-week program. All sessions were performed under coach supervision and at the same time of day. Control group participants were instructed not to perform additional stretching exercises outside their regular team practices. Adherence to the intervention protocol was monitored through weekly attendance logs and coach records.

Each session lasted approximately 25-30 minutes and was performed twice a week for eight weeks. All exercises were performed under the direct supervision of the research team to ensure proper form and safety. Each supervisor oversaw a maximum of two athletes at a time.

Data Collection Tools

Personal Information Form

The form prepared to identify the participants' individual characteristics included demographic and training-related information such as age, height, body weight, body mass index (BMI), and years of sports experience.

Shoulder Joint Range of Motion Measurement

Shoulder joint flexion, extension, internal rotation, external rotation, abduction, and glenohumeral horizontal abduction ranges of motion were measured using a standard two-arm goniometer (Baseline®, Fabrication Enterprises, USA). All measurements were performed with participants in a supine position, ensuring scapular stability. Anatomical reference points were identified as the acromion, lateral

Table 2. Flexibility exercises used in the shoulder flexibility training program.

Exercise	Start and Finish Position	Target Joint / Motion	Sets × Duration × Rest	Progression
Overhead shoulder stretch	Participant stands upright with both arms extended overhead; one arm is grasped at the elbow by the opposite hand and gently pulled backward. The trunk remains upright.	Shoulder flexion and external rotation	3 × 30 s × 15 s rest	The stretch angle slightly increased after week 2.
Another shoulder stretch (Cross-body shoulder stretch)	Participant stands with one arm extended across the chest at shoulder level; the opposite arm supports the elbow and pulls it gently toward the body.	Shoulder horizontal adduction and posterior capsule flexibility	3 × 30 s × 15 s rest	Gradual increase in pull distance over time.
Anterior shoulder stretch	Participant faces the wall with arms abducted to 90° and externally rotated; gently pushes the trunk forward to stretch the anterior shoulder capsule.	Shoulder horizontal abduction and external rotation	3 × 30 s × 15 s rest	The trunk lean gradually increased each week.
Hindu push-up	The participant starts in a plank position, raises the hips upward, and then lowers the trunk forward and downward in a smooth arching motion.	Shoulder extension, scapular stability, and trunk mobility	3 × 30 s × 15 s rest	Movement amplitude and tempo gradually increased.
Shoulder stretch (Behind-the-head triceps stretch)	Participant stands upright, places one arm behind the head, grasps the elbow with the opposite hand, and gently pulls downward and backward.	Shoulder internal rotation and triceps flexibility	3 × 30 s × 15 s rest	Pull angle slightly increased after week 2.
Wall shoulder stretch	Participant faces the wall, places hands on the wall above head level, keeps elbows straight, and lowers the trunk downward.	Shoulder flexion and scapular mobility	3 × 30 s × 15 s rest	Shoulder elevation and trunk lean gradually increased.

epicondyle of the humerus, olecranon, and the midline of the trunk. Each movement was measured three times by the same investigator, and the mean value was used for analysis. According to validated protocols for adolescent athletes, the intra-rater reliability coefficient (ICC) ranges between 0.90–0.94, and the standard error of measurement (SEM) between 1.5–2.0°^{28,29}.

Body Composition Measurement

A SECA stadiometer (Germany) was used for height measurements, and a digital SECA scale with 0.1 kg precision was employed for body weight. Measurements were taken barefoot, in an anatomical standing position, and while wearing standard sports clothing. Height was recorded in centimeters (cm), body weight in kilograms (kg), and body mass index was calculated using the formula [BMI = kg/m²].

Serve Accuracy Measurement

Serve accuracy was evaluated using a standardized zone-target protocol, as described for young volleyball players³⁰. Although specific test–retest reliability values (ICC) were not available, the protocol followed established procedures

previously applied in youth performance assessments. Each participant served 24 times: eight to the opponent's court zone 1, eight to zone 6, and eight to zone 5. To minimize learning effects, the serving order was randomly determined. All serves were performed standing without a jump (floating, etc.), and approximately 15 seconds of rest time was given between each attempt. The serves were scored as follows:

2 points: If the serve landed in the targeted zone,

1 point: If the serve landed inside the court but outside the target zone,

0 points: If the serve landed outside the court.

The total score was calculated by summing the points obtained from all zones, with a maximum possible score of 48 points per player. All measurements were conducted by the same investigator, blinded to group allocation. All serves were performed on the same court setup and within the same time frame (15:00–17:00).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA). Descriptive

Table 3. Pre- and Post-Intervention Flexion and Extension Values.

Variables	Group	Pre-Test Mean \pm SD (%95 CI)	Post-Test Mean \pm SD (%95 CI)	Cohen's d	Effect	F	p	η^2
Flexion $^\circ$	EG	174.00 \pm 15.53 (165.72-182.28)	190.37 \pm 8.98* (185.59-195.16)	1.29 Large	Time	46.47	0.001*	0.613
	CG	174.69 \pm 10.91 (168.87-180.509)	185.94 \pm 12.11* (179.48-192.39)	0.97 Medium	Time \times Group	1.63	0.211	0.052
					Group	0.25	0.624	0.008
Extension $^\circ$	EG	46.06 \pm 11.96 (39.69-52.44)	55.56 \pm 12.55* (47.57-63.55)	0.77 Medium	Time	17.60	0.001*	0.370
	CG	48.56 \pm 14.99 (41.88-55.25)	55.31 \pm 10.36* (49.79- 60.83)	0.52 Small	Time \times Group	0.50	0.483	0.017
					Group	0.08	0.781	0.003

Notes: * $p < 0.05$, EG: Experimental Group; CG: Control Group η^2 : Represents the partial eta squared effect size. $^\circ$: Degrees, CI: Confidence Interval.

Table 4. Pre- and Post-Intervention Abduction and Horizontal Hyperadduction Values.

Variables	Group	Pre-Test Mean \pm SD (%95 CI)	Post-Test Mean \pm SD (%95 CI)	Cohen's d	Effect	F	p	η^2
Abduction $^\circ$	EG	164.56 \pm 20.97 (153.39-175.73)	186.12 \pm 14.48* (178.41- 193.84)	1.20 Large	Time	80.12	0.001*	0.728
	CG	165.44 \pm 19.89 (154.84-176.04)	185.06 \pm 18.74* (175.08-195.04)	1.01 Medium	Time \times Group	0.18	0.677	0.006
					Group	0.001	0.988	0.001
Horizontal Hyperadduction $^\circ$	EG	26.6 \pm 5.2 (23.82- 29.319)	37.4 \pm 6.5* (33.97- 40.90)	1.86 Large	Time	87.16	0.001*	0.744
	CG	29.0 \pm 6.8 (25.39-32.61)	35.9 \pm 6.6* (32.36- 39.39)	1.03 Medium	Time \times Group	4.43	0.044*	0.129
					Group	0.05	0.829	0.002

Notes: * $p < 0.05$, EG: Experimental Group; CG: Control Group. η^2 : Represents the partial eta squared effect size. $^\circ$: Degrees, CI: Confidence Interval.

statistics were presented as mean \pm standard deviation (SD) and 95% confidence intervals (CI). The normality of the data was assessed using the Shapiro–Wilk test, and homogeneity of variances was tested with Levene's test. Within-group differences were analyzed using paired-sample t-tests. For primary endpoints (serve accuracy and shoulder internal/external rotation), analyses were conducted using analysis of covariance (ANCOVA) with post-intervention values as the dependent variable, baseline values as covariates, and Group (EG vs. CG) as the fixed factor. Adjusted between-group differences with 95% CIs are reported. ANCOVA was also applied to variables showing significant between-group differences to control for baseline differences. Effect sizes were calculated as Cohen's d for within-group changes, while partial eta squared (η^2) values were reported for main and interaction effects. Primary outcome variables included serve accuracy and internal and external rotation, whereas secondary outcomes comprised a range of other motion parameters.

Serve accuracy and shoulder IR/ER were prespecified primary outcomes; other ROM variables were exploratory, and no formal multiplicity adjustment was applied.

Effect sizes were interpreted as small (0.20), medium (0.50), and large (0.80). The level of statistical significance was set at $p < 0.05$ for all analyses.

Results

According to the findings presented in the Table 3; for the flexion variable, a large effect was observed in the experimental group (Cohen's d = 1.29), while a medium effect was found in the control group (Cohen's d = 0.97). The time factor was significant (F = 46.47; $p < 0.001$; $\eta^2 = 0.613$); however, the group effect ($\eta^2 = 0.008$) and the group \times time interaction were not significant ($p = 0.211$). For the extension variable, a medium effect was observed in the experimental group (Cohen's d = 0.77), whereas a small

Table 5. Internal and External Rotation Values Before and After Intervention.

Variables	Group	Pre-Test Mean \pm SD (%95 CI)	Post-Test (Mean \pm SD (%95 CI)	Cohen's d	Effect	F	p	η^2
Internal Rotation ^o	EG	67.4 \pm 19.2 (57.20-77.67)	84.9 \pm 10.3* (79.48-90.40)	1.14 Large	Time	43.40	0.001*	0.591
	CG	68.8 \pm 15.3 (60.62-76.87)	78.9 \pm 14.5* (71.16- 86.59)	0.68 Medium	Time \times Group	3.09	0.089	0.093
					Group	0.23	0.633	0.008
External ^o Rotation	EG	79.5 \pm 16.1 (70.93-88.07)	95.5 \pm 7.2* (91.66-99.34)	1.28 Large	Time	42.65	0.001*	0.587
	CG	72.1 \pm 13.2 (65.86-78,26)	85.2 \pm 13.4* (78,07-92,30)	1.05 Medium	Time \times Group	0.42	0.524	0.014
					Group	5.42	0.027*	0.153

Notes:* $p < 0.05$, EG: Experimental Group; CG: Control Group. η^2 : Represents the partial eta squared effect size.°: Degrees, CI: Confidence Interval.

Table 6. Pre- and Post-Intervention Serve Accuracy Values.

Variables	Group	Pre-Test Mean \pm SD (%95 CI)	Post-Test Mean \pm SD (%95 CI)	Cohen's d	Effect	F	p	η^2
Serve Accuracy	EG	26.4 \pm 4.2 (24.18-28.70)	43.6 \pm 2.6* (42.22-45.03)	4.87 Very Large	Time	178.81	0.001*	0.854
	CG	28.8 \pm 7.6 (24.78-32.85)	40.4 \pm 3.2* (38.67-42.08)	1.99 Large	Time \times Group	6.73	0.015*	0.183
					Group	0.11	0.741	0.004

Notes:* $p < 0.05$, EG: Experimental Group; CG: Control Group. η^2 : Represents the partial eta squared effect size.CI: Confidence Interval.

effect was identified in the control group (Cohen's $d = 0.52$). The time factor was significant ($F = 17.60$; $p < 0.001$; $\eta^2 = 0.370$); however, the group effect ($\eta^2 = 0.003$) and the group \times time interaction were not significant ($p = 0.483$). The 95% confidence flexion, EG ranged from 165.72–182.28° to 185.59–195.16°, and CG ranged from 168.87–180.50° to 179.48–192.39°; for extension, EG ranged from 39.69–52.44° to 47.57–63.55°, and CG ranged from 41.88–55.25° to 49.79–60.83°.

According to the findings presented in Table 4, for the abduction variable, a large effect was observed in the experimental group (Cohen's $d = 1.20$), while a medium effect was found in the control group (Cohen's $d = 1.01$). The time factor was significant ($F = 80.12$; $p < 0.001$; $\eta^2 = 0.728$); however, the group effect ($\eta^2 = 0.001$) and the group \times time interaction were not significant ($p = 0.677$). For the horizontal hyperadduction variable, a very large effect was detected in the experimental group (Cohen's $d = 1.86$), whereas a medium effect was observed in the control group (Cohen's $d = 1.03$). The time factor was significant ($F = 87.16$; $p < 0.001$; $\eta^2 = 0.744$), and a significant difference was also found in the group \times time interaction ($F = 4.43$; $p = 0.044$; $\eta^2 = 0.129$); however, the group effect was not

significant ($p = 0.829$; $\eta^2 = 0.002$). The 95% confidence EG ranged from 153.39–175.73° to 178.41–193.84°, and CG ranged from 154.84–176.04° to 175.08–195.04°; for horizontal hyperadduction, EG ranged from 23.82–29.31° to 33.97–40.90°, and CG ranged from 25.39–32.61° to 32.36–39.39°.

According to the findings presented in Table 5, a large effect was observed in the experimental group for internal rotation (Cohen's $d = 1.14$), while a medium effect was found in the control group (Cohen's $d = 0.68$). The main effect of time was significant ($F = 43.40$, $p < 0.001$, $\eta^2 = 0.591$); however, neither the group effect ($p = .633$, $\eta^2 = 0.008$) nor the time \times group interaction ($p = 0.089$, $\eta^2 = 0.093$) reached significance. For external rotation, the experimental group demonstrated a large effect (Cohen's $d = 1.28$), and the control group showed a medium effect (Cohen's $d = 1.05$). The main effect of time was significant ($F = 42.65$, $p < 0.001$, $\eta^2 = 0.587$), and the group effect was also significant ($F = 5.42$, $p = 0.027$, $\eta^2 = 0.153$, medium effect), although the time \times group interaction was not significant ($p = 0.524$, $\eta^2 = 0.014$). Baseline-adjusted ANCOVA confirmed a significant model and group effect for external rotation ($F(2,29) = 9.587$, $p = 0.001$; $F(1,29)$

= 4.275, $p = 0.048$; $\eta^2 = 0.398$ and 0.128 , respectively). The 95% confidence intervals ranged from $70.93\text{--}88.07^\circ$ to $91.66\text{--}99.34^\circ$ for the experimental group, and from $65.86\text{--}78.26^\circ$ to $78.07\text{--}92.30^\circ$ for the control group.

According to the findings presented in Table 6, a very large effect was observed in the serve accuracy variable in the experimental group (Cohen's $d = 4.87$), whereas a large effect was detected in the control group (Cohen's $d = 1.99$). The time factor was significant ($F = 178.81$; $p < 0.001$; $\eta^2 = 0.854$). The group \times time interaction was also significant ($F = 6.73$; $p = 0.015$; $\eta^2 = 0.183$, moderate effect), but the main effect of group was not significant ($p = 0.741$; $\eta^2 = 0.004$). Additionally, the 95% confidence intervals for the experimental group ranged from $24.18\text{--}28.70$ to $42.22\text{--}45.03$, and for the control group from $24.78\text{--}32.85$ to $38.67\text{--}42.08$. ANCOVA revealed an adjusted between-group mean difference of 3.52 points (95% CI [1.39, 5.66]; $p = 0.002$) in favor of the experimental group for serve accuracy.

Discussion

This study evaluated the effects of an eight-week flexibility exercise program on shoulder joint range of motion and serve accuracy in youth volleyball players. The findings obtained during the study showed that athletes in both the experimental and control groups experienced certain levels of improvement over time. However, the structured flexibility program applied to the experimental group produced greater effects compared to the level of improvement achieved through routine volleyball training alone. The fact that athletes in the experimental group showed more pronounced progress, particularly in some shoulder joint movements and in serve accuracy, suggests that flexibility exercises may be an important method contributing to performance development at the youth level.

At the same time, including a mixed-sex cohort aged 12–13 years in this study represents a developmental factor that should be considered when interpreting the results. The biological maturation processes occurring during early adolescence can lead to notable differences in muscle-tendon characteristics, joint laxity, and motor control³¹. Previous literature has indicated that female athletes generally exhibit greater shoulder joint laxity and connective tissue flexibility compared to males, which may influence shoulder biomechanics and injury susceptibility^{31–33}. Therefore, some of the improvements observed in range of motion and performance in this study may not solely reflect the effects of the flexibility program but could also be influenced by participants' sex and maturation status.

The increase observed in shoulder joint range of motion in both groups suggests that volleyball training may inherently contribute to improvements in flexibility^{5,6}. The findings indicated that a wide range of motion (ROM) variables improved over time; however, the group \times time

interaction reached statistical significance only for serve accuracy and hyperadduction. This demonstrates that the effect of the flexibility program was not evident across all movement planes but was limited specifically to these two variables. The improvements were specific to serve accuracy and selected ROM measures; no multiplicity correction was applied for exploratory outcomes. Although significant improvements in external rotation were observed in both groups, the absence of a significant interaction suggests that this change may be related to general training adaptations rather than a direct effect of the flexibility program. These movements play an important role in fundamental volleyball techniques such as serving and spiking, and improvements in shoulder mobility may support upper extremity biomechanics and enhance technical performance efficiency in young athletes^{7,8,15,34}.

The greater improvement in serve accuracy observed in the experimental group indicates that shoulder joint range of motion may reflect positively on serve accuracy. This finding is consistent with previous studies emphasizing the relationship between shoulder range of motion, serve technique, and ball speed^{4,14,17,18}. Moreover, improving serve accuracy indirectly contributes to in-game success². In addition to the contribution of flexibility exercises to performance, it is thought that they may indirectly affect injury risk factors by improving muscle control and movement coordination. However, since no injury data were collected in this study, this relationship should not be interpreted as causal. The observed improvements were limited to serve accuracy and selected ROM planes; as injury incidence was not assessed, no preventive implications can be drawn. Nevertheless, flexibility exercises are generally recognized as beneficial not only for performance enhancement but also for injury prevention. Previous studies support that such programs contribute to proprioception, dynamic stability, and overall movement efficiency^{1,20,22}. Therefore, regular flexibility training in youth athletes' programs may benefit performance and injury prevention. Furthermore, the effects of flexibility exercises are not limited solely to increasing joint range of motion but also contribute to performance through mechanisms involving proprioceptive feedback and neuromuscular control. PNF-based applications have been reported to improve muscle function, balance, and motor control, thereby enhancing the efficiency of the sensorimotor system^{24,35,36}. Moreover, neuro-athletic approaches incorporating proprioceptive elements have been shown to improve flexibility and serve accuracy in volleyball players, highlighting the practical significance of this interaction²⁵. These findings suggest that the improvement in serve accuracy observed in the present study may be associated with enhanced flexibility and adaptations in sensorimotor processes. Therefore, regular flexibility training in youth athletes' programs may enhance performance and contribute to maintaining shoulder health by improving movement quality.

Flexibility exercises may enhance neuromuscular control by regulating shoulder muscle activation³⁷. In

addition, vibration-based approaches have been shown to increase joint range of motion³⁸. These findings support the contribution of flexibility training to performance enhancement. The findings are consistent with prior evidence indicating that targeted flexibility interventions can improve joint mobility and sport-specific performance. An eight-week shoulder-focused training program has been shown to enhance shoulder strength, range of motion, and overall performance in volleyball players, supporting the role of structured exercise in optimizing upper extremity function³⁹. Improvements in joint mobility may also facilitate more precise motor control by enhancing proprioceptive feedback, which has been identified as a key determinant of upper extremity functional performance in volleyball athletes²³. Conversely, reductions in proprioceptive acuity and dynamic stability due to shoulder pain have diminished performance, underscoring the importance of preserving sensorimotor function through preventive training approaches⁴⁰. Furthermore, incorporating flexibility-based strategies has been demonstrated to improve technical skill accuracy, as evidenced by the positive effects of a flexibility-oriented program on block accuracy in volleyball players⁴¹. These findings collectively reinforce the potential of structured flexibility exercises to promote biomechanical efficiency and accuracy in volleyball-specific tasks.

Specific improvements were also observed in the control group, indicating that routine volleyball training effectively improves muscle strength, coordination, and joint flexibility^{16,42}. However, the increase in service performance in the experimental group suggests that additional flexibility programs may provide practical benefits. Examination of the effect sizes revealed particularly significant changes in serve accuracy. This indicates that short-term and structured flexibility programs can be an applicable method for youth athletes. Considering the importance of serve speed and accuracy in volleyball, it is recommended that such programs be integrated into training plans³.

Study Strengths & Limitations

This study has several strengths, including its randomized experimental design, focus on youth athletes, and the application of a practical, low-cost flexibility program that can be easily integrated into training routines. The statistically significant and considerable improvements observed in serve accuracy highlight the potential effectiveness of such interventions for performance enhancement. However, some limitations should be acknowledged. The relatively small sample size limits the generalizability of the findings. Although the assessor was blinded, complete blinding of participants was not possible, and adherence was monitored only through attendance logs. Potential learning effects during repeated testing and minor ambiguities in defining certain ROM measures may also have influenced the results. Moreover, as the participants were mixed-sex adolescents, the study did not account for maturation-related differences, which might

have affected flexibility and performance outcomes. Finally, the study design did not allow directly exploring underlying neuromuscular or proprioceptive mechanisms linking flexibility to serve accuracy.

Conclusions

The findings of this randomized controlled trial indicate that an eight-week shoulder flexibility program improved serve accuracy and specific shoulder range of motion parameters in young volleyball players. Although both groups showed improvement over time, the structured flexibility intervention led to greater gains, particularly in serve accuracy and shoulder mobility. These results suggest that incorporating targeted flexibility exercises into youth volleyball training may provide measurable benefits for technical skill application. However, the observed improvements are specific to the parameters tested and the time frame; further studies with larger samples and mechanical assessments are needed to clarify long-term and neuromuscular effects.

Ethics approval

The study obtained ethical approval from the Erzurum Teknik Üniversitesi Scientific Research and Publication Ethics Committee (Decision No. 14, Meeting No.04, dated 04/04/2024).

Consent to participate

Written informed consent was obtained from all participants, and parental consent was secured for those under 18.

Authors' Contributions

AES and SA contributed significantly to the manuscript's conception and design. AES was responsible for data collection, while SA and EA were responsible for data analysis and interpretation. All authors contributed to drafting the manuscript and critically revised its content. All authors read and approved the final version of the manuscript.

Acknowledgments

This study was derived from the first author's master's thesis. AI-based proofreading tools were used to assist in the language editing of the manuscript to ensure clarity and consistency in the writing process. This process was conducted under human supervision to maintain academic integrity. We want to express our sincere gratitude to all the athletes who voluntarily participated in this study.

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