

RESEARCH

Open Access



# The effect of static and dynamic core exercises on serve and spike speed in young volleyball players: a randomized controlled trial

Bilal Gok<sup>1\*</sup> and Gorkem Acar<sup>1\*</sup>

## Abstract

**Background** Volleyball is a high-intensity team sport demanding explosive upper-body skills whose performance depends on effective kinetic chain transfer through the core musculature. Although core training is widely incorporated into athletic conditioning, the differential effects of static versus dynamic core protocols on sport-specific ball-velocity outcomes remain insufficiently examined, particularly in adolescent athletes. This study investigated the effects of a six-week supplementary static or dynamic core exercise program on serve speed and spike speed in elite young male volleyball players.

**Methods** Thirty-one male volleyball players (aged 11–14 years) were randomly assigned to a dynamic core exercise group (DCEG,  $n = 15$ ) or a static core exercise group (SCEG,  $n = 16$ ). Both groups continued regular volleyball training and additionally performed a six-week, three-days-per-week core program applied before each training session. Serve and spike speeds were measured with a Bushnell Velocity Gun radar device at pre-test and post-test. Normality was confirmed by the Shapiro-Wilk test. Within-group comparisons used paired t-tests; between-group comparisons used analysis of covariance (ANCOVA) with pre-test values as the covariate.

**Results** Within-group analyses showed a significant improvement in spike speed for SCEG ( $t(15) = -5.115, p < .001$ ) and a significant improvement in serve speed for DCEG ( $t(14) = -7.299, p < .001$ ). ANCOVA revealed a significant between-group difference in serve speed ( $F(1, 28) = 31.001, p < .001$ , partial  $\eta^2 = 0.525$ ) favouring DCEG, while no significant between-group difference was found for spike speed ( $F(1, 28) = 0.250, p = .621$ , partial  $\eta^2 = 0.009$ ).

**Conclusions** Six weeks of supplementary core training was accompanied by improvements in serve and spike performance in elite young male volleyball players. Dynamic core exercises were more effective for serve speed, whereas static core exercises produced significant gains in spike speed. Because the trial did not include a no-treatment control group and the sample was small, these findings are preliminary and describe a comparison between two active core-training modalities rather than an absolute effect of core training; coaches may consider tailoring core training modality to the specific performance goal, pending confirmation in larger, adequately powered controlled trials.

\*Correspondence:

Bilal Gok  
[bigok@gelisim.edu.tr](mailto:bigok@gelisim.edu.tr)  
Gorkem Acar  
[gacar@gelisim.edu.tr](mailto:gacar@gelisim.edu.tr)

Full list of author information is available at the end of the article



© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

**Trial registration** ClinicalTrials.gov, NCT07641439. Registered 05 May 2026. Retrospectively registered (recruitment began 23 March 2026; see Methods for justification).

**Keywords** Volleyball, Spike speed, Serve speed, Core stability, Dynamic core exercises, Static core exercises, Adolescent athletes, Athletic performance

## Introduction

Volleyball is a high-intensity, multidirectional team sport with complex physical demands encompassing explosive power, speed, agility, and neuromuscular coordination [1]. The sport requires rapid transitions between offensive and defensive actions, imposing high metabolic and neuromuscular loads on athletes across all playing positions [2].

Among the technical skills that determine match outcomes, spiking and serving are considered the most critical offensive actions [3, 4]. Spike speed directly reflects the attacker's capacity to overcome defensive readiness, while serve speed creates immediate pressure at the start of each rally [5]. As competitive level increases, the ability to generate higher ball velocities becomes a decisive performance differentiator; biomechanical analyses confirm that elite attackers consistently achieve greater racket-free arm angular velocities and more effective proximal-to-distal sequencing compared with sub-elite players [3, 6].

From a biomechanical perspective, spike and serve execution are not isolated upper-limb movements; they rely on an integrated kinetic chain in which ground reaction forces are transmitted sequentially from the lower extremities through the pelvis and trunk to the distal segments of the upper limb [7]. This sequential proximal-to-distal energy transfer is governed by the structural and functional integrity of the core musculature [8]. The core refers to the lumbopelvic-hip complex, encompassing the abdominal muscles, back extensors, gluteal musculature, and deep stabilizers such as the transversus abdominis and multifidus [9]. Any deficit in core strength or stability attenuates the transfer of kinetic energy, reduces ball velocity, and increases the risk of musculoskeletal injury [10].

Core training interventions can broadly be classified into two categories: static (isometric) and dynamic [11]. Static core exercises—such as the front plank, side plank, and posterior plank—primarily target muscular endurance and spinal stabilization through sustained isometric contractions [11, 12]. Dynamic core exercises—including spiderman planks, bicycle crunches, and push-up variations—challenge the core musculature under conditions of controlled movement, requiring co-contraction of multiple muscle groups and greater neuromuscular coordination [13]. The relative contribution of each modality to sport-specific performance outcomes is an area of ongoing investigation [14].

Several studies have demonstrated positive effects of core training on athletic performance indicators. Reed et al. [15] reported that both isolated and integrated core stability programs improved performance measures across a range of sports. Hibbs et al. [16] documented that core stability and core strength training optimized overall athletic performance and reduced injury risk. Weston et al. [17] demonstrated that isolated core training significantly improved sprint performance in national-level junior swimmers, highlighting the transferability of core strength to sport-specific speed. In team sports, Prieske et al. [8] found that core strength training enhanced neuromuscular and athletic performance in elite youth soccer players. Machado et al. [18] demonstrated that an eight-week core training program significantly increased ball-throwing velocity in male handball players, emphasizing the role of trunk power in overhead sports [18].

In volleyball specifically, the generation of spike and serve speed involves shoulder internal rotation, elbow extension, and wrist flexion, all preceded by lower-limb drive and trunk rotation. Forthomme et al. [3] identified trunk rotation strength and shoulder isokinetic peak torque as significant correlates of spike velocity, underscoring the importance of core-trunk force production. Ziv and Lidor [5] further emphasized that vertical jump height and upper-body power, both of which are influenced by core stability, are primary determinants of spike efficiency. Coleman et al. [6] provided three-dimensional kinematic evidence that trunk lean angle and shoulder-to-wrist sequencing are biomechanical prerequisites for maximal spike velocity.

Despite these findings, relatively few studies have specifically compared the differential effects of static and dynamic core training protocols on serve and spike speed in adolescent volleyball players. This gap is particularly important because the neuromuscular demands of static and dynamic exercises differ substantially, and their specific contributions to ball-velocity outcomes may vary depending on the nature of the skill performed [13]. Evidence on appropriate core training design for youth athletes remains limited [19], and early adoption of core stability exercises is considered beneficial for long-term athletic development [20]. The present study aimed to address this gap by examining the effects of a six-week static and dynamic core exercise program on serve and spike speed in elite young male volleyball players.

## Methods

### Study design

A randomized, controlled, pre-test/post-test experimental design was used. Participants were randomly allocated to either the dynamic core exercise group (DCEG) or the static core exercise group (SCEG). Prior to the intervention, the study objectives, testing procedures, and exercise protocols were explained to all athletes, club officials, and parents/guardians. The study protocol was approved by the İstanbul Gelişim University Scientific Research Ethics Committee (Approval No. 2026-04-40; March 18, 2026). All procedures involving human participants were conducted in accordance with the ethical standards of the institutional research committee and with the principles of the Declaration of Helsinki and its subsequent amendments. Written informed consent was obtained from the parents or legal guardians of all participants, and written assent was obtained from each participant prior to data collection [21]. This randomized controlled trial was designed and reported in accordance with the CONSORT (Consolidated Standards of Reporting Trials) guidelines, and a completed CONSORT checklist is provided as an additional file. Participant recruitment and baseline (pre-test) measurements commenced in late March 2026, immediately following ethical approval (18 March 2026), and the six-week intervention, including post-test measurement, was completed in early May 2026. The trial was subsequently registered on ClinicalTrials.gov (NCT07641439) on 5 May 2026; registration was therefore retrospective. Prospective registration was not completed because the study was planned and approved as a single-centre, non-pharmacological sport-science intervention conducted within an institutional research programme, and the expectation of prospective registration for trials reported under CONSORT was recognised only during manuscript preparation; the trial was registered as soon as this omission was identified. No changes were made to the eligibility criteria, allocation procedure, intervention protocol, or outcome

measures after the trial commenced, and both pre-specified primary outcomes (serve speed and spike speed) are reported in full, so no outcome switching occurred. The authors nonetheless acknowledge that prospective registration is the expected standard and record this as a limitation of the present trial.

### Participants

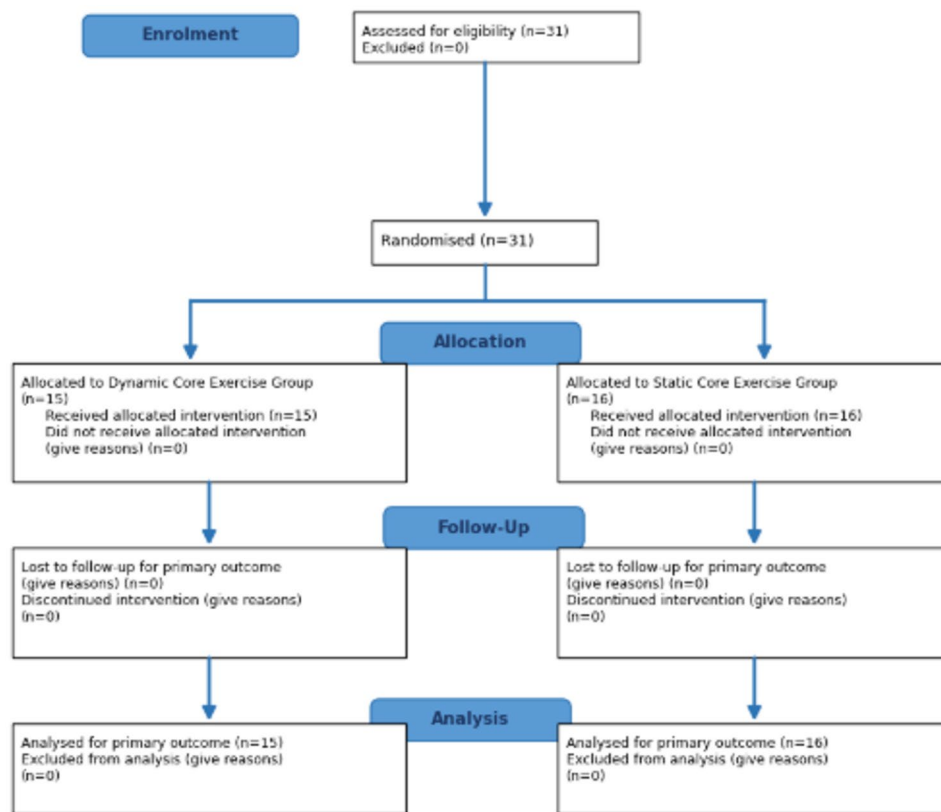
Thirty-one well-trained young male volleyball players (age range: 11–14 years) volunteered to participate. Random group allocation was performed by having each athlete draw a folded paper from a container; odd-numbered papers assigned participants to DCEG and even-numbered papers to SCEG. SCEG ( $n=16$ ) had mean height  $159.23 \pm 5.19$  cm and body weight  $51.80 \pm 8.18$  kg; DCEG ( $n=15$ ) had mean height  $166.26 \pm 6.72$  cm and body weight  $58.48 \pm 9.31$  kg. Descriptive characteristics are presented in Table 1. Participant flow through enrollment, allocation, follow-up, and analysis is presented in Fig. 1.

Inclusion criteria required a minimum of two years of continuous volleyball training at  $\geq 3$  sessions/week, each approximately 2 h. Athletes were excluded if they had sustained a shoulder, neck, or upper-limb injury in the preceding six months, or if they reported any cardiovascular or musculoskeletal condition precluding safe participation. All participants had joined organized volleyball training at 10.5 years of age and reported no history of injury prior to the study. Training age (years since joining organized volleyball) is reported alongside chronological age in Table 1. Independent-samples *t*-tests indicated that DCEG and SCEG did not differ significantly in age,  $t(29) = -1.09$ ,  $p = .284$ , or BMI,  $t(29) = 0.70$ ,  $p = .489$ , at baseline (Table 1). However, DCEG participants were significantly taller,  $t(29) = 3.27$ ,  $p = .003$ , and heavier,  $t(29) = 2.13$ ,  $p = .042$ , than SCEG. DCEG also demonstrated significantly higher pre-test serve speed,  $t(29) = 4.00$ ,  $p < .001$ , and pre-test spike speed,  $t(29) = 3.59$ ,  $p = .001$ , than SCEG. Given these baseline imbalances, ANCOVA with pre-test scores

**Table 1** Descriptive statistics of participants by group

| Variable                 | Group              | Min    | Max    | Mean   | SD    | t      | df | p      |
|--------------------------|--------------------|--------|--------|--------|-------|--------|----|--------|
| Age (years)              | Dynamic ( $n=15$ ) | 11.80  | 13.30  | 12.55  | 0.526 | -1.091 | 29 | 0.284  |
|                          | Static ( $n=16$ )  | 11.90  | 13.60  | 12.75  | 0.495 |        |    |        |
| Training Age (years)     | Dynamic ( $n=15$ ) | 1.30   | 2.80   | 2.05   | 0.526 | -1.091 | 29 | 0.284  |
|                          | Static ( $n=16$ )  | 1.40   | 3.10   | 2.25   | 0.495 |        |    |        |
| Height (cm)              | Dynamic ( $n=15$ ) | 154.20 | 176.30 | 166.26 | 6.725 | 3.273  | 29 | 0.003* |
|                          | Static ( $n=16$ )  | 143.50 | 167.80 | 159.23 | 5.191 |        |    |        |
| Weight (kg)              | Dynamic ( $n=15$ ) | 43.50  | 75.70  | 58.48  | 9.317 | 2.127  | 29 | 0.042* |
|                          | Static ( $n=16$ )  | 41.00  | 72.80  | 51.80  | 8.182 |        |    |        |
| BMI (kg/m <sup>2</sup> ) | Dynamic ( $n=15$ ) | 17.70  | 25.30  | 20.77  | 2.466 | 0.702  | 29 | 0.489  |
|                          | Static ( $n=16$ )  | 16.50  | 25.90  | 20.14  | 2.529 |        |    |        |

\* $p < .05$  (independent-samples *t*-test,  $df=29$ ). DCEG participants were significantly taller and heavier than SCEG at baseline; age and BMI did not differ significantly between groups. These anthropometric imbalances, together with baseline differences in pre-test serve and spike speed (see Participants section), support the use of ANCOVA with pre-test values as covariates for the primary between-group comparisons



**Fig. 1** CONSORT participant flow diagram. All volunteers who met eligibility criteria were randomized; no participants were lost to follow-up or excluded from the analysis during the six-week intervention. Received allocated intervention:  $n = 15$  (DCEG) and  $n = 16$  (SCEG). No participant discontinued the intervention or was lost to follow-up ( $n = 0$  in both groups), and all randomised participants were analysed for the primary outcomes

**Table 2** Static core exercise training program (SCEG)

| Static Exercises      | Weeks     | Sets | Duration | Rest |
|-----------------------|-----------|------|----------|------|
| Front Plank           | Weeks 1–2 | 3    | 30 s     | 60 s |
| Static Side Plank     | Weeks 3–4 | 3    | 45 s     | 60 s |
| Lower Abdominal Plank | Weeks 5–6 | 3    | 60 s     | 60 s |
| Posterior Plank       |           |      |          |      |

as covariates was selected as the primary between-group analysis to statistically account for these differences.

### Core training protocol

Both groups maintained their regular volleyball training schedule (3 sessions/week) and additionally performed four core exercises over six weeks, applied before each regular training session, at progressively increasing difficulty. Exercise techniques were taught by a qualified conditioning specialist during a familiarization session prior to the intervention [22]. Exercises were performed in three sets with a controlled, slow tempo. Inter-exercise rest was 30 s; inter-set rest was 60 s.

The SCEG performed: Front Plank, Static Side Plank, Lower Abdominal Plank, and Posterior Plank (time-based loading). The DCEG performed: Dynamic Side Plank, Spiderman Plank, Bicycle Plank, and Push-Up (repetition-based loading). Progressive overload was

implemented by increasing hold duration (SCEG) or repetitions (DCEG) every two weeks [22]. The progressive overload principle ensures continued neuromuscular adaptation and prevents training plateaus, consistent with established resistance training guidelines for youth athletes [19]. Training programs are detailed in Tables 2 and 3.

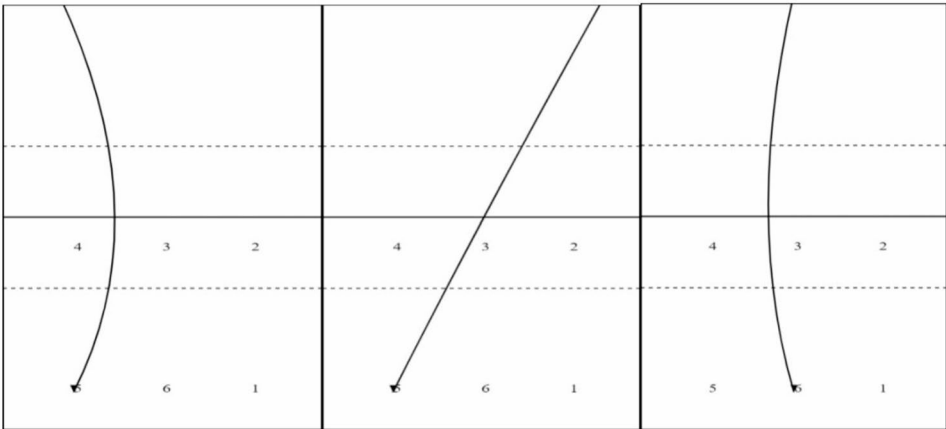
### Data collection

#### Anthropometric measurements

Body height was recorded using a SECA-213 stadiometer prior to the pre-test session. Body mass and body composition were assessed using an InBody 270 professional body composition analyzer. Body mass index (BMI) was calculated as mass (kg) divided by height squared ( $m^2$ ).

**Table 3** Dynamic core exercise training program (DCEG)

| Dynamic Exercises  | Weeks     | Sets | Repetitions | Rest |
|--------------------|-----------|------|-------------|------|
| Dynamic Side Plank | Weeks 1–2 | 3    | 8 R / 8 L   | 60 s |
| Spiderman Plank    | Weeks 3–4 | 3    | 10 R / 10 L | 60 s |
| Bicycle Plank      | Weeks 5–6 | 3    | 12          | 60 s |
| Push-Up            |           |      |             |      |



**Fig. 2** Schematic representation of the volleyball serve and spike speed assessment protocol. Serve speed was measured from position-specific serving zones, and spike speed was assessed from position-specific attack zones under standardized testing conditions (without net contact). Ball velocity was recorded using a Bushnell Velocity Gun radar device, and the highest value obtained from three trials was retained for statistical analysis

**Spike and serve speed measurement**

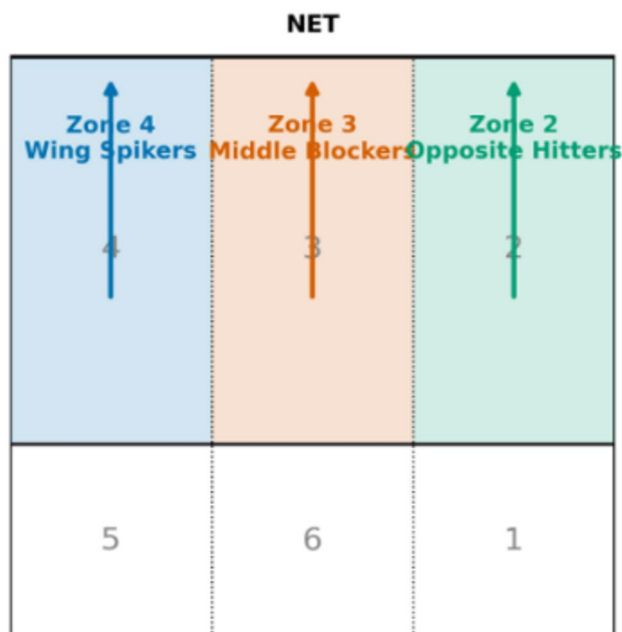
Ball speed was measured using a Bushnell Velocity Gun radar device (BUS-101911, Bushnell®, California, USA). The radar device was positioned directly behind the target area in accordance with the manufacturer’s recommendations to ensure accurate velocity measurements. Three trials were recorded per test; the maximum value was retained for analysis. Adequate rest was provided between trials. Measurements were conducted before training sessions, at the beginning (pre-test) and end (post-test) of the six-week period. The Bushnell radar gun has demonstrated excellent concurrent validity and inter-unit reliability when compared with a criterion radar system (Stalker ATS II). Previous investigations have reported very high intraclass correlation coefficients ( $ICC \geq 0.98$ ), strong correlations with the reference device, and low measurement error, supporting its suitability for assessing ball velocity in sport-specific performance tests [23]. To minimise inter-rater variability and ensure measurement consistency, all radar assessments were conducted by the same experienced investigator under standardized testing conditions throughout the study. This investigator operated the radar device and recorded all serve and spike velocities at both pre-test and post-test and was not blinded to group allocation, since the single-centre design and the investigator’s involvement in supervising the training sessions precluded blinded outcome assessment. Ball velocity was, however, captured instrumentally rather than by subjective rating, and identical device positioning, trial

numbers, rest intervals, and testing conditions were applied to both groups. Participants and coaching staff could likewise not be blinded to the assigned exercise modality, given the nature of the intervention.

For serve speed, participants served from their positional zones: setters and opposite hitters from zone 1 to zone 5, middle blockers from zone 5 to zone 5, and wing spikers from zone 6 to zone 6 (Fig. 2). For spike speed, with the condition that the ball must not contact the net, wing spikers attacked from zone 4, middle blockers from zone 3, and opposite hitters from zone 2 (Fig. 3). Liberos and setters were exempt from spike and serve speed measurements in accordance with official volleyball rules.

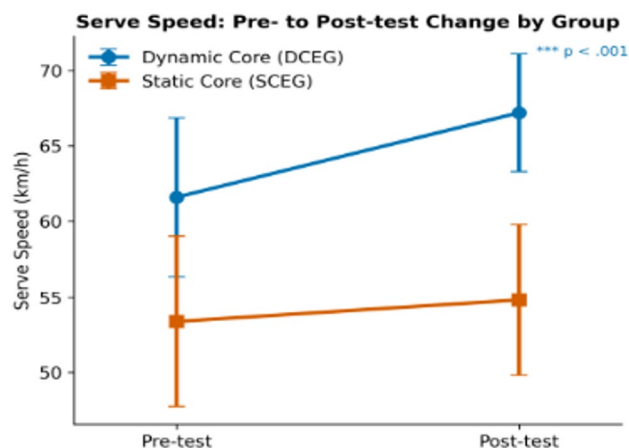
**Statistical analysis**

All statistical analyses were performed using SPSS software (version 24.0; IBM Corp., Armonk, NY, USA). The study was not powered a priori. A post-hoc power estimate was deliberately not computed, because observed (post-hoc) power derived from the study’s own effect size and p value is a monotonic transformation of that p value and therefore conveys no information beyond it. The precision of the estimates is instead expressed through effect sizes accompanied by 95% confidence intervals, and the implications of the small sample size (total  $N=31$ ) are addressed explicitly in the Limitations. Categorical variables were expressed as frequency (n) and percentage (%). Continuous variables were expressed as mean  $\pm$  standard deviation (SD).



**Fig. 3** Schematic representation of the attack (spike) zones. Wing spikers attacked from Zone 4, middle blockers from Zone 3, and opposite hitters from Zone 2, in accordance with standard volleyball court zone numbering

Distribution normality was examined via the Shapiro-Wilk test; skewness and kurtosis coefficients within  $\pm 3$  were interpreted as acceptable normality [24]. Shapiro-Wilk tests confirmed normality for all outcome variables in both groups (all  $p > .05$ ): pre-test spike speed (DCEG:  $W = 0.987$ ,  $p = .996$ ; SCEG:  $W = 0.966$ ,  $p = .763$ ), post-test spike speed (DCEG:  $W = 0.938$ ,  $p = .352$ ; SCEG:  $W = 0.921$ ,  $p = .177$ ), pre-test serve speed (DCEG:  $W = 0.933$ ,  $p = .305$ ; SCEG:  $W = 0.948$ ,  $p = .459$ ), and post-test serve speed (DCEG:  $W = 0.891$ ,  $p = .069$ ; SCEG:  $W = 0.892$ ,  $p = .060$ ). Homogeneity of variance was assessed using Levene's test. For the ANCOVA models, Levene's test confirmed homogeneity of error variances for both serve speed ( $F(1, 29) = 2.654$ ,  $p = .114$ ) and spike speed ( $F(1, 29) = 2.595$ ,  $p = .118$ ). Meeting normality assumptions, within-group pre-test to post-test comparisons were conducted using paired-samples  $t$ -tests. Between-group post-test differences were evaluated using ANCOVA with corresponding pre-test values as covariates. The assumption of homogeneity of regression slopes (covariate  $\times$  group interaction) was tested for each ANCOVA



**Fig. 4** Serve speed at pre-test and post-test for the Dynamic Core Exercise Group (DCEG) and Static Core Exercise Group (SCEG). Error bars represent  $\pm 1$  SD

model. Statistical significance was set at  $p < .05$ . Because statistically significant baseline differences were observed between the groups for both serve speed and spike speed, analysis of covariance (ANCOVA) was selected as the primary between-group analytical approach to adjust for these pre-existing differences. A  $2 \times 2$  mixed-design ANOVA was subsequently performed as a complementary sensitivity analysis to evaluate the robustness and consistency of the primary findings.

## Results

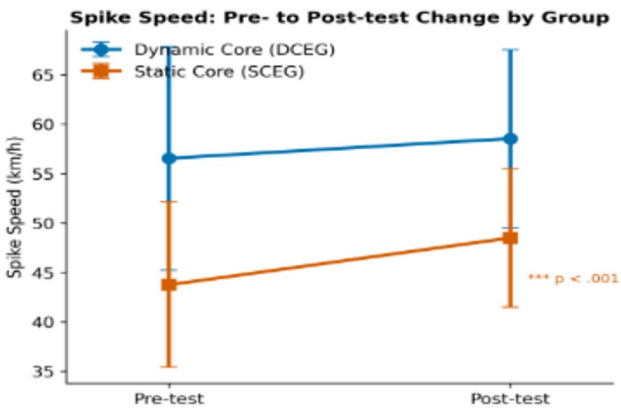
Within-group analyses are presented in Table 4. Serve and spike speeds at pre-test and post-test for both groups are illustrated in Figs. 4 and 5, respectively. SCEG demonstrated a statistically significant increase in spike speed between pre-test and post-test ( $43.75 \pm 8.35$  km/h vs.  $48.50 \pm 6.99$  km/h;  $t(15) = -5.115$ ,  $p < .001$ ), while no significant change was observed in serve speed for this group ( $t(15) = -0.815$ ,  $p = .428$ ). DCEG achieved a statistically significant improvement in serve speed ( $61.60 \pm 5.26$  km/h vs.  $67.20 \pm 3.91$  km/h;  $t(14) = -7.299$ ,  $p < .001$ ), while the change in spike speed was not statistically significant ( $t(14) = -1.468$ ,  $p = .164$ ). The corresponding pre-test to post-test changes in serve and spike speed, with 95% confidence intervals, are presented in Figs. 6 and 7, respectively.

Between-group ANCOVA results are presented in Table 5. ANCOVA revealed a statistically

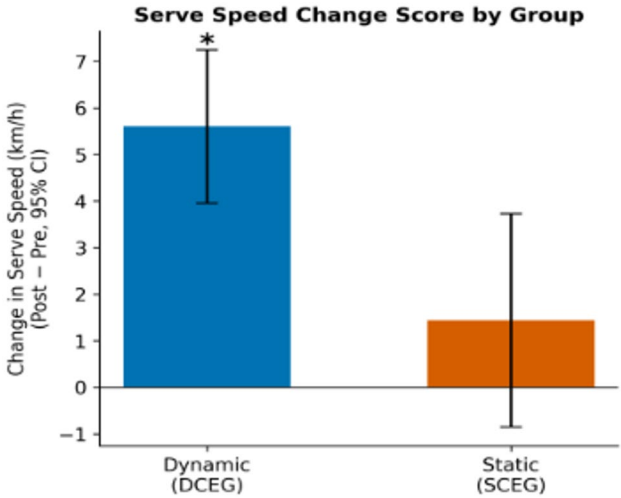
**Table 4** Within-group pre-test/post-test comparisons for spike speed and serve speed

| Variable           | Group   | Pre-test (Mean $\pm$ SD) | Post-test (Mean $\pm$ SD) | t      | df | p       | Cohen's dz | 95% CI (diff)  |
|--------------------|---------|--------------------------|---------------------------|--------|----|---------|------------|----------------|
| Spike Speed (km/h) | Dynamic | 56.53 $\pm$ 11.33        | 58.53 $\pm$ 8.99          | -1.468 | 14 | 0.164   | -0.38      | [-4.92, 0.92]  |
|                    | Static  | 43.75 $\pm$ 8.35         | 48.50 $\pm$ 6.99          | -5.115 | 15 | <0.001* | -1.28      | [-6.73, -2.77] |
| Serve Speed (km/h) | Dynamic | 61.60 $\pm$ 5.26         | 67.20 $\pm$ 3.91          | -7.299 | 14 | <0.001* | -1.89      | [-7.25, -3.95] |
|                    | Static  | 54.00 $\pm$ 5.32         | 54.81 $\pm$ 4.98          | -0.815 | 15 | 0.428   | -0.20      | [-1.31, 2.94]  |

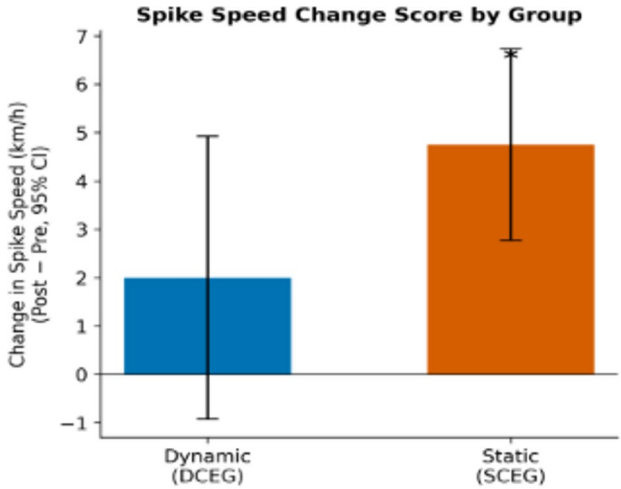
\* $p < .05$ . Cohen's dz =  $t/\sqrt{n}$ . CI = 95% confidence interval for the mean pre-test to post-test difference



**Fig. 5** Spike speed at pre-test and post-test for DCEG and SCEG. Error bars represent  $\pm 1$  SD



**Fig. 6** Change in serve speed (post-test minus pre-test) by group, with 95% confidence intervals derived from the paired-samples t-test. \*  $p < .05$



**Fig. 7** Change in spike speed (post-test minus pre-test) by group, with 95% confidence intervals derived from the paired-samples t-test. \*  $p < .05$

**Table 5** Between-group ANCOVA results for post-test spike and serve speed (pre-test as covariate)

| Variable           | Static (Mean $\pm$ SD) | Dynamic (Mean $\pm$ SD) | Static Adj. Mean (SE) | Dynamic Adj. Mean (SE) | F      | df    | p        | Partial $\eta^2$ |
|--------------------|------------------------|-------------------------|-----------------------|------------------------|--------|-------|----------|------------------|
| Spike Speed (km/h) | 48.50 $\pm$ 6.99       | 58.53 $\pm$ 8.99        | 52.97 (1.01)          | 53.76 (1.05)           | 0.250  | 1, 28 | 0.621    | 0.009            |
| Serve Speed (km/h) | 54.81 $\pm$ 4.98       | 67.20 $\pm$ 3.91        | 57.16 (0.85)          | 64.70 (0.88)           | 31.001 | 1, 28 | < 0.001* | 0.525            |

\* $p < .05$ . Levene's test confirmed homogeneity of error variances for serve speed ( $F(1, 29) = 2.654, p = .114$ ) and spike speed ( $F(1, 29) = 2.595, p = .118$ ). The homogeneity of regression slopes assumption was met for both models (covariate  $\times$  group interaction: spike speed,  $F(1, 27) = 0.095, p = .760$ ; serve speed,  $F(1, 27) = 0.036, p = .851$ ), supporting the validity of the ANCOVA approach

**Table 6** Results of the 2x2 mixed-design ANOVA (Group × Time) for spike and serve speed

| Outcome     | Effect       | F      | df    | p       | Partial $\eta^2$ |
|-------------|--------------|--------|-------|---------|------------------|
| Spike Speed | Group        | 13.258 | 1, 29 | 0.001   | 0.314            |
|             | Time         | 17.607 | 1, 29 | < 0.001 | 0.378            |
|             | Group × Time | 2.844  | 1, 29 | 0.102   | 0.089            |
| Serve Speed | Group        | 36.838 | 1, 29 | < 0.001 | 0.560            |
|             | Time         | 24.312 | 1, 29 | < 0.001 | 0.456            |
|             | Group × Time | 14.214 | 1, 29 | 0.001   | 0.329            |

significant difference in serve speed ( $F(1, 28)=31.001$ ,  $p < .001$ , partial  $\eta^2 = 0.525$ ) favouring DCEG (post-test:  $67.20 \pm 3.91$  km/h) over SCEG (post-test:  $54.81 \pm 4.98$  km/h). No significant between-group difference was observed for spike speed ( $F(1, 28)=0.250$ ,  $p = .621$ , partial  $\eta^2 = 0.009$ ).

To assess the robustness of the ANCOVA findings, a  $2 \times 2$  mixed-design ANOVA (Group × Time) was conducted for spike and serve speed as a complementary analysis (Table 6). For spike speed, the main effects of Group,  $F(1, 29)=13.258$ ,  $p = .001$ , partial  $\eta^2 = 0.314$ , and Time,  $F(1, 29)=17.607$ ,  $p < .001$ , partial  $\eta^2 = 0.378$ , were significant, but the Group × Time interaction was not,  $F(1, 29)=2.844$ ,  $p = .102$ , partial  $\eta^2 = 0.089$  — consistent with the non-significant ANCOVA result for spike speed reported above. For serve speed, the main effects of Group,  $F(1, 29)=36.838$ ,  $p < .001$ , partial  $\eta^2 = 0.560$ , and Time,  $F(1, 29)=24.312$ ,  $p < .001$ , partial  $\eta^2 = 0.456$ , were significant, and the Group × Time interaction was also significant,  $F(1, 29)=14.214$ ,  $p = .001$ , partial  $\eta^2 = 0.329$  — consistent with the significant ANCOVA result favoring DCEG. The convergence of the ANCOVA and mixed ANOVA approaches across both outcomes supports the robustness of the between-group effects reported in this study.

A possible interpretation of the dissociation between outcomes in Table 6 is outlined below. Because the underlying mechanisms were not directly tested in the present study, this explanation should be regarded as a post hoc hypothesis requiring empirical confirmation rather than as an established mechanism. Serve speed is a closed, self-paced skill in which force generation depends primarily on trunk rotation and shoulder–arm sequencing initiated from a stable base — a mechanical pattern that may be more closely approximated by the dynamic core exercises applied here (e.g., rotational and anti-rotational loading). This correspondence could plausibly contribute to the significant Group × Time interaction favouring DCEG, although no kinematic or electromyographic data were collected to verify it. Spike speed, by contrast, is an open skill constrained by approach timing, set quality and jump mechanics; the additional degrees of freedom involved may have diluted between-group differentiation in training response, which would be consistent with the non-significant interaction despite both

groups improving over time. This pattern therefore suggests — but does not demonstrate — that the two core-training modalities may differ less in overall effectiveness than in the specific motor skill to which each best transfers. Direct testing of this hypothesis with biomechanical and neuromuscular measures is required before it can be accepted.

## Discussion

This study examined the effects of six-week static and dynamic core exercise programs supplementary to regular volleyball training on serve and spike speed in elite young male volleyball players. The main findings were: (1) SCEG achieved a significant within-group improvement in spike speed; (2) DCEG achieved a significant within-group improvement in serve speed; and (3) between-group analysis confirmed a significant advantage for DCEG in serve speed, while spike speed did not differ significantly between groups.

Beyond statistical significance, the magnitude of these changes carries direct practical relevance for training prescription. DCEG's improvement in serve speed corresponded to a very large within-group effect ( $dz = -1.89$ ), and SCEG's improvement in spike speed likewise reflected a large effect ( $dz = -1.28$ ), indicating that both changes are unlikely to be artifacts of measurement noise and are large enough to be meaningful in a competitive context, where serve and spike velocity differences of even a few km/h can affect an opponent's reaction time. By contrast, the non-significant changes — DCEG's spike speed ( $dz = -0.38$ ) and SCEG's serve speed ( $dz = -0.20$ ) — corresponded to small effects, suggesting these outcomes were not merely underpowered but genuinely modest in magnitude. This pattern reinforces the interpretation that each training modality produced a targeted rather than a generalized improvement: statistical significance and effect size converged on the same conclusion for all four within-group comparisons, strengthening confidence that the modality-specific pattern of adaptation reflects a genuine training effect rather than a statistical artifact.

The significant improvement in serve speed observed in DCEG is consistent with the biomechanical requirements of the volleyball serve. Serve execution—particularly the jump serve—requires coordinated hip extension, trunk rotation, and shoulder acceleration, movement

patterns that closely mirror those targeted by dynamic core exercises [7, 13]. Dynamic exercises such as the spiderman plank and dynamic side plank challenge the core in conditions of controlled movement, developing rotational power generation and stabilization under dynamic load [13]. The capacity to generate and transfer rotational force is a fundamental determinant of serve velocity [3, 7]. Zhang et al. [25] reported in a systematic review that core training produces beneficial effects on athletic skill performance and ball velocity across multiple sports, directly supporting the present result. Machado et al. [18] further demonstrated significant increases in throwing velocity following core training in handball, corroborating the transferability of dynamic trunk power to overhead velocity tasks. From a practical perspective, the observed improvement of approximately 5–6 km·h<sup>-1</sup> in serve velocity may represent a meaningful competitive advantage by reducing the opponent's available reaction time and increasing the effectiveness of offensive play during match situations.

The significant gain in spike speed within SCEG is mechanistically explained by the role of static exercises in enhancing lumbopelvic stability, postural control, and force-transmission efficiency. Spiking involves a three-step approach run, a maximum-effort vertical jump, and mid-air stabilization followed by high-velocity upper-limb contact [6]. Static exercises such as the front plank and side plank develop the isometric endurance and stiffness of the trunk musculature, providing the stable platform from which distal power is effectively transferred [11, 16]. This is consistent with McGill [14]'s evidence-based framework, which posits that trunk stiffness—developed through isometric training—is a prerequisite for safe and efficient power transmission to the extremities. Yıldırım et al. [26] previously reported significant improvements in spike speed following a six-week core stabilization program in adolescent volleyball players, and Tse et al. [20] demonstrated that core endurance training improved performance in athletic tasks requiring stable force transmission, both consistent with the present findings.

The absence of a significant between-group difference in spike speed may be partially explained by the multifactorial nature of spiking. Unlike the serve—a closed skill executed under controlled conditions—spiking is an open skill dependent on set quality, approach timing, jump mechanics, and positional variability [27]. Attributing spike speed changes exclusively to a single training variable is therefore methodologically challenging. The high baseline technical proficiency of elite youth athletes may additionally have constrained the ceiling for measurable core-specific improvements in spike velocity within this brief intervention period. In addition, serve and spike velocities were recorded from position-specific

court zones, and setters, middle blockers, wing spikers and opposite hitters differ systematically in approach run, contact height, and typical serving and attacking trajectories. Because playing position was neither used as a stratification variable at randomisation nor entered as a covariate, position-specific technical differences may have contributed to the variability in measured velocities — particularly for spike speed — and should be borne in mind when interpreting the between-group comparison.

The six-week intervention, while sufficient to elicit neuromuscular adaptations, may limit observation of maximal structural changes. Research indicates that longer interventions (8–12 weeks) tend to produce more pronounced adaptations in muscle strength and power output [20]. Çakır and Ergin [28] reported that an eight-week core training program produced significant improvements in agility, explosive strength, and balance in young female volleyball players, supporting the premise that extended duration may yield broader benefits. Ozmen and Aydogmus [29] similarly found that twelve weeks of core strength training improved dynamic balance and agility in adolescent badminton players, further emphasizing the dose–response relationship between intervention length and adaptations.

Several limitations should be acknowledged when interpreting these findings. First, the trial did not include a true (no-treatment) control group that continued regular volleyball training without any supplementary core protocol. Consequently, the improvements observed in both groups cannot be unambiguously attributed to core training per se, since they may also reflect continued sport-specific practice, familiarisation with the velocity-testing protocol, or normal motor development over the six-week period. The design supports a comparison between two active core-training modalities, and the findings should be interpreted in that light rather than as evidence of an absolute training effect. Second, playing position, dominant arm characteristics, and external training loads were not controlled for. In addition, biological maturation status (e.g., maturity offset or Tanner stage) was not assessed. Given the age range of the participants (11–14 years), individual differences in biological maturation may have influenced neuromuscular development and training responsiveness, thereby contributing to the variability observed in performance outcomes. Neither maturity-offset estimates (e.g., derived from the Mirwald equation) nor Tanner staging were collected, so maturation could not be entered as a covariate or used as a stratification variable. This is particularly relevant because the two groups already differed significantly in height and weight at baseline — differences that may themselves partly reflect divergent maturational status — and differential maturation trajectories during the six-week intervention therefore remain a plausible

uncontrolled confounder. A further limitation is that outcome assessment was not blinded: the investigator who operated the radar device was aware of group allocation. Although ball velocity was recorded instrumentally, which restricts the scope for subjective bias, the absence of blinded assessment remains a methodological limitation. Measurement was also confined to ball velocity, excluding other relevant outcomes such as serve accuracy, spike success rate, jump height, balance, and EMG-based muscle activation [25]. The study was, moreover, not powered a priori, and the achieved sample size was small (total  $N=31$ ), which limits the precision of the estimates and the sensitivity to detect small-to-moderate between-group differences; for the reasons set out in the Statistical Analysis section, a post-hoc power estimate was not computed. Interpretation should therefore rest on the effect sizes and 95% confidence intervals reported in Table 4 rather than on binary significance testing alone. Groups also differed significantly at pre-test in serve speed, spike speed, height, and weight; ANCOVA with pre-test values as covariates was therefore used to statistically account for this baseline imbalance, and the reported between-group effects should be interpreted with this in mind. Finally, the trial was registered retrospectively, as detailed and justified in the Methods.

Notwithstanding these limitations, this study provides novel comparative data on the differential effects of static and dynamic core training on serve and spike speed in well-trained young male volleyball players. The findings align with the broader literature supporting the specificity principle in core training: the exercise modality that most closely replicates the neuromuscular demands of the target skill produces the greatest performance transfer [11, 13].

Future randomized controlled trials incorporating electromyographic assessments, three-dimensional biomechanical analyses, and biological maturation indicators are warranted to further elucidate the neuromuscular mechanisms underlying the differential effects of static and dynamic core training on volleyball-specific performance. Such trials should additionally include a non-training control group, be powered a priori to detect between-group differences of practical relevance, and be prospectively registered.

## Conclusions

A six-week supplementary core training intervention improved volleyball-specific ball velocity performance in elite young male volleyball players, with dynamic core exercises producing greater improvements in serve speed and static core exercises eliciting greater gains in spike speed. Between-group ANCOVA confirmed a significant advantage for dynamic core training in serve performance. These findings should nonetheless be regarded as

preliminary and hypothesis-generating. In the absence of a no-treatment control group they describe the relative performance of two active core-training modalities rather than an absolute effect of core training, and the small sample ( $N=31$ ), the limited precision of the resulting estimates, and the significant baseline imbalance between groups all constrain the strength of the inferences that can be drawn. Accordingly, the results are best used to inform the design of adequately powered, prospectively registered trials. Coaches may consider — rather than be advised to adopt — a modality-specific emphasis in which dynamic core exercises are prioritised when serve velocity is the primary objective and static core exercises when spike velocity is targeted, pending confirmation in larger controlled trials that incorporate a control group and biological maturation indicators.

## Abbreviations

|      |                             |
|------|-----------------------------|
| BMI  | Body Mass Index             |
| DCEG | Dynamic Core Exercise Group |
| EMG  | Electromyography            |
| SCEG | Static Core Exercise Group  |

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13102-026-02013-z>.

Supplementary Material 1.

## Acknowledgements

No.

## Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript. [Note to authors — delete before submission: please confirm that this statement accurately covers every stage of preparation AND revision. If any generative AI tool was used at any stage (including language editing of this revision), replace the sentence above with a disclosure such as: “Generative AI (tool, version) was used solely for language editing; the authors reviewed all output and take full responsibility for the content of the manuscript.”]

## Authors' contributions

BG: Writing – original draft, Writing – review and editing, Investigation, Visualization, Methodology, Formal Analysis. GA: Writing – original draft, Writing – review and editing, Investigation, Methodology, Supervision, Formal Analysis.

## Funding

The author(s) declare that they have received no financial support for the research and/or publication of this article.

## Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## Declarations

### Ethics approval and consent to participate

This study was approved by the Istanbul Gelisim University Scientific Research Ethics Committee (18 March 2026; Approval No. 2026-04-40). Written informed consent was obtained from parents/guardians of all participants, and written assent was obtained from each participant prior to data collection.

The authors confirm that all methods and experiments involving human participants were performed in accordance with the relevant guidelines and regulations, including the principles of the Declaration of Helsinki (as revised in 2013) and its subsequent amendments.

Prior to participation, all participants were informed about the purpose, procedures, potential risks, and benefits of the study. Written informed consent was obtained from all participants. For participants under the age of 18 years, written informed consent was additionally obtained from their parents or legal guardians. Participation was voluntary, and participants were free to withdraw from the study at any time without any consequences.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare no competing interests.

#### Author details

<sup>1</sup>Faculty of Sport Sciences, İstanbul Gelişim University, İstanbul, Türkiye

Received: 26 June 2026 / Accepted: 18 August 2026

Published online: 25 August 2026

#### References

- Sheppard JM, Gabbett TJ, Stanganelli LCR. An analysis of playing positions in elite men's volleyball: considerations for competition demands and physiologic characteristics. *J Strength Cond Res*. 2009;23(6):1858–66. <https://doi.org/10.1519/JSC.0b013e3181b45c6a>.
- Palao JM, Santos JA, Ureña A. Effect of team level on skill performance in volleyball. *Int J Perform Anal Sport*. 2004;4(2):50–60. <https://doi.org/10.1080/24748668.2004.11868304>.
- Forthomme B, Croisier JL, Ciccarone G, Crielaard JM, Cloes M. Factors correlated with volleyball spike velocity. *Am J Sports Med*. 2005;33(10):1513–9. <https://doi.org/10.1177/0363546505274935>.
- Marques MC, van den Tillaar R, Vescovi JD, González-Badillo JJ. Changes in strength and power performance in elite senior female professional volleyball players during the in-season: a case study. *J Strength Cond Res*. 2011;25(11):3133–9. <https://doi.org/10.1519/JSC.0b013e318212e7a3>.
- Ziv G, Lidor R. Vertical jump in female and male volleyball players: a review of observational and experimental studies. *Scand J Med Sci Sports*. 2010;20(4):556–67. <https://doi.org/10.1111/j.1600-0838.2009.01083.x>.
- Coleman SG, Benham AS, Northcott SR. A three-dimensional cinematographic analysis of the volleyball spike. *J Sports Sci*. 1993;11(4):295–302. <https://doi.org/10.1080/02640419308729999>.
- Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med*. 2006;36(3):189–98. <https://doi.org/10.2165/00007256-200636030-00001>.
- Prieske O, Muehlbauer T, Borde R, Gube M, Bruhn S, Granacher U. Neuromuscular and athletic performance following core strength training in elite youth soccer: role of instability. *Scand J Med Sci Sports*. 2016;26(1):48–56. <https://doi.org/10.1111/sms.12407>.
- Akuthota V, Ferreiro A, Moore T, Fredericson M. Core stability exercise principles. *Curr Sports Med Rep*. 2008;7(1):39–44. <https://doi.org/10.1097/01.CSMR.0000308663.13278.69>.
- Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med*. 2007;35(7):1123–30. <https://doi.org/10.1177/0363546507301585>.
- Behm DG, Drinkwater EJ, Willardson JM, Cowley PM. The use of instability to train the core musculature. *Appl Physiol Nutr Metab*. 2010;35(1):91–108. <https://doi.org/10.1139/H09-127>.
- Stanton R, Reaburn PR, Humphries B. The effect of short-term Swiss ball training on core stability and running economy. *J Strength Cond Res*. 2004;18(3):522–8. <https://doi.org/10.1519/1533-4287>.
- Willardson JM. Core stability training: applications to sports conditioning programs. *J Strength Cond Res*. 2007;21(3):979–85. <https://doi.org/10.1519/R-20255.1>.
- McGill SM. Core training: evidence translating to better performance and injury prevention. *Strength Cond J*. 2010;32(3):33–46. <https://doi.org/10.1519/SSC.0b013e3181df4521>.
- Reed CA, Ford KR, Myer GD, Hewett TE. The effects of isolated and integrated core stability training on athletic performance measures: a systematic review. *Sports Med*. 2012;42(8):697–706. <https://doi.org/10.2165/11633450-00000000-000000>.
- Hibbs AE, Thompson KG, French D, Wrigley A, Spears I. Optimizing performance by improving core stability and core strength. *Sports Med*. 2008;38(12):995–1008. <https://doi.org/10.2165/00007256-200838120-00004>.
- Weston M, Hibbs AE, Thompson KG, Spears IR. Isolated core training improves sprint performance in national-level junior swimmers. *Int J Sports Physiol Perform*. 2015;10(2):204–10. <https://doi.org/10.1123/ijspp.2013-0488>.
- Manchado C, García-Ruiz J, Cortell-Tormo JM, Tortosa-Martínez J. Effect of core training on male handball players' throwing velocity. *J Hum Kinet*. 2017;56(1):177–85. <https://doi.org/10.1515/hukin-2017-0035>.
- Faigenbaum AD, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, et al. Youth resistance training: updated position statement paper from the National Strength and Conditioning Association. *J Strength Cond Res*. 2009;23(Suppl 5):S60–79. <https://doi.org/10.1519/JSC.0b013e31819df407>.
- Tse MA, McManus AM, Masters RS. Development and validation of a core endurance intervention program: implications for performance in college-age rowers. *J Strength Cond Res*. 2005;19(3):547–52. <https://doi.org/10.1519/15492.1>.
- World Medical Association. WMA Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013;310(20):2191–4. <https://doi.org/10.1001/jama.2013.281053>.
- Gür F, Kor, Özen G, Koç H, editors. Sporun Kavramsal Temelleri-4: Antrenman. İstanbul: Efe Akademi Yayınları; 2020. pp. 293–308.
- Hernández-Belmonte A, Sánchez-Pay A. Concurrent validity, inter-unit reliability and biological variability of a low-cost pocket radar for ball velocity measurement in soccer and tennis. *J Sports Sci*. 2021;39(12):1312–9. <https://doi.org/10.1080/02640414.2020.1868090>.
- Shapiro SS, Wilk MB. An analysis of variance test for normality (complete samples). *Biometrika*. 1965;52(3–4):591–611. <https://doi.org/10.1093/biomet/52.3-4.591>.
- Zhang S, Li X, Yu H, Chen Y. Effect of core training on skill performance among athletes: a systematic review. *Front Physiol*. 2022;13:915259. <https://doi.org/10.3389/fphys.2022.915259>.
- Yıldırım K, Beycan U, Beyzadeoğlu T. Adölesan voleybol oyuncularında core stabilizasyon egzersizlerinin smaç hızına etkisi [Effect of core stabilization exercises on spike speed in adolescent volleyball players]. *İstanbul Gelişim Üniversitesi Sağlık. Bilimleri Dergisi*. 2021;15:496–505.
- Sattler T, Sekulic D, Hadzic V, Uljevic O, Dervisevic E. Vertical jumping tests in volleyball: reliability, validity, and playing-position specifics. *J Strength Cond Res*. 2012;26(6):1532–8. <https://doi.org/10.1519/JSC.0b013e318234e838>.
- Çakır M, Ergin E. The effect of core training on agility, explosive strength and balance in young female volleyball players. *J Sport Sci Res*. 2022;7(2):437–49.
- Ozmen T, Aydogmus M. Effect of core strength training on dynamic balance and agility in adolescent badminton players. *J Bodyw Mov Ther*. 2016;20(3):565–70. <https://doi.org/10.1016/j.jbmt.2015.12.006>.

#### Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.