**Official Title:**

# The Effect of Combined Core and Shoulder Strengthening on Tennis Serve Speed, Serve Accuracy, and Total Glenohumeral Arc of Rotation in Healthy Tennis Players: A Randomized Controlled Trial

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# Clinical Trial Protocol

**The Effect of Combined Core and Shoulder Strengthening on Tennis Serve Speed, Serve Accuracy, Total Glenohumeral Arc of Rotation, and Shoulder/Core Strength in Healthy Tennis Players: A, Randomized Controlled Trial**

## Hypotheses

**Primary hypothesis**

Compared with shoulder-only training and with continued tennis training alone, the addition of core strengthening to shoulder training will produce significantly greater improvements in flat serve ball speed in healthy non-professional tennis players.

**Secondary hypotheses**

- Combined core + shoulder training will produce greater improvement in serve accuracy than shoulder-only training or tennis training alone.
- Combined core + shoulder training will produce greater improvement in TGAR than shoulder-only training or tennis training alone.
- Combined core + shoulder training will produce greater improvement in core strength/endurance and shoulder rotational strength than the comparator groups.

## 4. Study Design

- Design: Double-blind (assessor- and data-analyst-blinded), three-arm, parallel-group, randomized controlled trial.
- Level of evidence: Level 1 (RCT).
- Duration of intervention: 12 weeks.
- Setting: [insert institution / tennis academy / university sports science lab].
- Timeline: Baseline assessment (Week 0) → Intervention (Weeks 12)

4.1 Study Arms

| Arm | Label | Content |
|---|---|---|
| Arm 1 | Shoulder + Core (Experimental, EG) | Shoulder strengthening + core strengthening + continued regular tennis training |
| Arm 2 | Shoulder +sham core (Active Comparator, CG1) | Shoulder strengthening + sham/placebo core exercises (non-loading trunk mobility) + continued regular tennis training |

*Rationale for the three-arm design: Arm 3 isolates the effect of ongoing tennis practice and skill development from the two structured exercise interventions, directly addressing the confound identified*

*in the pilot study — namely, whether improvements are attributable to the intervention itself or simply to continued play.*

# 5. Study Population

## 5.1 Inclusion Criteria

- Healthy adults aged 18–35 years
- Recreational to competitive non-professional tennis players (currently playing ≥2 sessions/week for ≥1 year; NTRP 3.0–5.0 or equivalent ITN; no professional ranking or tour-level competition history)
- Right- or left-hand dominant (serve arm recorded)
- Able to perform a full flat serve without pain
- Willing to maintain current tennis training routine and refrain from starting other new strength/conditioning programs during the study

## 5.2 Exclusion Criteria

- Current or history of shoulder pain/injury in the past 6 months (e.g., rotator cuff pathology, labral injury, impingement)
- Low back pain or lumbar spine pathology in the past 6 months
- Prior shoulder or spine surgery
- Systemic conditions affecting neuromuscular function (e.g., uncontrolled diabetes, neurological disorders)
- Pregnancy
- Current participation in a structured core or shoulder strengthening program
- Professional/tour-level competitive status

## 5.3 Sample Size and Power Calculation

Based on an anticipated small-to-moderate effect size (d = 0.35) for the primary outcome (serve ball speed) between EG and comparator arms, with $\alpha = 0.05$ (two-tailed) and power = 0.80, using G*Power (ANCOVA: fixed effects, 3 groups):

- Estimated required sample size: n = 63 per group (189 total)
- Adjusting for an anticipated 15% attrition over 12 weeks: n = 73 per group (146 total)

*Note: these values are illustrative. Exact numbers should be finalized with a biostatistician using pilot-study variance estimates once available.*

## 5.4 Recruitment

Participants recruited via university/club tennis programs, local tennis federations, and social media advertisement. Screening via phone/questionnaire followed by in-person eligibility confirmation and physical screening (Physical Activity Readiness Questionnaire, shoulder/back pain screen).

# 6. Randomization and Blinding

### 6.1 Randomization

- Computer-generated block randomization (block sizes of 6 and 9, randomly varied) stratified by sex and baseline NTRP/ITN level.
- Allocation sequence generated by an independent statistician not involved in recruitment or assessment.
- Concealed allocation via sequentially numbered, opaque, sealed envelopes (SNOSE) or a web-based randomization system (e.g., REDCap randomization module).

### 6.2 Blinding

- Participants: Not blinded to whether they are performing core exercises (true double-blinding of participants is not feasible in exercise trials of this nature), but blinded to the specific study hypothesis.
- Outcome assessors: Blinded to group allocation during all pre- and post-testing.
- Data analysts/statisticians: Blinded to group allocation (coded as A/B/C) until primary analysis is complete.
- Blinding integrity check: Post-study questionnaire asking assessors to guess group allocation, analyzed for above-chance accuracy.

## 7. Interventions

All participants continue their regular tennis training (frequency and hours logged weekly via training diary — see Section 9.5).

### 7.1 Shoulder Strengthening Program (Arms 1 and 2)

Delivered 2×/week for 10 weeks under supervision of a licensed physical therapist or certified strength and conditioning specialist. Progressive resistance program including:

- External/internal rotation strengthening (resistance band, cable, or dumbbell) at 0° and 90° abduction
- Scapular stabilization exercises (rows, Y-T-W raises, serratus punch)
- Posterior shoulder stretching (sleeper stretch, cross-body stretch) for the TGAR component
- Progressive overload every 2 weeks based on tolerated resistance/repetitions

### 7.2 Core Strengthening Program (Arm 1 only)

Delivered 2×/week for 10 weeks, same sessions as the shoulder program (combined ~50–60 minute sessions), progressive core program including:

- Anti-rotation exercises (Pallof press)
- Rotational power exercises (medicine ball rotational throws, cable woodchoppers)
- Anterior/lateral/posterior chain stability (plank variations, side plank, bird-dog)
- Progressive overload via increased resistance, hold time, or instability surface every 2 weeks

### 7.3 Sham Core Exercises (Arm 2 only)

Low-intensity, non-progressive trunk mobility exercises with minimal loading (e.g., seated trunk rotations without resistance, cat-camel stretches), matched for session time and attention to control for non-specific training effects, without targeting core strength/endurance adaptation.

### 7.4 Adherence Monitoring

Attendance logged at every session; adherence defined a priori as ≥80% session completion (16/20 sessions) for inclusion in per-protocol analysis. Intention-to-treat (ITT) analysis will be the primary analysis; per-protocol analysis conducted as a sensitivity analysis.

## 8. Outcome Measures

### 8.1 Primary Outcome

Flat serve ball speed (km/h or mph), measured via radar gun (e.g., Stalker Pro II) or equivalent validated device, averaged across the best 5 of 10 flat serves hit into the deuce-side service box, measured at baseline (Week 0) and post-intervention (Week 11).

### 8.2 Secondary Outcomes

**Serve accuracy**

- Target-based scoring system: standardized service box divided into scoring zones (e.g., 5 concentric/quadrant zones worth 1–5 points); participant hits 10 flat serves aimed at a designated target zone (e.g., wide serve to deuce court corner); accuracy score = mean points across 10 serves.
- Recorded simultaneously with ball speed trials (speed–accuracy trade-off examined as an exploratory outcome).

**Total glenohumeral arc of rotation (TGAR)**

- Passive internal rotation (IR) + external rotation (ER) range of motion measured via goniometry (or inclinometer) with scapula stabilized, participant supine, shoulder abducted to 90°, elbow flexed to 90°. TGAR = IR + ER (degrees). Measured bilaterally.

**Shoulder rotational strength**

- Peak IR and ER isometric or isokinetic torque (Nm), measured via hand-held dynamometer (standardized stabilization protocol) or isokinetic dynamometer (60°/sec and 180°/sec) if available, at 0° abduction. ER/IR strength ratio calculated. Measured bilaterally.

**Core strength/endurance**

- McGill core endurance battery: trunk flexor endurance test (seconds), bilateral side-bridge/plank endurance test (seconds), Biering-Sørensen back extensor endurance test (seconds).

### 9.1 Primary Analysis

ANCOVA on post-intervention serve ball speed, with baseline serve speed and weekly concurrent tennis training hours as covariates, and group (EG/CG1/CG2) as the fixed factor. Planned pairwise contrasts (Bonferroni-corrected): EG vs. CG1, EG vs. CG2, CG1 vs. CG2.

### 9.2 Secondary Analyses

Same ANCOVA model applied to serve accuracy, TGAR, shoulder strength, and core endurance/power outcomes. Mediation analysis (e.g., PROCESS macro or structural equation modeling) will test whether change in shoulder/core strength mediates the relationship between group assignment and change in serve ball speed.

### 9.3 Missing Data

Multiple imputation (if missingness >5% and appears missing-at-random) or last-observation-carried-forward as a sensitivity analysis; intention-to-treat as the primary approach.

### 9.4 Significance Level

$\alpha = 0.05$ (two-tailed) for the primary outcome; Bonferroni or Holm correction applied for secondary/multiple comparisons.

### 9.5 Effect Size Reporting

Partial eta-squared (ANCOVA) and Cohen's d (pairwise contrasts) reported with 95% confidence intervals for all outcomes.

### 9.6 Pre-Registration of Analysis Plan

Full statistical analysis plan (SAP) to be pre-registered on ClinicalTrials.gov/OSF prior to unblinding, specifying primary/secondary outcomes, covariates, and analysis models in advance to prevent post hoc analytic flexibility.

## 10. Data Management

- Data collected on standardized case report forms (CRFs), entered into a secure electronic database (e.g., REDCap) with restricted access.
- Participant identifiers replaced with coded study IDs; master key held only by the Principal Investigator.
- Data retained per institutional/ethics committee requirements (typically 5–10 years post-publication).

## 11. Safety and Adverse Events

- All exercise sessions supervised by a licensed clinician/certified trainer.
- Adverse events (e.g., muscle soreness beyond expected DOMS, injury during testing or training) recorded on an AE log, graded by severity, and reported to the ethics committee per institutional policy.
- Participants may withdraw at any time without penalty; those reporting shoulder or back pain during the intervention will be assessed by the study clinician and may be withdrawn from the exercise protocol (data retained for ITT analysis where possible).