A Protocol for Evaluating the Role of Spinal Manipulation During Neuromuscular Development in Adolescent Athletes （English version）

1.Participants

The participants in this study will be male adolescent athletes from the sports specialty teams at Shandong Heze Martial Arts School. A total of 70 to 80 eligible male students will be recruited. Inclusion criteria require that all participants:

- have had no significant musculoskeletal injuries or major internal/external medical conditions within the past three months,
- have at least two years of systematic training in a specific sport discipline, and
- maintain a stable training frequency of no less than 2–3 sessions per week.

Before enrollment, all participants will attend a mandatory orientation session organized by the research team to ensure full understanding of the study's objectives, procedures, and potential risks. Participation in the study is entirely voluntary and requires the joint signing of a written informed consent form by both the participant and their legal guardian.

2.Study Setting and Timeline

This study is scheduled to be conducted over an 4-week period. Study planning commenced on August 1, 2025. Participant recruitment began on August 2, 2025, with the final participant enrolled by August 5, 2025. The first week was allocated for eligibility screening, participant ID coding, and baseline testing preparations.

This was followed by a 4-week intervention phase and a final post-testing week, during which outcome data were collected. Final data collection was completed by September 10, 2025.

The study targets 70–80 eligible male adolescent athletes from the sports specialty

teams at Shandong Heze Martial Arts School, selected based on predefined inclusion criteria, including training experience, current health status, and consistent weekly training frequency.

A randomized controlled design was employed. Participants were randomly assigned to either an experimental or a control group. Both groups received the same standardized neuromuscular training (NMT) program, conducted four times per week for four weeks, including exercises for foundational strength, agility, core stability, and balance.

The experimental group additionally received spinal manipulation twice weekly (before Monday and Friday sessions), totaling eight sessions. The control group will only receive a set up manipulation without real thrust.

All participants underwent a comprehensive battery of nine physical performance tests both before and after the intervention, assessing lower limb maximal strength, muscular endurance, power, agility and balance control. The primary objective was to investigate the effect of periodic full-spine chiropractic adjustments on sport-specific performance and neuromuscular regulation in adolescent athletes.

The entire study was conducted at the gymnasium, training field, and rehabilitation room of Shandong Heze Martial Arts School. Performance testing and training sessions were jointly supervised by certified strength and conditioning coaches and research assistants. All spinal adjustments were performed on-site by licensed Doctor of Chiropractic (DCs) to ensure procedural safety and consistency.

3.Randomization Process:

Participants were randomly assigned to the experimental or control group using a computerized random number generator in Microsoft Excel.

The “=RAND()” function was used to generate a random number for each participant, which was sorted to determine group assignment.

An independent researcher, uninvolved in recruitment, intervention, or outcome

assessment, managed the allocation sequence. Assignments were sealed in opaque envelopes to ensure allocation concealment and preserve the integrity of the randomization process.

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4. Study Procedure

This study aims to investigate the effect and feasibility of periodic lumbopelvic spinal manipulation combined with standardized neuromuscular training (NMT) on multidimensional lower-extremity performance in adolescent athletes from sport-specialty teams. Specifically, the study evaluates improvements in maximal strength, muscular endurance, explosive power, agility, and balance following the intervention.

The study is divided into three major phases:

1. Pre-Intervention Phase (Baseline Testing)
2. Intervention Phase
3. Post-Intervention Phase (Outcome Assessment and Data Analysis)

Step 1: Pre-Intervention Phase

This phase is designed to collect baseline data before any intervention takes place, which serves as a reference for evaluating intervention effects. All tests are conducted in a controlled environment, following standardized procedures executed by trained assessors. The testing sequence includes 9 multidimensional physical performance tests.

Step 2: Intervention Phase

- Week 1: preparation (participant coding, eligibility screening, informed consent collection, baseline testing),
- Weeks 2–5: formal 4-week intervention period,

- Week 6: post-testing and data collation.

During the intervention period, participants are randomly assigned to either the experimental group or the control group.

- Both groups engage in standardized neuromuscular training (NMT) four times per week.
- The experimental group additionally receives full-spine chiropractic adjustments every Monday and Friday before training (8 sessions in total).
- The control group does not receive spinal adjustments.

Step 3: Post-Intervention Phase (Outcome Testing and Data Analysis)
Upon completion of the intervention, all participants undergo a post-test battery identical to the baseline assessments, including 9 multidimensional physical performance tests. The results are compared within and between groups to evaluate the impact of full-spine chiropractic adjustment. Objective performance data and statistical analyses will be used to comprehensively assess the applicability and effectiveness of spinal manipulation in the context of structured athletic training in adolescents.

5.Testing Procedures：
(1) Baseline Testing Phase (Day 1-4)

Testing will follow a standardized sequence: beginning with a structured warm-up, followed by nine physical performance tests conducted in a fixed order.

This phase is designed to record baseline physical performance data prior to intervention, serving as a reference for evaluating intervention outcomes. All assessments will be conducted in a controlled and consistent environment, adhering to standardized protocols.
The testing process includes a warm-up routine, nine primary physical performance tests, and systematic data recording, all of which will be administered by trained

evaluators.

5.1 Standardized Warm-Up Protocol (10 minutes)

The warm-up routine will be led by a certified trainer to ensure consistent neuromuscular activation across all participants. The sequence is as follows:

5.1.1 Dynamic Warm-Up (~5 minutes)

- Jogging for 2 laps (approximately 400 meters)
- High knees and jumping jacks, 30 seconds each
- Walking lunges: 10-meter shuttle, repeated twice
- Hip circles and knee circles: 15 repetitions each

5.1.2 Sport-Specific Activation (~3 minutes)

- Simulated vertical jumps in place × 3 repetitions
- Isometric half squats, held for 10 seconds × 2 sets
- 10-meter shuttle runs × 2 repetitions (to enhance start reactivity)

5.2 Resting Check and Preparation (~2 minutes)

- Participants will wear a fingertip heart rate monitor to record resting heart rate.
- The evaluator will reconfirm the participant's ID, physical condition, and attire to ensure compliance with testing requirements.
- Participants exhibiting abnormalities (e.g., dizziness or hypoglycemia) will either reschedule for retesting or be withdrawn from the session.

5.3 Physical Performance Test Battery

This study includes nine physical performance tests targeting key athletic capacities such as strength, endurance, explosive power, agility, balance, and coordination. All tests will be conducted after a standardized warm-up, under the supervision and instruction of trained evaluators. The testing environment will be standardized, with safety protocols and scoring criteria in place to ensure both data validity and participant safety.

5.3.1 Bench Press 1RM Test

Purpose: To assess the maximum upper-body strength output.

Equipment: Flat bench press rack and a standard Olympic barbell.

Procedure: After completing 3 warm-up sets, participants will gradually increase the load. Each attempt is followed by a 3–5 minute rest interval. The maximum weight successfully lifted once with proper techniquewill be recorded.

Measurement Unit: Kilograms (kg).

Safety Requirement: A spotter must be present at all times to assist and ensure safety.

5.3.2 Squat 1RM Test

Purpose: To assess the maximal lower-limb strength capacity.

Equipment: Squat rack, standard barbell, and weightlifting belt.

Procedure: Following warm-up sets, the load is gradually increased. Each squat must reach a depth where the thighs are below parallel to the ground. The maximum weight successfully lifted under these criteria will be recorded.

Measurement Unit: Kilograms (kg).

Technique Standard: Participants must maintain controlled movement without using momentum or prematurely terminating the motion.

5.3.3 40kg Squat Max Repetitions Test

Purpose: To evaluate lower-limb muscular endurance under moderate load conditions.

Procedure: The barbell is fixed at 40 kg.
Each squat must reach a depth of at least 90 degrees at the knee joint.
Participants will perform as many properly executed repetitions as possible without rest.

Measurement Unit: Repetitions (count).

Control Criteria: The test will be terminated if the participant shows poor form, disrupted rhythm, or reaches muscular failure.

5.3.4 Pull-Up Max Repetitions Test

Purpose: To assess the repetitive strength endurance of the latissimus dorsi and biceps brachii muscles.

Equipment: Standard fixed pull-up bar.

Procedure: Starting from a full hang, each repetition is counted when the chin rises above the bar.
Kipping, swinging, or using momentum is not allowed. Participants perform pull-ups continuously until failure.

Measurement Unit: Repetitions (count).

Evaluation Criteria: Only fully completed and technically correct repetitions are counted; any failed attempts are excluded.

5.3.5 100m Sprint Test

Purpose: To assess maximum sprinting speed and neuromuscular coordination.

Equipment: Regulation running track or open field, distance markers, and stopwatch.

Procedure: Participants start in a self-selected standing position. The sprint is conducted once, and time is recorded by two timers simultaneously for accuracy.

Measurement Unit: Seconds (recorded to two decimal places).

Control Requirements: Surface must be dry, participants must wear non-slip footwear, and complete a thorough warm-up beforehand.

5.3.6 Standing Broad Jump

Purpose: To measure horizontal explosive power of the lower limbs.

Procedure: Participants jump forward from a two-footed stance. The heels must not

move backward after landing. Distance is measured from the takeoff line to the rear heel on landing.
Each participant performs three trials, and the longest distance is recorded.

Measurement Unit: Centimeters (cm).

Exception Handling: If the landing is unstable or the movement deviates from standard, one retest is allowed.

5.3.7 T-Test Agility

Purpose: To evaluate directional change ability, start explosiveness, and deceleration control.

Setup: Cones are arranged in a T-shape: 9.14 meters forward from the starting point, and 4.57 meters to each side of the top of the T.

Procedure: Participants run from the start line → forward sprint → lateral shuffle to both sides → backward run to the start line.
The test must be completed along the prescribed route.

Measurement Unit: Seconds.

Termination Criteria: The test is invalid if the participant misses a cone, follows the wrong route, or falls.

5.3.8 Two-Point Agility Test (4.9 m Shuttle)

Purpose: To assess short-distance change-of-direction and reactive agility.

Procedure: The distance between the start and turnaround point is 4.9 meters. Participants complete one full shuttle (9.8 meters), emphasizing quick starts and precise turns.

Measurement Unit: Seconds.

Safety Measures: Ensure the outsole is dry and the surface is stable during testing.

5.3.9 Box Agility Test (5.8 m × 4.9 m)

Purpose: To evaluate multidirectional agility and rhythm control in a closed-loop movement task.

Procedure: The test path forms a rectangle (5.8 m long × 4.9 m wide). Participants run clockwise around the perimeter for one full lap, touching each corner.

Measurement Unit: Seconds.

Control Standards: Participants must perform controlled and accurate direction changes. Short cutting the path is strictly prohibited.

5.4 Test Sequence and Fatigue Management Strategy

To minimize fatigue-related interference and ensure the reliability of test results, all physical performance tests will be conducted in the following standardized order:

1. Pull-Up Max Repetitions
2. Bench Press 1RM
3. Squat 1RM
4. 40kg Squat Max Repetitions
5. Standing Broad Jump
6. T-Test Agility
7. Two-Point Agility Test (4.9 m)
8. Box Agility Test (5.8 m × 4.9 m)
9. 100m Sprint Test

A 2–5 minute rest interval will be provided between each test to allow for adequate recovery of heart rate and body temperature.
If an individual's heart rate remains above 160 bpm, the rest period will be appropriately extended.

The full testing battery is expected to take approximately 120 minutes per group and will be conducted in a rotating group format.

5.5 Data Collection and Recording Management

All test data will be recorded manually by designated personnel using standardized paper-based Pre-Test Record Forms.
Each participant will be assigned a unique identification code (e.g., A01, B12) for

anonymized tracking throughout the testing process.

Each test station will be staffed with one test administrator, one data recorder, and one on-site supervisor to ensure procedural accuracy and data integrity.

5.6 Safety Monitoring and Emergency Response

5.6.1 Risk Identification

Agility and power-based tests may pose a risk of sprains or falls.

Maximal strength testing (e.g., 1RM) carries a risk of soft tissue injury or loss of control under load.

Hot environments or high testing density may lead to abnormally elevated heart rate.

5.6.2 Safety Precautions

A fully equipped first aid kit (including cold packs, bandages, adhesive bandages) will be available at the testing site.

Each testing group will be assigned at least one staff member certified in CPR.

All high-intensity tests (e.g., 1RM) will be conducted with dual-spotter protection to ensure safety.

Complete warm-up and cool-down protocols will be performed before and after testing to reduce injury risk.

5.6.3 Incident Management Procedure

Testing will be immediately terminated if any of the following occurs:

Dizziness, confusion, vomiting, or other physiological distress

Sprain, fall, or inability to maintain balance

Verbal expression of strong subjective discomfort

Response protocol:

Move the participant to a designated observation area.

Document the incident on-site.

Complete the "Test Incident Report Form".

If the condition is severe, notify the legal guardian and initiate referral procedures.

5.7 Test Administrator Responsibilities and Training Requirements

All test administrators must attend pre-study standardized training, including operational protocols and emergency handling.

Before each test, administrators must verify equipment functionality, environmental conditions, and the participant’s readiness.

During data collection, results must be jointly confirmed and signed by two personnel.

No role reassignment or task switching is allowed without written authorization from the lead investigator.

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(2) Intervention Phase (Day 2 to Day 28)

This phase constitutes the core intervention period, lasting for four weeks (28 days). All participants will be randomly assigned to either an experimental group or a control group, both of which will follow an identical physical training program. In addition, the experimental group will receive spinal manipulation interventions on top of the training regimen.

The entire intervention protocol is designed to be structured and reproducible, ensuring consistency in variable control and enhancing comparability of outcome data across groups.

5.8 Physical Training Program (Applicable to Both Experimental and Control Groups)

5.8.1 Training Duration and Frequency

Duration: 4 weeks in total

Frequency: 4 sessions per week (Monday, Tuesday, Thursday, and Friday)

Total Training Sessions: 16 units

Session Length: Each session lasts approximately 45 to 60 minutes

5.8.2 Session Structure (Detailed Training Plan)

Each training session will last approximately 50 minutes, consisting of the following three components:

Dynamic Warm-Up (10 minutes)

Main Training Segment (30 minutes)

Cool-Down and Recovery (10 minutes)

5.8.2.1 Dynamic Warm-Up (Total Duration: 10 Minutes)

Exercise	Execution	Duration/Reps	Sets	Rest Between Sets
Jogging	Track or field loop	2 minutes	1 set	—
High Knee Run	In place	30 seconds	2 sets	15 seconds
Jumping Jacks	In place	30 seconds	2 sets	15 seconds
Walking Lunges	10-meter shuttle	2 shuttles	2 sets	15 seconds
Joint Circles	Major joints, in sequence	10 circles per joint × 2 directions	1 set	—

5.8.2.2 Main Training Segment (Total Duration: 30 Minutes)

(1) Bodyweight Strength Training (12 minutes)

Exercise	Reps/Time	Sets	Rest Between Sets
Squats	15 reps	3 sets	30 seconds
Lunges	12 reps per leg	3 sets	30 seconds
Push-Ups	12 reps	3 sets	30 seconds
Burpees	10 reps	2 sets	45 seconds

Rest 30 seconds between each exercise.

After completing burpees, rest 1 minute before starting the next module.

(2) Agility and Reaction Training (10 minutes)

Exercise	Execution	Time	Sets	Rest Between Sets
Ladder Drills	3 patterns in rotation	30 seconds	2 sets	30 seconds
Ring Jumps	Alternating single/double leg	30 seconds	2 sets	30 seconds
Shuttle Runs	5-meter shuttle × 2 rounds	5 round trips	2 sets	45 seconds

Light footwork and deep breathing are used between drills.

No additional extended rest intervals are set.

(3) Dynamic Core Training (8 minutes)

Exercise	Execution	Duration	Sets	Rest Between Sets
Plank Variations	Front + side planks, alternating	30 seconds each	2 sets	20 seconds

Side Bridge	30 seconds per side	2 sets	20 seconds	
Dynamic Twists	Seated or standing torso rotation	30 seconds	2 sets	20 seconds

5.8.2.3 Cool-Down and Recovery (Total Duration: 10 Minutes)

Exercise	Duration	Sets	Rest Between Sets
Static Stretching (Major Muscle Groups)	30 seconds per muscle group	8 exercises total	No rest (performed continuously)
Diaphragmatic Breathing + Progressive Relaxation	3 minutes	1 set	—

5.8.3. Standardized Training Management

All training sessions are supervised by a consistent coaching team.

Technical criteria are established for each exercise to ensure movement quality.

Each session includes RPE (Rating of Perceived Exertion) scoring on a 0–10 scale to monitor fatigue and load response.

Training attendance and participant feedback are documented in the Intervention Period Training Log.

5.9 Spinal Manipulation Intervention (Experimental Group)

5.9.1 Intervention Objectives

The goal of the spinal manipulation intervention is to:

Enhance neuromuscular control and postural integration across the entire spinal column,

Facilitate spinal nerve conduction and improve proprioceptive regulation,

Promote training adaptation and improve neuromuscular efficiency related to strength

and agility performance.

5.9.2 Intervention Frequency and Timing

Spinal manipulations will be performed twice per week, scheduled as follows:

Before Monday sessions, to prime the nervous system for the training cycle,

Before Friday sessions, to facilitate integration and metabolic recovery.
A total of 8 sessions will be delivered over 4 weeks (2 sessions/week).
Before each session, a rapid spinal functional assessment will be performed by the practitioner to determine the priority segments for treatment.

5.9.3 Intervention Personnel

All spinal manipulations will be performed by licensed Doctors of Chiropractic (DCs).
Each session will be accompanied by one non-operating observer responsible for documenting the procedure and any post-intervention reactions.
All personnel involved will have completed training in standardized intervention procedures and ethical conduct protocols.

5.9.4 Manual Technique Overview (Full-Spine Adjustment)

Technique: High-velocity, low-amplitude (HVLA) thrusts targeting segmental dysfunctions or restricted motion areas.

Region of Application:

Lumbar spine (L1–L5)

Sacroiliac joints (SI joints)

Each session will focus on one segment, based on findings from the day's pre-intervention assessment.

5.9.5 Assessment and Adjustment Procedure

Pre-Adjustment Evaluation:

A rapid palpatory assessment will be conducted to evaluate segmental mobility, identify tender points, and detect areas of abnormal muscle tone.

Adjustment Execution:
Based on the assessment findings, 2 to 5 dysfunctional spinal segments will be selected for targeted HVLA (High-Velocity, Low-Amplitude) thrust adjustments.

Post-Adjustment Observation:
Participants will be monitored on-site for 2–3 minutes to ensure there are no adverse reactions such as dizziness or worsening of pain.

Documentation:
The session record form will be completed by the assigned observer, including treated segments, participant responses, and subjective feedback.

Total Duration:
Each intervention session, including evaluation, manipulation, and observation, will be completed within 10 minutes.

5.9.6 Intervention Safety Control

Prior to each adjustment session, participants will be assessed for suitability for manual therapy.
If any contraindications are detected (e.g., acute pain, inflammation, fever), the intervention will be temporarily withheld.
If a participant reports discomfort after the session, a Post-Intervention Reaction Form will be completed, and the participant will be monitored for 24 hours.

5.9.7 Intervention Compliance and Monitoring Mechanism

Each participant will be issued a personal training/intervention log card.

Any absence from training/intervention requires documented justification.

A project coordinator will review attendance and training completion on a weekly

basis.

Participants with ≥2 consecutive absences will be classified as low adherence cases, and their data will be flagged for separate statistical analysis.

5.9.8 Environmental and Logistical Management of the Intervention Phase

All interventions will take place in designated on-campus training areas and treatment rooms with proper ventilation and temperature control.

All equipment will be disinfected after each session.

Spinal manipulations will be performed on treatment tables, with single-use sanitary sheet replacements after each participant.

5.9.9 Testing Equipment and Tools

Multiple precision stopwatches (for timing sprint and agility tests)

Standard vertical jump apparatus (for standing broad jump and vertical jump measurements)

High accuracy measuring tape (for jump distances and field markings)

2–4 marker cones (for T-test, box agility, and two-point agility test layouts)

Standard squat rack (for 1RM squat testing and loaded strength training)

Standard Olympic barbell (20 kg) and assorted weight plates (10 kg, 5 kg, 2.5 kg, etc.)

Spring collars and safety clamps (for secure weight fixation)

Multiple weightlifting belts (for safety during squats and bench press)

Training mats and treatment tables (for spinal manipulation and post-intervention observation)

Pre- and post-test record books, data entry forms, pens, and data backup folders

All equipment will be checked for functionality and disinfected by designated personnel before and after each use, to ensure measurement accuracy, device integrity, and operational safety.

Post-Test Phase (Day 29)

5.10.1. Purpose of Testing

The post-test is designed to evaluate the effect of spinal manipulation combined with physical training on participants' performance after a 4-week intervention period. All test items and procedures are identical to the pre-test, allowing for paired comparative analysis.

5.10.2. Test Items and Sequence

The post-test includes 9 standardized physical performance tests, conducted in the following order:

1. Pull-Up Max Repetitions
2. Bench Press 1RM
3. Squat 1RM
4. 40kg Squat Max Repetitions
5. Standing Broad Jump
6. T-Test Agility
7. Two-Point Agility Test (4.9 m)
8. Box Agility Test (5.8 m × 4.9 m)
9. 100m Sprint Test

The test sequence is identical to the pre-test phase. A 2–5-minute recovery interval will be given between each test.

The estimated total test duration is approximately 120 minutes.

5.10.3. Test Procedure

Check-In and ID Verification: Participants will sign in using their assigned ID number and confirm no injuries or physical discomfort outside the study.

Warm-Up Routine: A 10-minute standardized dynamic warm-up will be conducted,

consistent with the pre-test protocol.

Group Rotation Execution: Testing will be carried out in three rotating groups. The same evaluators as in the pre-test will be assigned to each task to minimize assessment bias.

Data Recording: All outcomes will be recorded using the Post-Test Record Form, identical to the pre-test version, and must be jointly signed by both the evaluator and recorder.

5.10.4. Psychological Readiness and Fatigue monitoring

To assess psychological status and fatigue throughout the intervention period, two monitoring tools were used.

- Psychological readiness evaluation: participants completed the Sport Readiness Questionnaire (SRQ) at the beginning of each training week. The SRQ evaluates four psychological domains using a 0-10 numeric scale: perceived motivation; sleep quality from the previous night; emotional stress; and confidence in athletic performance. All responses were self-reported on paper forms and analyzed descriptively. These data provided insight into participants' mood, mental readiness, and emotional state over the 4-week training period.
- Fatugue Monitoring: Training-induced fatigue was monitored using the Rate of Perceived Exertion (RPE) scale based on the Borg CR10 system. Athletes reported their RPE after each training session. Weekly Session-RPE Load was calculated by multiplying RPE by the session duration in mintues: Session Load = RPE x 90 (mintutes). Weekly loads were tabulated to quantify total training burden and identify cumulative fatigue patterns.