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# The Impact of Functional Movement Strength Training on Core Muscle Activation and Trunk Kinematics During Jumping Heading in Adolescent Soccer Players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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**Abstract**

**Background.** Functional Movement Strength Training (FMST) integrates functional, strength, and plyometric exercises to enhance neuromuscular coordination and movement performance. Although these training modalities have been investigated individually in soccer, their combined effects on core muscle activation and trunk kinematics during jumping heading in adolescent players remain unclear.

**Objectives.** This study aimed to examine the effects of an eight-week FMST program on core muscle activation and trunk kinematics during jumping heading in adolescent male soccer players.

**Materials and Methods.** A quasi-experimental pretest–posttest design with a control group was employed. Thirty adolescent soccer players were allocated into an Experimental Group (EG; n = 16), which completed an eight-week FMST program (three sessions per week), and a Control Group (CG; n = 14), which continued regular training. Muscle activity was assessed using surface electromyography, and kinematic variables of the neck, trunk, hip, knee, and ankle were analyzed during the preparation, take-off, and ball-contact phases of jumping heading. Data were analyzed using Linear Mixed Model analysis.

**Results.** A significant Group × Time interaction was observed for rectus abdominis (RA) activation ($p < 0.05$), with greater increases in the EG compared to the CG. Furthermore, significant interactions were also found for hip angle during the preparation phase, and for neck angle and trunk tilt during the take-off phase ($p < 0.05$). No significant differences were identified during the ball-contact phase.

Conclusions. Using FMST was associated with increased RA activation and phase-specific modifications in trunk-related kinematics during jumping heading. These findings suggest that integrated training approaches may enhance trunk control and neuromuscular coordination in adolescent soccer players.

**Keywords:** soccer, heading, functional training, kinematics, electromyography and muscle activity.

## Introduction

Among adolescents, soccer is a popular sport in Africa, America, the Eastern Mediterranean, and Europe, with a prevalence of approximately 30% (Hulteen et al., 2017). Soccer is a unique sport because it can use the head to contact the ball, which is called heading (Bonn et al., 2021). Heading can be used to score goals, defense and offense, control, or pass the ball, which is an integral part of football (Sandmo et al., 2020). At the 2018 World Cup in Russia, heading contributed 18.9% of all goals scored (Mićović et al., 2023).

Heading is a complex and multidimensional component of soccer involving mechanical demands across all parts of the body (Mehnert et al., 2005; Shewchenko et al., 2005). The kinematics heading were preparation, ball contact and follow-through (Rusdiana et al., 2020; Sekine et al., 2022). The greater hyperextension of the trunk during the preparation phase, the greater the speed at which the trunk comes into contact with the ball, thus providing which has been associated with greater trunk velocity and force generation (Kirkendall & Garrett, 2001; Rusdiana et al., 2020). The trunk flexes forward to contact the ball (Doewes et al., 2023; Rusdiana et al., 2020; Sekine et al., 2022) while the head and shoulders move in unison with the trunk (Doewes et al., 2023; Rusdiana et al., 2020). Stability and stiffness in the cervical region are essential to minimize unwanted angular movements, enabling the head–neck–trunk unit to function as a single, complex unit (Caccese et al., 2018).

Core muscles are muscles critically involved in and play an important role during activities such as jumping, heading (Becker et al., 2018; Eckner et al., 2018; Kristensen et al., 2004). Defined as the muscles around the hips and trunk, the core muscles are vital. The abdominal muscles, in particular, are strongly activated before and during ball contact to maintain body stability throughout the preparation and contact phases (Sekine et al., 2022). Core muscles are needed to support the jump (Kumahara et al., 2021; Sasaki et al., 2019) and to maintain balance when dynamic motion (Lifshitz et al., 2020). In a jumping heading, the core musculature is essential, not only to provide kinetic momentum but also to stabilize and ready the lower limbs (Sasaki et al., 2019).

Previous research has examined various training interventions to enhance heading performance. Plyometric training has been shown to improve jump height in heading contexts (Matsuda et al., 2024). Neck strengthening protocols have produced inconsistent findings: no significant effects on neck and head kinematics (Doewes et al., 2023), whereas improvements in head kinematics following combined neck and trunk strengthening (Müller & Zentgraf, 2021). Trunk-focused interventions have also been shown to modify abdominal muscle activation patterns during heading (Sekine et al., 2022). Beyond heading-specific interventions, functional training has been widely investigated for general soccer performance enhancement (Carvutto et al., 2021; Jia, 2023; Philip et al., 2022).

Despite these findings, several important gaps remain. First, previous studies have typically examined functional training, strength training, and plyometric training as isolated or partially combined interventions. To date, no study has integrated these three components within a single structured program specifically targeting jumping heading performance in adolescent soccer players. Second, prior investigations have generally focused on either muscle activation patterns or kinematic variables independently, with limited studies simultaneously evaluating both neuromuscular activation and segmental kinematics during distinct phases of jumping heading. Third, most biomechanical and intervention studies on heading have involved adult or collegiate populations (Müller & Zentgraf, 2021; Sekine et al., 2022), whereas evidence specific to adolescent players remains scarce. Considering that neuromuscular maturation and motor control strategies are still developing during adolescence (Sonesson et al., 2022), training adaptations in this population may differ from those observed in adults.

Functional Movement Strength Training (FMST) represents an integrative training approach that combines elements of functional training, resistance-based strength development, and plyometric exercise within a structured program. Such an approach is theoretically aligned with the biomechanical demands of jumping heading, which requires coordinated trunk stabilization, lower-limb force production, and efficient energy transfer between body segments. By simultaneously targeting neuromuscular control, force-generating capacity, and explosive movement characteristics, FMST may provide a comprehensive stimulus relevant to sport-specific performance adaptations.

Therefore, the purpose of this study was to investigate the effects of an eight-week Functional Movement Strength Training (FMST) program on core muscle activation patterns and trunk kinematics during jumping heading in adolescent soccer players. We hypothesized that FMST would be associated with (1) greater core muscle activation during jumping heading and (2) phase-specific modifications in trunk kinematics compared with regular training alone.

## Materials and Methods

### *Study Design and Participant*

The present study employed a quasi-experimental pretest–posttest design with a control group. Two soccer schools (SSB) affiliated with the local football association (ASKOT) were purposively selected for participation. Both SSBs competed at the same regional level and followed comparable regular training schedules (three sessions per week), ensuring a relatively similar training background prior to the intervention. Group allocation was performed at the cluster level, whereby one SSB was assigned to the experimental group and the other to the control group. This cluster-based assignment was implemented to prevent contamination between training programs and to maintain ecological validity within a real-world youth soccer training environment.

A total of 30 Indonesian male adolescent soccer players with a minimum of one year of playing experience were recruited for the study. Players from the SSB assigned to the experimental group comprised 16 participants (EG; n = 16), while players from the other SSB formed the control group (CG; n = 14). All participants were actively engaged in regular soccer training at their respective SSBs throughout the study period. The EG had a mean age of 16.00 ± 0.86 years, height of 166.81 ± 5.63 cm, body mass of 58.81 ± 6.75 kg, and body mass index (BMI) of 21.11 ± 2.00 kg/m². The CG had a mean age of 15.64 ± 0.71 years, height of 164.92 ± 6.81 cm, body mass of 49.92 ± 10.51 kg, and BMI of 18.22 ± 2.99 kg/m². Exclusion criteria included (1) failure to obtain written parental or guardian consent, (2) the presence of a current musculoskeletal injury or ongoing injury rehabilitation, and (3) playing in the goalkeeper position.

Prior to data collection, all participants and their parents or legal guardians were informed about the study objectives, procedures, potential benefits, and risks, and written informed consent was obtained. The study protocol was reviewed and approved by the Ethical Clearance Committee of Dr. Soetomo General Hospital (RSUD Dr. Soetomo), Surabaya, Indonesia (Reference No: 1250/KEPK/III/2025), and all procedures were conducted in accordance with the Declaration of Helsinki.

### *FMST Intervention*

The EG completed an eight-week FMST program in addition to their regular soccer training, whereas the CG continued their usual soccer training without additional intervention. The FMST program was implemented over eight consecutive weeks, with three sessions per week (total:

**Table 1.** Program Design FMST

| Week | Modul | Exercise | Sets × Repetitions | Rest |
|---|---|---|---|---|
| 1-2 | Mobility & Motor Control | 90/90 hip stretch; Spiderman Stretch; Straight-leg adductor Rocking; Half-kneeling hip flexor Stretch; Nordic Hamstring; Squat; Unassisted Leg Lower; squats; Lunge | 2–3 sets × 8–12 reps | 30-45 s |
| 3-4 | Strength & Power (Neck And Core Muscle) | Head Ball Isometric Partner-assisted; Neck Resistance; Neck Band (Flexi & Extension); Quadruped hip extension on elbows; Quadruped alternating arm and leg; Sit-Up; Push Up; Russian Twist; Reach-Through Tug of War; Throw Ball | 3 sets × 8–12 reps | 60 s |
| 5-6 | Strength & Power (Core And Leg Muscle) | Plank; Abdominal Cruch; Single Leg Squat; Sprint 20 meter; Glute bridge; Glute bridge—one leg lift; V-up; Oblique bridge; Trunk stability Rotation Knee flexed; Lunges; Sit Up | 3 sets × 10–12 reps | 90 s |
| 7-8 | Plyometrics | Cone Hop; Hurdle Jump (10-30 cm); Box jump; Single leg hop Zig zag; | 3 sets × 6–8 reps | 90-120s |

24 sessions). Each session lasted approximately 60 minutes and followed a progressive periodized structure.

Weeks 1–2 (Foundation Phase): Emphasis was placed on mobility, postural alignment, and fundamental motor control exercises to establish movement quality and trunk stabilization. Weeks 3–6 (Strength Development Phase): Training focused on progressive resistance exercises targeting the neck, trunk, and lower-limb musculature through multi-joint functional movements. External resistance and exercise complexity were gradually increased. Weeks 7–8 (Power and Plyometric Phase): Plyometric and explosive movement drills were incorporated to stimulate stretch–shortening cycle activity and inter-segmental coordination relevant to jumping tasks. Exercise intensity and task complexity were progressively increased across phases to ensure overload and adaptation. A detailed description of the FMST protocol, including specific exercises and volume parameters, is presented in Table 1.

### *Data Measurement and Experimental Task*

Data collection was conducted at the Gait and Motion Laboratory of Dr. Soetomo General Hospital, Surabaya. Participants performed a standardized jumping heading without a run-up, starting from a stationary position and barefoot to ensure consistent ground interaction. The ball was suspended at a height corresponding to each participant's standing height to standardize task demands. Participants performed a forward jumping header (not lateral), and arm swing was permitted to replicate natural movement. Two successful trials were recorded for each participant, and the mean values were used for analysis.

### *Muscle Activation*

Core and lower-extremity muscle activity was assessed using surface electromyography (sEMG) with an eight-channel system (HW-SYSTEM 8CH, Mega Electronics Ltd., Finland) and Peak Module 2000 software. Electrodes were placed on the dominant side, defined as the preferred side for daily activities; when dominance was unclear, the right side was selected for consistency. Skin preparation included shaving (if necessary), cleaning, and drying to reduce impedance.

Muscles analyzed included the sternocleidomastoid (SCM), rectus abdominis (RA), erector spinae (ES), gluteus maximus (GMax), biceps femoris (BF), vastus medialis (VM), and gastrocnemius (GC). EMG signals were also recorded from the hip flexor region corresponding anatomically to the psoas major (PM); however, this signal represents activity of the superficial hip flexor region rather than the deep psoas major muscle specifically. Bipolar electrode configurations were applied according to SENIAM recommendations.

EMG signals were sampled at 1000 Hz and band-pass filtered between 20 and 450 Hz. Signals were full-wave rectified and processed using a root mean square (RMS) algorithm with a 100-ms moving window using MATLAB software. Raw EMG data were processed by laboratory personnel, and only RMS amplitude outputs were provided for analysis.

EMG amplitudes were not normalized to maximal voluntary contraction (MVC). Therefore, RMS values were analyzed as non-normalized amplitudes to examine relative changes in muscle activation patterns across the preparation, take-off, and ball-contact phases. Findings were interpreted in terms of relative neuromuscular activation changes rather than absolute muscle activation levels.

### *Kinematics Analysis*

Jumping heading kinematics were recorded and analyzed using an AMTI ORG 05 motion analysis system in conjunction with CMAX (Clinical Motion Analysis System) software version 2016 and using a Basler acA2000-50gc camera operating at 100 Hz. All kinematic variables were analyzed in the sagittal plane. The kinematic variables analyzed included joint angles of the neck, trunk, hip, knee, and ankle. Joint angle definitions were adapted from previously published studies (Wojtusch & Von Stryk, 2015). Reflective markers were placed on specific anatomical landmarks to calculate segmental angles. The neck angle was defined using the tragus, seventh cervical vertebra (C7), and acromion. The trunk angle was defined using the seventh cervical vertebra (C7), eighth thoracic vertebra (T8), and fifth lumbar vertebra (L5). The hip angle was determined using the acromion, greater trochanter, and lateral knee joint line. The knee angle was defined by the greater trochanter, lateral knee joint line, and lateral malleolus. The ankle angle was defined using the lateral knee joint line, lateral malleolus, and the second metatarsophalangeal (MTP) joint.

The jumping heading movement was divided into three phases: preparation, take-off, and ball contact. The preparation


a.Preparation b.Take-off c.Ball-contact

**Fig. 1.** Kinematics jumping heading

phase was defined as the period from the initiation of trunk extension to the onset of knee flexion. The take-off phase was defined from peak knee flexion to toe-off, and the ball-contact phase was defined as the interval surrounding initial head–ball contact, as illustrated in Figure 1. Mean joint angles for each phase were extracted for statistical analysis. Each participant completed two successful trials, and the average values were used for subsequent analyses.

### *Statistical analysis*

Descriptive statistics (mean and standard deviation) were calculated for all variables. Baseline differences between groups were examined prior to intervention. Statistical analysis was performed using a Linear Mixed Model (LMM) to account for the repeated-measures design. Group (Experimental vs. Control), Time (Pre-test vs. Post-test), and the Group × Time interaction were included as fixed effects, with participants specified as random effects. The primary outcome of interest was the Group × Time interaction, which examined whether changes in muscle activation and kinematic variables during the jumping heading task differed between groups over time. All analyses were two-tailed, with statistical significance set at $p < 0.05$. Statistical analyses were conducted using SPSS version 27 (IBM Corp., Armonk, NY, USA).

## Results

Figure 2 and Figure 3 illustrate the temporal patterns and RMS amplitude of muscle activity across the preparation, take-off, and ball-contact phases of the jumping heading task. Following the FMST intervention, the Experimental Group (EG) demonstrated higher RMS EMG amplitudes across all analyzed muscles during the post-test compared with the pre-test. In contrast, the Control Group (CG) showed minimal changes in EMG amplitude across testing sessions.

In the EG, the activation of the sternocleidomastoid (SCM), rectus abdominis (RA), erector spinae (ES), and gastrocnemius (GC) muscles occurred earlier during the post-test compared with the pre-test. No notable changes in activation were observed in the CG.

Across both groups, during the preparation phase, increased activation was observed in trunk and hip-related musculature, particularly the erector spinae (ES). During the take-off phase, activation of lower-limb muscles, including the gastrocnemius (GC), biceps femoris (BF), vastus medialis (VM), and gluteus maximus (GMax), became more pronounced. In the ball-contact phase, concurrent activation of the sternocleidomastoid (SCM) and rectus abdominis (RA) was observed. ES activity peaked prior to ball contact and gradually decreased thereafter.

Table 2 presents the results of the LMM for RMS muscle activity during the jumping heading. A significant Group × Time interaction was observed for the rectus abdominis (RA) muscle ($F = 6.12$, $p = 0.02$). The EG demonstrated higher RMS EMG values at post-test compared with pre-test, whereas no significant changes were observed in the Control Group. No significant Group × Time interactions were found for the remaining muscles ($p > 0.05$), indicating that changes in RMS EMG amplitude over time did not differ significantly between groups for these muscles.

Table 3 summarizes the LMM results for kinematic variables during the jumping heading. Significant Group × Time interactions were identified in specific movement phases. During the preparation phase, a significant interaction was observed for the hip angle ($F = 7.29$, $p = 0.01$), indicating greater pre–post changes in the EG compared with the CG.

During the take-off phase, significant Group × Time interactions were found for the neck angle ($F = 5.48$, $p = 0.02$) and trunk tilt angle ($F = 11.43$, $p < 0.01$). No significant Group × Time interactions were observed for any kinematic variables during the ball-contact phase ($p > 0.05$).

## Discussion

This study investigated the effects of an eight-week FMST program on core muscle activation and trunk kinematics during jumping heading in male adolescent soccer players. LMM analysis revealed significant Group × Time interactions for RA activation and selected trunk-related kinematic variables, indicating that temporal changes differed between the EG and CG. Given the anatomical and functional role of the trunk in integrating core musculature

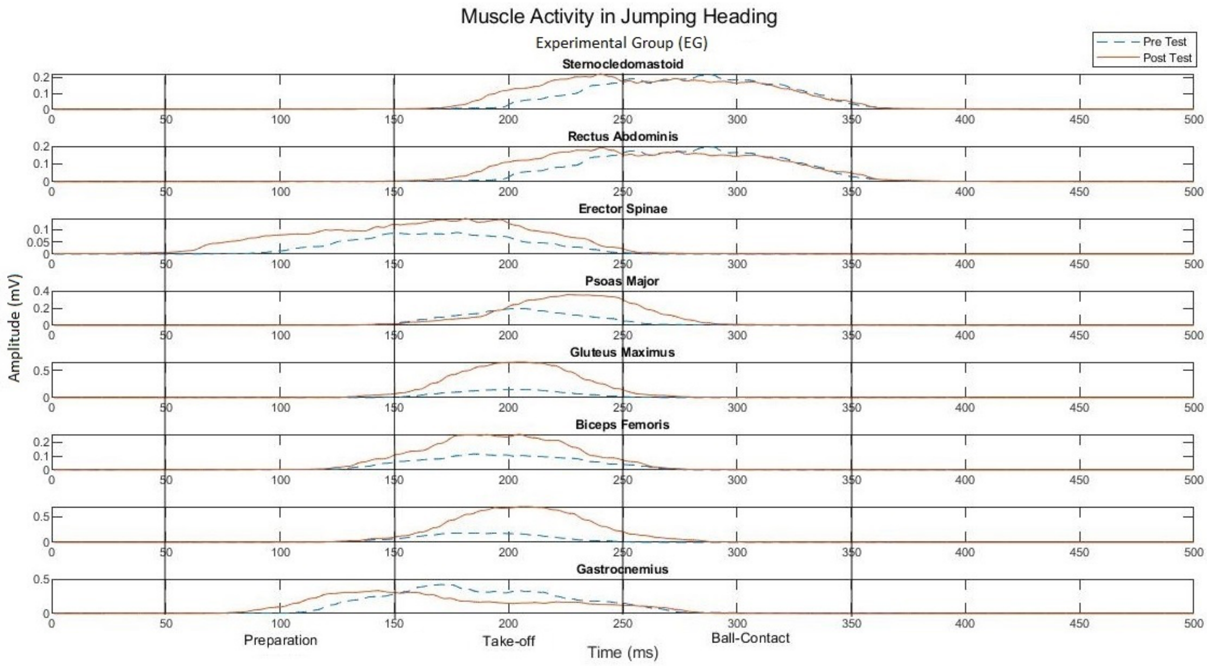


**Fig. 2.** Muscle activity during jumping heading was measured in the experimental group (EG)

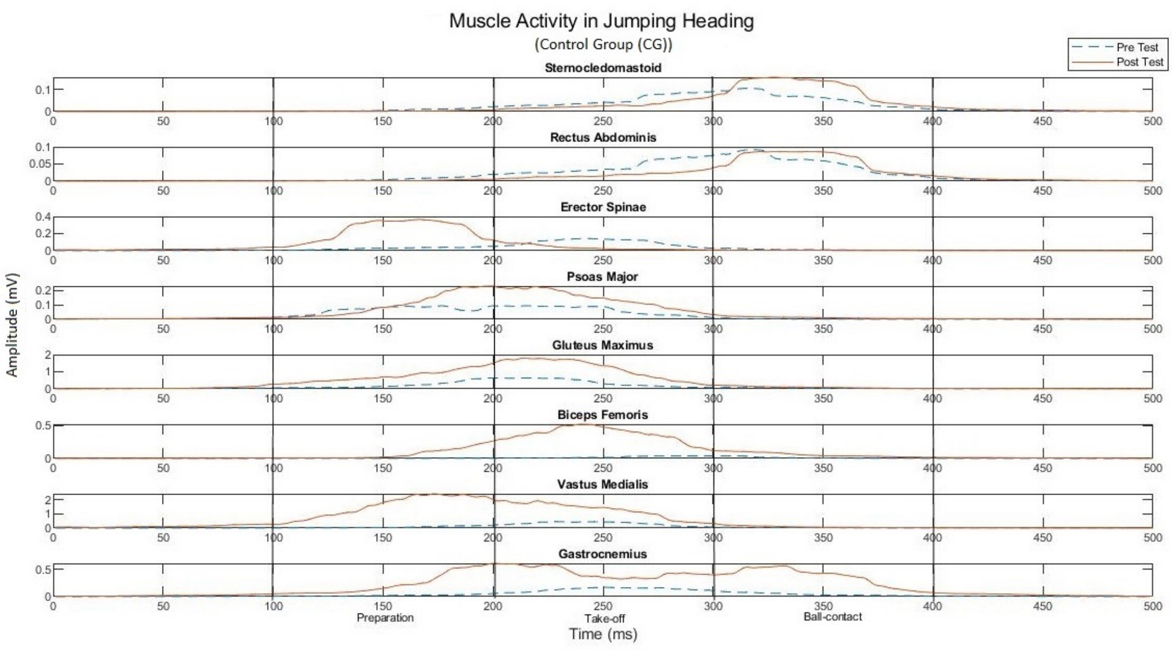


**Fig.3. Muscle** activity during jumping heading was measured in the control group (CG)

and coordinating multi-segmental movement, these findings suggest that FMST may induce alterations in neuromuscular activation magnitude and trunk movement characteristics during jumping heading.

The FMST program was associated with altered muscle activation patterns, characterized by increased RMS EMG amplitude during jumping heading. These changes in activation magnitude may reflect improved neuromuscular efficiency and altered motor unit recruitment strategies. Efficient neuromuscular function is governed by motor unit recruitment patterns (Aslam et al., 2025) , with key adaptations including elevated firing rates, changes in recruitment thresholds, and enhanced motor neuron responsiveness to synaptic inputs (Del Vecchio et al., 2019).

The ES demonstrated descriptively higher RMS amplitudes following the intervention, although these changes were not statistically significant. This adaptation suggests enhanced trunk engagement during the preparatory and propulsive phases of jumping heading. Specifically, greater ES activity facilitates trunk extension during take-off, optimizing body positioning prior to ball contact. Concurrently, lower-limb musculature, including the GC,

**Table 2.** LMM results for root mean square (RMS) electromyography (EMG) activity during the jumping heading

| RMS (mV) | | EG | | CG | | Linear Mixed Model | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Group | | Time | | Group x Time | |
| | | Pre | Post | Pre | Post | F | p | F | p | F | p |
| SCM | M | 0.48 | 0.52 | 0.30 | 0.25 | 19.45 | <0.01 | 0.01 | 0.95 | 2.97 | 0.09 |
| | SD | 0.17 | 0.18 | 0.15 | 0.07 | | | | | | |
| RA | M | 0.39 | 0.44 | 0.27 | 0.21 | 15.91 | <0.01 | 0.26 | 0.60 | 6.12 | 0.02* |
| | SD | 0.14 | 0.16 | 0.13 | 0.05 | | | | | | |
| ES | M | 0.28 | 0.46 | 0.19 | 0.19 | 4.04 | 0.05 | 1.28 | 0.26 | 1.26 | 0.27 |
| | SD | 0.13 | 0.61 | 0.06 | 0.08 | | | | | | |
| PM | M | 0.29 | 0.33 | 0.23 | 0.23 | 4.28 | 0.04 | 2.44 | 0.12 | 1.85 | 0.18 |
| | SD | 0.13 | 0.13 | 0.06 | 0.11 | | | | | | |
| GMax | M | 0.42 | 0.51 | 0.49 | 0.54 | 0.21 | 0.64 | 2.12 | 0.15 | 0.25 | 0.61 |
| | SD | 0.24 | 0.28 | 0.43 | 0.37 | | | | | | |
| BF | M | 0.18 | 0.21 | 0.27 | 0.21 | 1.55 | 0.22 | 0.27 | 0.60 | 3.34 | 0.07 |
| | SD | 0.08 | 0.07 | 0.2 | 0.09 | | | | | | |
| VM | M | 0.47 | 0.52 | 0.50 | 0.40 | 0.97 | 0.33 | 0.40 | 0.52 | 3.77 | 0.06 |
| | SD | 0.14 | 0.15 | 0.16 | 0.14 | | | | | | |
| GC | M | 0.49 | 0.51 | 0.49 | 0.50 | 0.01 | 0.93 | 0.16 | 0.68 | 0.20 | 0.88 |
| | SD | 0.13 | 0.14 | 0.18 | 0.29 | | | | | | |

Note: *) p-value<0.05; M: Mean; SD: Standard Deviation; SCM: Sternocleidomastoid; RA: Rectus Abdominis; ES: Erector Spinae; PM: Psoas Major; GMax: Gluteus Maximus; BF: Biceps Femoris; VM: Vastus Medialis; GC: Gastrocnemius; EG: Experimental Group; CG: Control Group.

**Table 3** The results LMM on kinematic jumping heading

| Kinematics (0) | | EG | | CG | | Linear Mixed Model | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Group | | | | Group x Time | |
| | | Pre | Post | Pre | Post | F | p | F | p | F | p |
| Preparation | | | | | | | | | | | |
| Neck Angle | M | 11.53 | 16.97 | 16.72 | 18.77 | 2.61 | 0.11 | 11.13 | 0.00 | 2.46 | 0.12 |
| | SD | 5.5 | 8.31 | 5.08 | 6.79 | | | | | | |
| Trunk Tilt | M | 7.58 | 11.7 | 8.45 | 9.64 | 0.01 | 0.89 | 2.54 | 0.12 | 0.64 | 0.42 |
| | SD | 7.43 | 7.93 | 7.72 | 7.92 | | | | | | |
| Hip Angle | M | 32.98 | 35.71 | 42.44 | 38.43 | 2.46 | 0.12 | 0.02 | 0.88 | 7.29 | 0.01* |
| | SD | 11.5 | 12.46 | 9.69 | 7.29 | | | | | | |
| Knee Angle | M | 59.62 | 59.94 | 72.64 | 69.96 | 7.05 | 0.01 | 0.36 | 0.55 | 0.84 | 0.36 |
| | SD | 12.28 | 15.33 | 12.59 | 10.25 | | | | | | |
| Ankle Angle | M | 21.26 | 17.68 | 27.28 | 26.48 | 6.40 | 0.01 | 1.24 | 0.27 | 0.36 | 0.55 |
| | SD | 10.1 | 9.37 | 4.65 | 8.63 | | | | | | |
| Take-off | | | | | | | | | | | |
| Neck Angle | M | 41.82 | 32.33 | 41.15 | 35.52 | 7.60 | 0.01 | 1.2 | 0.28 | 5.48 | 0.02* |
| | SD | 11.72 | 13.71 | 13.89 | 8.77 | | | | | | |
| Trunk Tilt | M | 17.47 | 24.16 | 11.31 | 9.75 | 15.58 | <0.01 | 4.74 | 0.03 | 11.43 | <0.01* |
| | SD | 9.17 | 9.69 | 5.77 | 6.82 | | | | | | |
| Hip Angle | M | 3.63 | 6.2 | 7.97 | 7.9 | 5.39 | 0.02 | 1.68 | 0.20 | 1.83 | 0.18 |
| | SD | 3.31 | 2.8 | 7.07 | 3.7 | | | | | | |
| Knee Angle | M | 5.83 | 7.77 | 10.78 | 11.1 | 4.26 | 0.04 | 0.61 | 0.43 | 0.26 | 0.60 |
| | SD | 5.85 | 6.41 | 8.34 | 5.62 | | | | | | |
| Ankle Angle | M | 32.5 | 40.63 | 31.16 | 36.85 | 0.59 | 0.44 | 14.45 | <0.00 | 0.51 | 0.47 |
| | SD | 7.68 | 13.22 | 10.41 | 11.13 | | | | | | |
| Ball-contact | | | | | | | | | | | |
| Neck Angle | M | 41.82 | 32.33 | 41.15 | 35.52 | 0.08 | 0.77 | 14.18 | <0.01 | 0.83 | 0.37 |
| | SD | 11.72 | 13.71 | 13.89 | 8.77 | | | | | | |
| Trunk Tilt | M | 6.16 | 8.12 | 8.34 | 5.72 | 0.75 | 0.39 | 1.34 | 0.25 | 1.34 | 0.25 |
| | SD | 6.01 | 5.68 | 6.57 | 3.36 | | | | | | |
| Hip Angle | M | 20.65 | 21.84 | 21.68 | 20.4 | 0.03 | 0.85 | 0.03 | 0.85 | 1.80 | 0.19 |
| | SD | 7.23 | 7.1 | 7.14 | 7.74 | | | | | | |
| Knee Angle | M | 11.91 | 11.47 | 12.42 | 17.56 | 0.38 | 0.54 | 1.96 | 0.17 | 0.43 | 0.51 |
| | SD | 10.01 | 8.87 | 6.87 | 15.55 | | | | | | |
| Ankle Angle | M | 32.13 | 38.43 | 32.12 | 37.56 | 0.01 | 0.99 | 8.02 | 0.01 | 0.01 | 0.99 |
| | SD | 10.81 | 16.24 | 10.08 | 8.88 | | | | | | |

Note: *) p<0.05; M: Mean; SD: Standart Deviation; EG: Experimental Group; CG: Control Group.

exhibited increased activation during preparation, reflecting enhanced readiness for vertical propulsion.

The RA exhibited elevated activation during the take-off phase, with temporal patterns synchronous with the SCM. This coordination suggests integrated recruitment of trunk and neck musculature during movement preparation. Notably, RA activity increased markedly at ball contact, likely contributing to trunk stabilization during impact. Biomechanically, the core musculature functions as the primary stabilizer and mobilizer during jumping heading, controlling trunk motion to ensure appropriate extension and forward progression toward the ball (Sekine et al., 2022). The observed increases in muscle activation magnitude following FMST support the notion of improved trunk control and inter-muscular coordination.

The significant Group × Time interaction for RA activation indicates greater increases in RMS EMG amplitude in the EG compared with the CG. These changes should be interpreted as neuromuscular adaptations rather than direct indicators of muscle hypertrophy or maximal strength gains. Previous research has demonstrated that functional and strength-based training interventions can modify neuromuscular activation and inter-muscular coordination during sport-specific tasks (Khazaei et al., 2023; Wang et al., 2024; Xiao et al., 2021).

Increased RMS EMG amplitude is commonly associated with altered motor unit recruitment strategies, enhanced neural drive, or improved motor unit synchronization (Aslam et al., 2025; Del Vecchio et al., 2019). In the present context, higher RA activation in the EG likely reflects improved recruitment efficiency and enhanced muscle coordination rather than absolute force production capacity. Functional training emphasizes multi-planar movements, multi-joint coordination, and dynamic postural demands, which may facilitate adaptations in postural control and movement coordination during complex actions such as jumping heading (Xiao et al., 2025).

FMST demonstrated a significant Group × Time interaction ($p < 0.05$) for trunk tilt during the take-off phase. This kinematic change aligns with the observed increases in ES and RA activation amplitudes, suggesting coordinated adaptations in trunk musculature recruitment and positioning strategy. Alterations in preparatory trunk positioning may reflect improved trunk control and modified movement strategies following training.

During take-off, the capacity to achieve greater trunk extension or increased tilt angle is biomechanically advantageous, as this enhanced range of motion generates greater momentum upon ball contact (Kirkendall & Garrett, 2001). Functional training induces kinematic adaptations by emphasizing the integration of upper and lower body motion alongside improvements in motor control (Khazaei et al., 2023). Such approaches focus on coordinated movement patterns across multiple body segments, which may facilitate phase-specific trunk kinematic adjustments during complex sport-specific tasks (Tomljanović et al., 2011). Collectively, these findings suggest that FMST may elicit phase-specific modifications in trunk kinematics, particularly during the preparatory stage of jumping heading.

Several limitations should be acknowledged. First, the sample was restricted to male adolescent players; future research should incorporate broader age ranges and female athletes to enhance generalizability. Second, EMG measurements were limited to the dominant side and assessed RMS amplitude only; future studies should incorporate onset timing analysis and bilateral assessment to provide comprehensive insight into neuromuscular timing and potential inter-limb asymmetries. Third, the experimental paradigm did not include actual ball delivery, potentially limiting ecological validity. Finally, objective performance outcomes—such as ball velocity and heading accuracy—were not assessed and should be incorporated in subsequent investigations to determine the functional significance of these neuromuscular and kinematic adaptations.

## Conclusions

This study demonstrates that an eight-week FMST program is associated with changes in core muscle activation patterns and phase-specific trunk kinematics during jumping heading in male adolescent soccer players. Notably, FMST was linked to greater RA activation and modifications in preparatory trunk positioning, which may reflect adaptations in neuromuscular control and movement strategy. These findings suggest that FMST may be a practical and time-efficient training approach to support the development of soccer-specific movement mechanics, particularly jumping heading, in adolescent players.

## Ethics Approval

This study was approved by the Ethical Clearance Committee of RSUD Dr. Soetomo Surabaya East Java Indonesian (Reference No: 1250/KEPK/III/2025)

## Informed Consent

Written informed consent was obtained from all participant and their legal guardians.

## Data Availability Statement

Data are not publicly available due to ethical or privacy restrictions.

## AI Transparency Statement

The authors used AI-assisted (DeepL and ChatGPT) tools for language editing only and take full responsibility for the content.

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### Conflict of interest

The authors declare no conflict of interest.

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# Вплив функціонального силового тренування рухів на активацію м'язів кору та кінематику тулуба під час виконання удару головою у стрибку у футболістів підліткового віку

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

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**Обґрунтування**. Функціональне силове тренування рухів (ФСТР) поєднує в собі функціональні, силові та пліометричні вправи для покращення нервово-м'язової координації та результативності рухів. Попри наявність досліджень цих методів тренування у футболі як окремих компонентів, їхній комбінований вплив на активацію м'язів кору та кінематику тулуба під час удару головою у стрибку у гравців підліткового віку залишається недостатньо вивченим.

**Мета.** Це дослідження мало на меті вивчити вплив восьмитижневої програми функціонального силового тренування рухів на активацію м'язів кору та кінематику тулуба під час удару головою у стрибку у футболістів підліткового віку.

**Матеріали та методи.** У дослідженні застосовано квазіекспериментальний претест-посттестовий дизайн із контрольною групою. Тридцять футболістів підліткового віку були розподілені на експериментальну групу (ЕГ; n = 16), яка виконувала восьмитижневу програму ФСТР (три заняття на тиждень), та контрольну групу (КГ; n = 14), що продовжувала регулярні тренування. Активність м'язів оцінювали за допомогою поверхневої електроміографії, а кінематичні показники шиї, тулуба, стегна, колінного та гомілковостопного суглобів аналізували під час фаз підготовки, відштовхування та контакту з м'ячем при ударі головою у стрибку. Аналіз даних проводився з використанням лінійної змішаної моделі.

**Результати.** Спостерігалася значуща взаємодія Група × Час для активації прямого м'яза живота (ПМЖ) ($p < 0.05$), причому в експериментальній групі (ЕГ) встановлено суттєвіше зростання порівняно з контрольною групою (КГ). Крім того, значущі взаємодії було виявлено для кута згинання стегна під час фази підготовки, а також для кута нахилу шиї та тулуба під час фази відштовхування ($p < 0.05$). Під час фази контакту з м'ячем значущих відмінностей виявлено не було.

**Висновки.** Застосування програми ФСТР асоційоване з підвищеною активацією прямого м'яза живота та фазово-специфічними модифікаціями кінематичних показників тулуба під час удару головою у стрибку. Отримані результати свідчать про те, що підходи на основі інтегрованого тренування сприяють покращенню контролю тулуба (стабільності корпусу) та нервово-м'язової координації у футболістів підліткового віку.

**Ключові слова:** футбол, удар головою, функціональне тренування, кінематика, електроміографія, м'язова активність.

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