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ENHANCING SOCCER ATHLETES' PERFORMANCE: A KINEMATIC ANALYSIS OF AGILITY TRAINING

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Abstract

This study investigates how a targeted training program impacts agility and kinematic performance in soccer players. The Agility T-test was used to measure dynamic movement skills, focusing on execution time and joint movements. Seventeen players performed the test under dominant and non-dominant conditions at two time points—baseline (after summer) and follow-up (after winter). The first change of direction classified trials as dominant or non-dominant. Motion data were captured with Xsens MTw Awinda sensors, and paired t-tests compared baseline and follow-up results.

The analysis showed a clear improvement in performance. Execution times decreased by an average of 1.03 seconds on the dominant side and 0.9 seconds on the non-dominant side. Key kinematic changes included a greater range of motion at the knee during forward running and better hip rotation control on both sides. Interestingly, a reduction in ankle plantar and dorsiflexion range of motion was observed. Significant changes were also noted in knee internal rotation during lateral shufflings.

These findings highlight the program's effectiveness in enhancing agility and movement efficiency through improved lower limb strength and motor coordination developed over the four-month training program.

Keywords: Kinematic analysis, Agility test, Football training.

1. Introduction

Understanding the impact of training programs on athletic performance is a key focus in contemporary sports science research.^{1,2} In football, which involves frequent high-intensity sprints and abrupt changes of direction, the risk of lower-limb injuries—particularly ACL injuries—is notably high.³⁻⁵ Targeted neuromuscular, strength, and agility training programs have been shown to reduce these risks significantly and simultaneously improve performance, underscoring the importance of investigating their effects.^{6,7} In particular, analysing biomechanics and agility offers valuable insights into the effectiveness of various training approaches. Agility, defined as the ability to maintain control of body position while quickly changing direction, play a crucial role in both team sports and individual performance.^{8,9} Growing interest surrounds the factors influencing agility and the development of effective testing protocols and training strategies to assess and improve this quality.¹⁰ Hence, research on the impact of targeted training on agility is not only about enhancing performance but also about mitigating injury risk, a key concern in sports like soccer.

To assess agility and movement proficiency, various tests are employed, each with unique strengths and limitations. The Illinois Agility Test¹¹, the 5-0-5 Agility Test⁸, and the Arrowhead Agility Test¹² are among the most commonly used tests in soccer training. Specifically, the Illinois Agility Test evaluates agility through a series of forward and backward runs interspersed with slaloms between cones, making it ideal for measuring changes of direction (COD) at different angles.¹¹ The 5-0-5 Agility Test focuses on the ability to execute rapid 180° COD, particularly useful for identifying asymmetries between dominant and non-dominant legs.⁸ The Arrowhead Agility Test introduces diagonal runs, making it especially useful for replicating the kinds of movements athletes perform in football.¹³

Despite their utility, these tests have limitations, particularly in isolating the contribution of different phases of movement or capturing the relation interplay between speed, coordination, and strength. The Agility T-test¹⁴, another commonly used test to assess agility, addresses many of these limitations by combining linear sprints, lateral movements,

and backward runs into a single protocol, offering a holistic evaluation of an athlete's agility.^{15,16} Moreover, its straightforward design ensures reproducibility and reliability, making it one of the most widely used tests in sports.¹⁷

Moreover, the Agility T-test is particularly valuable to distinguish between performance on dominant and non-dominant sides, an essential factor in sports requiring symmetrical agility. Indeed, during the test, athletes perform directional changes that challenge their ability to coordinate movements bilaterally, reflecting real-game scenarios.⁹ Furthermore, this test has been shown to be highly reliable when combined with advanced motion analysis tools, such as inertial measurement units (IMUs), to assess not only execution time but also the kinematics of specific joints.^{17,18}

Despite the wide use of agility tests and motion analysis tools, a gap remains in understanding the combined effects of targeted training programs on both agility performance and kinematic changes in specific movements. This study investigated the dual impact of a structured training program on agility performance and the kinematic adaptations of specific movements in young soccer players. By integrating the Agility T-test to measure change-of-direction ability and IMU-based kinematic analysis to capture detailed biomechanical data.

2. Materials and Methods

2.1. Study design

This single-arm experimental study analysed the effectiveness of a specific training program on soccer players to improve the agility and generate kinematic changes. All participants met the inclusion criteria: (i) men older than 18 years old, (ii) at least 2 years of experience, (iii) not suffer any lower-limb injury in the last 6 months before the data collection. Prior to data collection, all participants were briefed on the study protocols, including the potential risks involved. This study was approved by the University of Bologna Bioethics Committee (protocol No. 0025861). Informed consent was obtained from each participant prior to their involvement, and all procedures adhered to the approved protocol. In order to maintain the subjects' privacy, all data were anonymized before the analysis, in accordance with the principles of the Declaration of Helsinki.

2.2. Participant

A total of 21 amateur football players from an Italian non-professional league were initially recruited for the study. Four players were excluded: two due to transfers to other teams during the winter transfer window and two for disciplinary reasons that left them out of the squad. Consequently, the final analysis included a cohort of 17 players. Participants were amateur football players with a mean playing experience of 16.0 ± 5.4 years. The study sample comprised participants with a mean age of 27.5 years (SD = 5.3). The mean weight of the participants was 78.2 kg (SD = 7.0). The mean height was 179.9 cm (SD = 5.5).

2.3. Training Program

The training program was conducted over four months during the competitive season to maintain and enhance physical performance while addressing the specific demands of soccer. Athletes trained twice per week (Tuesday and Thursday), with each session lasting approximately 90 minutes. The training program focused on explosive strength, reactive agility, and coordination, incorporating exercises designed to simulate the multidirectional and high-intensity nature of soccer gameplay. The structure of the weekly training sessions is summarized in Table 1.

Table 1. Weekly training structure

Day	Focus
Tuesday	Explosive strength training: Sprint drills with resistance (e.g., sled pushes), plyometric exercises (e.g., drop jumps, bounding), and core stability work (e.g., planks, side planks). Sets were shorter (3–5 repetitions) with 1-minute recovery intervals.
Thursday	Reactive agility and tactical preparation: Agility drills incorporating unpredictable directional changes triggered by external cues (e.g., coach’s signals) and small-sided games emphasizing decision-making, spatial awareness, and fatigue resistance.

Each training session was structured into three phases:

1. Warm-up: Dynamic stretching and light jogging to prepare for high-intensity efforts.
2. Central phase: Focused on the day’s specific training objective, either explosive strength or reactive agility.
3. Cooldown: Low-intensity running and static stretching to facilitate recovery and reduce muscle soreness.

The explosive strength training included exercises such as sprint drills with resistance (e.g., sled pushes) to enhance lower limb power, plyometric tasks (e.g., drop jumps and bounding) to improve reactive strength, and core exercises (e.g., planks) to stabilize the trunk and support efficient force transmission. The reactive agility sessions incorporated directional changes in response to external cues to replicate match scenarios, while small-sided games combined physical and tactical elements to enhance decision-making and technical execution under fatigue.

2.4. Testing Procedures

The agility was evaluated through an Agility T-test (fig. 1), as described by the National Strength and Conditioning Association.¹⁴ The test was divided into five phases of the movement: forward sprinting, three side shuffling, and backpedaling. The test was considered “dominant” if the first COD (point A in fig.1) between forward and side runs was executed in the direction of the dominant foot, and “non-dominant” otherwise. Each player performed the Agility T-test two times (dominant and non-dominant) per each time points: pre-period training (baseline), conducted at the conclusion of summer conditioning; and post-period training (follow-up), conducted after winter conditioning. All the players were tested the same day and hour and on the same field at both baseline and follow-up. The experimental tests were performed on an outdoor soccer field, and therefore, variations in environmental conditions, including ground surface and weather, could potentially affect participants' performance.

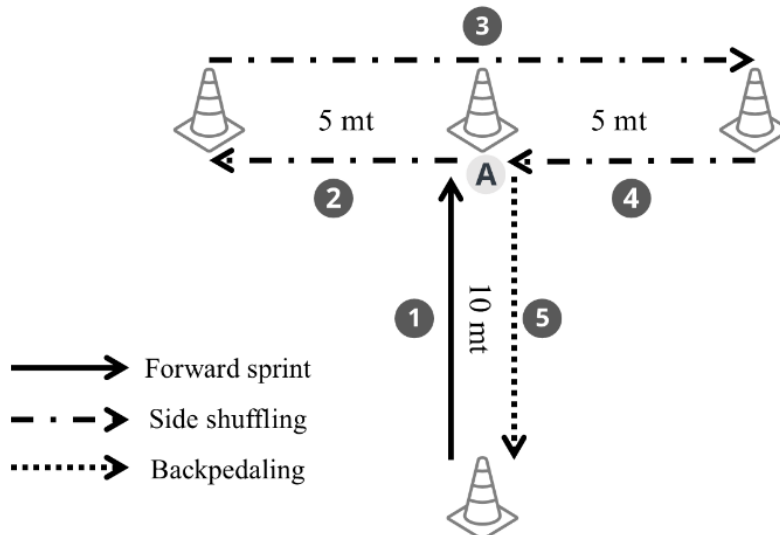


Fig. 1. Schematic illustration of Agility T-test.

2.5. Data Collection

Participants, while performing the Agility T-test, utilized the MVN Biomech Link system (Xsens Technologies BV, Enschede, The Netherlands), a previously validated setup consisting of seven inertial measurement units, a transmission pack, and a battery.^{19,20} The sensors were positioned on the feet, lower leg (tibia, near the knee), upper leg (mid-lateral thigh), and sacrum. Calibration required participants to assume the N-pose—a standardized posture characterized by standing upright with relaxed upper limbs parallel to the body, fully extended lower limbs, and feet positioned parallel.²¹ Anthropometric measurements were incorporated to scale the proprietary biomechanical model within the Xsens Motion Tracking System. This facilitated motion capture calibration using the Xsens MVN

Analyze software (version 2023.2). The Xsens MVN system has shown fair to excellent accuracy in sagittal plane motion analysis when compared with gold-standard optoelectronic systems. This makes it particularly suitable for capturing sport-specific, on-field movements.¹⁹ During testing, participants wore their own shoes to ensure both comfort and the maintenance of natural movement patterns.

2.6. Data Processing

The running measurements were post-processed using the Xsens MVN Analyze software (v. 2021.0.1), operating in the “High-definition reprocessing” mode under the “no-level” processing scenario. This specific configuration fixes the pelvis segment in space, ensuring that all kinematic parameters are expressed relative to it. This approach is particularly recommended for joint angle analysis in biomechanics due to its reliability in capturing relative motion across body segments.^{22,23}

The test movements were divided into five distinct phases and categorized as forward sprinting, shuffling, and backpedaling, as previously described. For each participant, five key moments of the movement were identified and analyzed: 1) the start of the test with a forward sprint, 2) COD at 90° and 3-4) 180°, and 5) the final backward sprint toward the starting line. These phases provided a structured framework for segmenting the movement and analyzing joint kinematics. For each phase, specific frames were extracted using the Xsens MVN Analyze software (v. 2023.2) and compiled into an Excel spreadsheet for all participants. After the segmentation, the range of motion (ROM) for each joint were extracted. The performance metric was the total execution time of the agility test measured with a chronometer.

2.7. Statistical analysis

The statistical analysis was performed in IBM SPSS Statistics version 25.0 (SPSS Inc., Chicago, IL) for the Windows statistical software package. The normality of the data distributions was assessed using the Shapiro–Wilk test. A Wilcoxon signed-rank test was employed to evaluate the differences in all kinematic parameters (e.g., ROM of hip, knee, and ankle joints). Paired t-test was used for performance outcomes (e.g., execution time during the Agility T-test). Kinematic parameters were analyzed for each of the five phases of the Agility T-test, providing a comprehensive evaluation of joint performance during forward runs, lateral movements, and backward runs. The significance threshold was set at $p < 0.05$. Furthermore, beyond reporting p-values, we calculated an overall effect size (ES) and derived its 95% confidence interval (CI) via a bootstrap procedure.²⁴ ES values of 0.2, 0.5, and 0.8 were considered to be small, moderate, and large differences, respectively.²⁵

3. Results

The proposed training program resulted in a statistically significant improvement in agility performance, as evidenced by the reduction in execution time of the Agility T-test.

Specifically, the mean execution time decreased by 1.03 seconds ($p < 0.001$) on the dominant side and 0.9 seconds ($p < 0.001$) on the non-dominant side (Table 2).

Table 2. Execution time comparison pre vs post training program

Test Side	Pre	Post	P-value	ES	CI
Dominant	12.6 ± 0.7	11.6 ± 0.6	< 0.001*	0.76	[0.56 – 0.87]
Non-Dominant	12.6 ± 0.7	11.7 ± 0.5	< 0.001*	0.75	[0.49 – 0.87]

Note: Pre- and post-intervention data are presented as medians and interquartile ranges (IQR). ES denotes the effect size, and CI represents the confidence interval of the effect size. The bold asteric symbol (*) is utilized to highlight significant differences.

Post-training, significant changes in joint range of motion (ROM) were observed across test phases (Tables 3–7). In the forward sprint, robust improvements were observed at the hip and knee. The hip showed significant increases in abduction/adduction ($\approx 8^\circ$), flexion/extension ($\approx 14^\circ$), and internal/external rotation ($\approx 15^\circ$) with high effect sizes (ES ranging from 0.68 to 0.88). Likewise, the knee demonstrated marked enhancements in abduction/adduction (up to 15°) and internal/external rotation (up to 9.6°). A significant reduction in dominant-side ankle dorsiflexion/plantarflexion ($\approx 6^\circ$) was also noted.

During lateral shufflings, consistent changes emerged in hip internal/external rotation (e.g., 1st shuffle dominant side: $p = 0.001$, ES = 0.76; 2nd shuffle: $p < 0.001$, ES = 0.82), with fewer modifications at the knee and ankle.

During backpedaling, significant increases were recorded at the hip—in abduction/adduction ($\approx 10^\circ$ dominant; $\approx 6^\circ$ non-dominant), flexion/extension ($\approx 6^\circ$ dominant; $\approx 9^\circ$ non-dominant), and internal/external rotation ($\approx 9^\circ$ dominant; $\approx 5^\circ$ non-dominant)—while a significant reduction in non-dominant ankle dorsiflexion/plantarflexion ($\approx 9^\circ$) was observed. All results are detailed in Tables 2 through 7, providing comprehensive data on execution times and kinematic parameters across the different test phases.

Table 3. Forward Sprint comparison ROM pre vs post training program

Joint	Movement	Test Side	Pre	Post	P-value	ES	CI
Hip	Abduction/ Adduction	Dominant	22.5 (2.4)	30.6 (11.0)	0.02*	0.56	[0.14 - 0.86]
		Non dominant	21.1 (4.7)	28.6 (7.2)	0.001*	0.77	[0.53 - 0.88]
	Flexion/ Extension	Dominant	72.4 (6.0)	85.9 (8.1)	0.001*	0.77	[0.5 - 0.88]
		Non dominant	74.7 (11.3)	89.4 (11.6)	< 0.001*	0.88	[0.88 - 0.88]
	Internal/ External Rotation	Dominant	18.9 (12.4)	33.9 (9.7)	0.003*	0.68	[0.34 - 0.88]
		Non dominant	18.3 (4.6)	32.7 (7.8)	< 0.001*	0.87	[0.81 - 0.88]
Knee	Abduction/ Adduction	Dominant	19.6 (5.9)	31.4 (17.5)	< 0.001*	0.72	[0.55 - 0.84]
		Non dominant	17.8 (7.0)	33.0 (11.1)	< 0.001*	0.74	[0.54 - 0.84]
	Flexion/ Extension	Dominant	81.0 (14.3)	88.1 (18.1)	0.145	0.36	[0.03 - 0.72]
		Non dominant	80.4 (17.1)	84.3 (14.8)	0.459	0.19	[0.02 - 0.6]
	Internal/ External Rotation	Dominant	17.2 (5.4)	23.4 (8.5)	0.001*	0.59	[0.33 - 0.78]
		Non dominant	17.6 (3.6)	27.2 (10.4)	< 0.001*	0.83	[0.78 - 0.84]
Ankle	Abduction/ Adduction	Dominant	37.7 (9.2)	39.0 (15.2)	0.517	0.17	[0.01 - 0.6]
		Non dominant	33.5 (4.8)	35.2 (12.7)	0.08	0.43	[0.03 - 0.82]
	Dorsiflexion/ Plantarflexion	Dominant	64.2 (5.0)	58.0 (10.3)	0.02*	0.56	[0.14 - 0.84]
		Non dominant	66.3 (11.0)	63.1 (12.3)	0.057	0.46	[0.07 - 0.84]
	Internal/ External Rotation	Dominant	31.2 (7.2)	34.3 (15.2)	0.051	0.48	[0.06 - 0.81]
		Non dominant	30.2 (7.9)	29.5 (6.2)	0.404	0.21	[0.02 - 0.64]

Note: Pre- and post-intervention data are presented as medians and interquartile ranges (IQR). ES denotes the effect size, and CI represents the confidence interval of the effect size. The bold asteric symbol (*) is utilized to highlight significant differences.

Table 4. 1st lateral shuffling comparison ROM pre vs post training program

Joint	Movement	Test Side	Pre	Post	P-value	ES	CI
Hip	Abduction/ Adduction	Dominant	28.6 (8.5)	29.6 (3.8)	0.854	0.05	[0.01 - 0.57]
		Non dominant	28.1 (8.6)	28.3 (9.3)	0.329	0.25	[0.02 - 0.66]
	Flexion/ Extension	Dominant	38.9 (22.2)	44.4 (14.2)	0.257	0.2	[0.01 - 0.53]
		Non dominant	56.5 (21.7)	56.8 (19.0)	0.089	0.42	[0.05 - 0.77]
	Internal/ External Rotation	Dominant	21.1 (7.3)	27.7 (11.0)	0.001*	0.76	[0.51 - 0.88]
		Non dominant	19.6 (7.5)	27.0 (9.3)	0.013*	0.59	[0.17 - 0.87]
Knee	Abduction/ Adduction	Dominant	23.7 (9.3)	26.1 (4.8)	0.678	0.11	[0.01 - 0.61]
		Non dominant	23.7 (8.0)	26.0 (5.2)	0.305	0.18	[0.01 - 0.51]
	Flexion/ Extension	Dominant	51.5 (7.9)	60.5 (7.2)	0.008*	0.63	[0.27 - 0.84]
		Non dominant	60.6 (11.7)	57.2 (12.8)	0.579	0.14	[0.01 - 0.6]
	Internal/ External Rotation	Dominant	17.5 (5.6)	24.4 (8.2)	0.517	0.17	[0.01 - 0.67]
		Non dominant	16.4 (7.1)	20.7 (4.5)	0.046*	0.35	[0.04 - 0.65]
Ankle	Abduction/ Adduction	Dominant	43.5 (6.5)	48.1 (10.8)	0.459	0.19	[0.02 - 0.6]
		Non dominant	47.3 (11.9)	44.6 (11.0)	0.579	0.14	[0.01 - 0.59]
	Dorsiflexion/ Plantarflexion	Dominant	42.1 (11.4)	42.4 (11.0)	1	0.01	[0.01 - 0.53]
		Non dominant	44.5 (10.4)	41.5 (13.2)	0.579	0.14	[0.02 - 0.61]
	Internal/ External Rotation	Dominant	41.3 (12.2)	44.3 (16.2)	0.322	0.18	[0.01 - 0.51]
		Non dominant	39.8 (9.0)	43.4 (9.4)	0.378	0.22	[0.02 - 0.66]

Note: Pre- and post-intervention data are presented as medians and interquartile ranges (IQR). ES denotes the effect size, and CI represents the confidence interval of the effect size. The bold asteric symbol (*) is utilized to highlight significant differences.

Table 5. 2nd lateral shuffling comparison ROM pre vs post training program

Joint	Movement	Test Side	Pre	Post	P-value	ES	CI
Hip	Abduction/ Adduction	Dominant	32.1 (7.7)	31.3 (5.6)	0.854	0.05	[0.01 - 0.57]
		Non dominant	33.6 (6.1)	36.1 (9.9)	0.459	0.19	[0.01 - 0.64]
	Flexion/ Extension	Dominant	61.2 (11.1)	61.8 (12.4)	0.378	0.22	[0.02 - 0.69]
		Non dominant	58.6 (14.1)	62.3 (15.7)	0.747	0.09	[0.01 - 0.56]
	Internal/ External Rotation	Dominant	24.1 (6.1)	32.2 (12.9)	< 0.001*	0.82	[0.64 - 0.88]
		Non dominant	27.4 (6.3)	33.6 (13.9)	0.002*	0.72	[0.4 - 0.88]
Knee	Abduction/ Adduction	Dominant	26.2 (5.6)	28.2 (9.8)	0.738	0.06	[0 - 0.41]
		Non dominant	24.9 (5.4)	26.9 (3.5)	0.086	0.32	[0.03 - 0.61]
	Flexion/ Extension	Dominant	68.3 (14.8)	68.1 (8.4)	0.487	0.18	[0.01 - 0.61]
		Non dominant	72.1 (15.3)	69.9 (4.6)	0.145	0.36	[0.02 - 0.72]
	Internal/ External Rotation	Dominant	17.5 (6.6)	22.8 (7.4)	0.006*	0.51	[0.2 - 0.74]
		Non dominant	19.5 (7.0)	23.5 (3.6)	0.015*	0.45	[0.14 - 0.71]
Ankle	Abduction/ Adduction	Dominant	56.3 (13.8)	53.3 (10.1)	0.12	0.38	[0.03 - 0.75]
		Non dominant	49.7 (13.7)	45.1 (8.8)	0.098	0.41	[0.03 - 0.82]
	Dorsiflexion/ Plantarflexion	Dominant	50.6 (5.8)	50.7 (11.0)	1	0.01	[0.01 - 0.53]
		Non dominant	49.2 (11.6)	47.0 (6.1)	0.098	0.41	[0.03 - 0.83]
	Internal/ External Rotation	Dominant	46.3 (12.1)	47.6 (13.3)	0.927	0.03	[0.01 - 0.55]
		Non dominant	45.0 (8.5)	46.1 (13.8)	0.263	0.28	[0.02 - 0.67]

Note: Pre- and post-intervention data are presented as medians and interquartile ranges (IQR). ES denotes the effect size, and CI represents the confidence interval of the effect size. The bold asteric symbol (*) is utilized to highlight significant differences.

Table 6. 3rd lateral shuffling comparison ROM pre vs post training program

Joint	Movement	Test Side	Pre	Post	P-value	ES	CI
Hip	Abduction/ Adduction	Dominant	29.9 (8.8)	32.1 (6.4)	0.132	0.37	[0.02 - 0.78]
		Non dominant	27.2 (11.0)	28.2 (7.1)	0.963	0.02	[0.01 - 0.52]
	Flexion/ Extension	Dominant	47.6 (11.8)	51.2 (11.5)	0.306	0.26	[0.02 - 0.69]
		Non dominant	37.7 (21.2)	47.9 (16.1)	0.04*	0.5	[0.1 - 0.84]
	Internal/ External Rotation	Dominant	25.1 (7.6)	30.9 (5.8)	0.003*	0.69	[0.37 - 0.88]
		Non dominant	22.9 (9.8)	31.3 (9.6)	0.023*	0.55	[0.12 - 0.88]
Knee	Abduction/ Adduction	Dominant	26.6 (11.2)	26.8 (7.2)	0.597	0.1	[0.01 - 0.44]
		Non dominant	22.1 (6.8)	25.7 (11.6)	0.505	0.12	[0.01 - 0.5]
	Flexion/ Extension	Dominant	59.6 (17.0)	63.7 (14.3)	0.579	0.14	[0.01 - 0.64]
		Non dominant	60.9 (9.8)	57.1 (8.3)	0.611	0.13	[0.01 - 0.6]
	Internal/ External Rotation	Dominant	19.8 (6.1)	28.5 (8.8)	0.041*	0.36	[0.04 - 0.68]
		Non dominant	19.8 (6.9)	22.5 (8.9)	0.439	0.14	[0.01 - 0.46]
Ankle	Abduction/ Adduction	Dominant	44.0 (10.3)	44.1 (17.8)	0.678	0.11	[0.01 - 0.55]
		Non dominant	41.9 (7.9)	40.9 (13.5)	0.782	0.07	[0.01 - 0.57]
	Dorsiflexion/ Plantarflexion	Dominant	48.9 (11.4)	45.0 (10.4)	0.306	0.26	[0.02 - 0.67]
		Non dominant	54.5 (10.1)	46.9 (7.1)	0.027*	0.53	[0.11 - 0.82]
	Internal/ External Rotation	Dominant	40.4 (7.1)	39.8 (18.9)	0.306	0.26	[0.02 - 0.69]
		Non dominant	42.8 (10.4)	44.3 (10.0)	0.071	0.44	[0.05 - 0.8]

Note: Pre- and post-intervention data are presented as medians and interquartile ranges (IQR). ES denotes the effect size, and CI represents the confidence interval of the effect size. The bold asteric symbol (*) is utilized to highlight significant differences.

Table 7. Backpedaling comparison ROM pre vs post training program

Joint	Movement	Test Side	Pre	Post	P-value	ES	CI
Hip	Abduction/ Adduction	Dominant	20.2 (3.9)	30.2 (8.9)	0.001*	0.77	[0.53 - 0.88]
		Non dominant	20.5 (7.1)	26.8 (7.6)	0.015*	0.58	[0.18 - 0.88]
	Flexion/ Extension	Dominant	46.5 (6.6)	52.7 (20.5)	0.031*	0.52	[0.11 - 0.82]
		Non dominant	49.3 (7.4)	58.4 (14.7)	0.02*	0.56	[0.15 - 0.87]
	Internal/ External Rotation	Dominant	18.8 (4.8)	28.2 (8.6)	0.004*	0.67	[0.34 - 0.88]
		Non dominant	20.7 (5.2)	26.1 (6.1)	0.02*	0.56	[0.13 - 0.83]
Knee	Abduction/ Adduction	Dominant	15.6 (10.9)	22.5 (8.4)	0.132	0.37	[0.03 - 0.74]
		Non dominant	19.0 (5.7)	21.1 (6.7)	0.548	0.15	[0.01 - 0.61]
	Flexion/ Extension	Dominant	75.2 (7.5)	67.9 (16.5)	0.611	0.13	[0.01 - 0.61]
		Non dominant	80.9 (7.1)	75.7 (6.0)	0.08	0.43	[0.04 - 0.8]
	Internal/ External Rotation	Dominant	16.7 (4.4)	22.9 (5.3)	0.487	0.18	[0.01 - 0.68]
		Non dominant	19.0 (5.5)	23.1 (6.3)	0.459	0.19	[0.01 - 0.66]
Ankle	Abduction/ Adduction	Dominant	44.1 (16.3)	45.8 (13.1)	0.174	0.34	[0.02 - 0.75]
		Non dominant	39.2 (10.7)	41.7 (15.2)	0.517	0.17	[0.01 - 0.59]
	Dorsiflexion/ Plantarflexion	Dominant	49.8 (11.4)	45.4 (15.7)	0.132	0.37	[0.03 - 0.76]
		Non dominant	57.8 (7.5)	49.1 (14.4)	0.015*	0.58	[0.17 - 0.87]
	Internal/ External Rotation	Dominant	26.7 (7.2)	30.1 (5.5)	0.263	0.28	[0.02 - 0.66]
		Non dominant	27.3 (7.0)	29.5 (8.6)	0.284	0.27	[0.02 - 0.67]

Note: Pre- and post-intervention data are presented as medians and interquartile ranges (IQR). ES denotes the effect size, and CI represents the confidence interval of the effect size. The bold asteric symbol (*) is utilized to highlight significant differences.

4. Discussion

The present study provides preliminary evidence suggesting that a targeted training program may positively influence agility performance and joint kinematics in soccer players. These findings are in alignment with existing literature emphasizing the critical role of multidirectional movement proficiency in sports like soccer.¹⁷ By analyzing the

performance in the Agility T-test, we observed statistically significant improvements in test execution time for both the dominant (-1.0 s; $p < 0.001$) and non-dominant sides (-0.9 s; $p < 0.001$), supporting prior research that links improvements in agility to optimized coordination and lower limb strength.^{26,27}

A detailed analysis of joint kinematics revealed that the training program induced meaningful changes in the ROM across key joints involved in the test. For instance, the hip joint exhibited increased internal and external rotation ROM for both the dominant and non-dominant sides, suggesting enhanced control and flexibility. Similarly, improvements in knee joint ROM during forward and lateral phases underscore the importance of dynamic strength and proprioceptive training in augmenting functional joint mobility.²⁸ However, a notable decrease in ankle plantar/dorsiflexion ROM ($p = 0.001$) was observed, likely reflecting the adaptation to specific movement patterns during agility drills.²⁹

The observed enhancements can be attributed to the structured training program, which incorporated exercises targeting strength, coordination, and proprioception. According to Seitz et al.³⁰, lower limb strength is directly associated with improved sprint and agility performance. This relationship appears to be supported by our findings, as players showed improvements in both time-based performance and joint kinematics. Additionally, exercises designed to stimulate reactive agility, such as tagging and directional changes, contributed to the observed gains in lateral movement efficiency.⁸

One interesting aspect of this study is the differential response between the dominant and non-dominant sides. While both sides demonstrated significant improvements, the slightly larger gains observed on the dominant side may reflect its preexisting biomechanical advantage or greater neural efficiency in executing sport-specific movements.³¹ This finding highlights the potential need for further training adaptations that address asymmetries in functional performance.

Despite these promising results, several limitations should be acknowledged. First, this study was designed as a preliminary feasibility investigation, and thus involved a relatively small sample of 17 healthy male amateur athletes, limiting the generalizability of findings. Additionally, no formal power analysis was conducted prior to the study. Another significant limitation is the absence of a control group, which restricts the ability to isolate the effects of the targeted training from potential confounding factors such as environmental conditions and changes in the participants' training state between testing periods. Future studies would benefit from controlled experimental designs that include a control group to better evaluate the specific impacts of the proposed training protocols. Furthermore, environmental conditions differed between baseline and follow-up assessments, with cooler temperatures during the post-test potentially affecting muscle function and joint mechanics. Another limitation is the exclusive focus on the lower limbs. Incorporating total-body kinematic analysis could provide insights into the coordination between upper and lower body segments and its contribution to agility performance.³² Furthermore, the segmentation of movements, particularly during the Change of Direction (COD) phase, was not performed. Segmenting and analyzing the COD separately could provide deeper insights into specific biomechanical adaptations and performance improvements in this critical phase of agility tasks.

5. Conclusion

In conclusion, the findings of this preliminary study suggest that targeted training programs integrating strength, coordination, and proprioceptive exercises can positively influence joint kinematics, potentially enhancing agility and athletic performance in soccer players. Nevertheless, given the methodological limitations, including lack of a control group and variable environmental conditions, these results should be interpreted cautiously.

Future research should investigate the longitudinal impact of such training across an entire season, particularly its role in injury prevention and overall athletic development. Incorporating surface-specific training programs and whole-body kinematic analyses could provide deeper insights into the biomechanical mechanisms underlying agility and performance improvements. This work lays a first step for advancing our understanding of targeted training's impact on athletic performance and joint functionality.

Author Contributions

Conceptualization, Salvatore Pinelli, Raffaele Zinno and Laura Bragonzoni; Data curation, Salvatore Pinelli; Formal analysis, Raffaele Zinno; Investigation, Giulio Senesi and Maria Scoppolini Massini; Methodology, Raffaele Zinno and Salvatore Pinelli ; Validation, Giulio Senesi, Erika Pinelli, Maria Scoppolini Massini; Visualization, Salvatore Pinelli; Writing - original draft, Salvatore Pinelli, Giulio Senesi, Maria Scoppolini Massini; Writing - review & editing, Erika Pinelli, Raffaele Zinno and Laura Bragonzoni

Ethical Compliance

Research experiments conducted in this article with humans were approved by the Bioethical Committee and responsible authorities of our research organization(s) following all guidelines, regulations, legal, and ethical standards as required for humans or animals.

Conflicts of Interest

There are no conflicts to declare.

References

1. Siramaneerat I, Chaowilai C. Impact of specialized physical training programs on physical fitness in athletes. *jhse*. 2020;17(2). doi:10.14198/jhse.2022.172.18
2. Barnett A, Cerin E, Reaburn P, Hooper S. The effects of training on performance and performance-related states in individual elite athletes: a dynamic approach. *J Sports Sci*. 2010;28(10):1117-1126. doi:10.1080/02640414.2010.497817
3. Grindstaff TL, Hammill RR, Tuzson AE, Hertel J. Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: a numbers-needed-to-treat analysis. *J Athl Train*. 2006;41(4):450-456.
4. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med*. 1999;27(6):699-706. doi:10.1177/03635465990270060301

5. Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med.* 2005;33(7):1003-1010. doi:10.1177/0363546504272261
6. Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ.* 2005;330(7489):449. doi:10.1136/bmj.38330.632801.8F
7. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19(1):51-60. doi:10.1519/13643.1
8. Sheppard J, Young W. Agility Literature Review: Classifications, Training and Testing. *Journal of sports sciences.* 2006;24:919-932. doi:10.1080/02640410500457109
9. Sporis G, Jukic I, Milanovic L, Vucetic V. Reliability and factorial validity of agility tests for soccer players. *J Strength Cond Res.* 2010;24(3):679-686. doi:10.1519/JSC.0b013e3181c4d324
10. Paul DJ, Gabbett TJ, Nassis GP. Agility in Team Sports: Testing, Training and Factors Affecting Performance. *Sports Med.* 2016;46(3):421-442. doi:10.1007/s40279-015-0428-2
11. Getchell B. *Physical Fitness: A Way of Life. Second Edition.* John Wiley & Sons, Inc; 1979.
12. Rago V, Brito J, Figueiredo P, Ermidis G, Barreira D, Rebelo A. The Arrowhead Agility Test: Reliability, Minimum Detectable Change, and Practical Applications in Soccer Players. *J Strength Cond Res.* 2020;34(2):483-494. doi:10.1519/JSC.0000000000002987
13. Joo CH. The effects of short-term detraining on exercise performance in soccer players. *J Exerc Rehabil.* 2016;12(1):54-59. doi:10.12965/jer.160280
14. Semenick D. TESTS AND MEASUREMENTS: The T-test. *Strength & Conditioning Journal.* 1990;12(1):36.
15. Paole K, Madole K, Garhammer J, Lacourse M, Rozenek R. Reliability and Validity of the T-Test as a Measure of Agility, Leg Power, and Leg Speed in College-Aged Men and Women. *The Journal of Strength & Conditioning Research.* 2000;14(4):443.
16. Raya MA, Gailey RS, Gaunaud IA, et al. Comparison of three agility tests with male servicemembers: Edgren Side Step Test, T-Test, and Illinois Agility Test. *J Rehabil Res Dev.* 2013;50(7):951-960. doi:10.1682/JRRD.2012.05.0096
17. Munro AG, Herrington LC. Between-session reliability of four hop tests and the agility T-test. *J Strength Cond Res.* 2011;25(5):1470-1477. doi:10.1519/JSC.0b013e3181d83335
18. Picerno P. 25 years of lower limb joint kinematics by using inertial and magnetic sensors: A review of methodological approaches. *Gait Posture.* 2017;51:239-246. doi:10.1016/j.gaitpost.2016.11.008
19. Nijmeijer EM, Heuvelmans P, Bolt R, Gokeler A, Otten E, Benjaminse A. Concurrent validation of the Xsens IMU system of lower-body kinematics in jump-landing and change-of-direction tasks. *Journal of Biomechanics.* 2023;154:111637. doi:10.1016/j.jbiomech.2023.111637

20. Karatsidis A, Bellusci G, Schepers HM, de Zee M, Andersen MS, Veltink PH. Estimation of Ground Reaction Forces and Moments During Gait Using Only Inertial Motion Capture. *Sensors (Basel)*. 2016;17(1):75. doi:10.3390/s17010075
21. de Leva P. Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics*. 1996;29(9):1223-1230. doi:10.1016/0021-9290(95)00178-6
22. Debertin D, Wargel A, Mohr M. Reliability of Xsens IMU-Based Lower Extremity Joint Angles during In-Field Running. *Sensors*. 2024;24(3):871. doi:10.3390/s24030871
23. Schepers M, Giuberti M, Bellusci G. *Xsens MVN: Consistent Tracking of Human Motion Using Inertial Sensing.*; 2018. doi:10.13140/RG.2.2.22099.07205
24. Fritz CO, Morris PE, Richler JJ. Effect size estimates: current use, calculations, and interpretation. *J Exp Psychol Gen*. 2012;141(1):2-18. doi:10.1037/a0024338
25. Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155-159. doi:10.1037//0033-2909.112.1.155
26. Comfort P, Bullock N, Pearson SJ. A comparison of maximal squat strength and 5-, 10-, and 20-meter sprint times, in athletes and recreationally trained men. *J Strength Cond Res*. 2012;26(4):937-940. doi:10.1519/JSC.0b013e31822e5889
27. Jovanovic M, Sporis G, Omrcen D, Fiorentini F. Effects of speed, agility, quickness training method on power performance in elite soccer players. *J Strength Cond Res*. 2011;25(5):1285-1292. doi:10.1519/JSC.0b013e3181d67c65
28. Cronin JB, Hansen KT. Strength and power predictors of sports speed. *J Strength Cond Res*. 2005;19(2):349-357. doi:10.1519/14323.1
29. Bangsbo J, Mohr M, Krstrup P. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci*. 2006;24(7):665-674. doi:10.1080/02640410500482529
30. Seitz LB, Reyes A, Tran TT, Saez de Villarreal E, Haff GG. Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis. *Sports Med*. 2014;44(12):1693-1702. doi:10.1007/s40279-014-0227-1
31. Kovacikova Z, Zemková E. The Effect of Agility Training Performed in the Form of Competitive Exercising on Agility Performance. *Res Q Exerc Sport*. 2021;92(3):271-278. doi:10.1080/02701367.2020.1724862
32. McGovern A, Dude C, Munkley D, et al. Lower limb kinematics of male and female soccer players during a self-selected cutting maneuver: Effects of prolonged activity. *Knee*. 2015;22(6):510-516. doi:10.1016/j.knee.2015.05.005