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Article

The Effect of Spinal Asymmetries on Physical Fitness Parameters in Young Elite Soccer Players

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Abstract: The purpose of the study was to examine the effect of spinal asymmetries on specific physical fitness parameters in young elite soccer players. Fifty male soccer players, all members of the under 17 (U17) and 15 (U15) National teams of Cyprus, were initially evaluated for thoracic kyphosis, lumbar lordosis and scoliosis asymmetries. Based on the spinal asymmetries' initial evaluation, soccer players were categorized into the asymmetry group (AG) and normal group (NG) per spinal asymmetry. Hamstring and lower-back flexibility, countermovement jump (CMJ) and lower body isokinetic maximum force were evaluated between AG and NG. CMJ with arm swing was lower in kyphotic posture AG compared with the NG (AG: 41.70 ± 3.59 cm, NG: 44.40 ± 4.34 cm; $p = 0.028$). Single leg CMJ was lower in both legs in scoliotic posture AG compared with the NG (right: AG: 17.42 ± 1.86 cm, NG: 19.16 ± 2.42 cm, $p = 0.008$, left: AG: 17.54 ± 1.33 cm, NG: 19.97 ± 2.91 cm; $p = 0.002$). Sit-and-reach flexibility was lower in scoliotic posture AG (AG: 20.44 ± 5.76 cm, NG: 24.82 ± 6.83 cm; $p = 0.024$) and higher in lordotic posture AG (AG: 25.95 ± 6.59 cm, NG: 21.73 ± 6.45 cm; $p = 0.04$) both compared with the NG. No significant difference was found for quadriceps and hamstrings concentric peak torque between the AG and NG ($p > 0.05$). The current study revealed that kyphotic and scoliotic posture asymmetries deteriorate neuromuscular explosiveness performance and diminish lower limbs' flexibility in young International-level soccer players.

Keywords: body posture; countermovement jump; sit-and-reach flexibility; isokinetic power



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1. Introduction

Soccer is a multifaceted sport that demands high physical, technical, tactical and mental skill levels that a player has to progressively develop in order to be able to compete at an elite level [1,2]. During recent decades, the rapid increase in the number of soccer competitions, along with the demanding nature of long-term development training programs [3], has led to a significant increase in the incidence of injuries among both professional [4] and young soccer players in particular [5].

Regular participation and early specialization may also increase the risk of developing postural asymmetries, which may subsequently progressively lead to the development of acute and/or chronic injuries [6,7]. Recent evidence suggests that postural asymmetries may gradually result in dysfunctions in the execution of movement, tissue structural modifications due to overuse, changes in muscle contraction, and neuromechanical and biomechanical changes in movement execution [8–12]. All of these biological and anatomical abnormalities may lead to pathological and/or dysfunctional positioning and subsequently may diminish exercise performance in athletes [8]. It was observed, for example, that due to spinal asymmetries, any muscle, either in a shortened or lengthened functional state, can be weak and/or underactive due to (a) altered length–tension relationships, (b) reciprocal inhibition leading to the modification of muscle fibers' recruitment strategy and (c) the

biomechanical dysfunction of movement patterns [13]. A significant increase in spine curvature and malalignment was found to be associated with increased training exposure in adults [6] and in young soccer players in particular [5].

For example, body posture and foot arches were compared between a group of young soccer players and a control group, including non-athlete boys (13–15 years old). It was observed that the most frequent postural deformities were the deepening of thoracic kyphosis, scapular protrusion, forward rotated shoulders, and poor knee and foot arch alignment. The researchers presumed that upper-body postural deformities might occur due to the anatomical position a player usually takes when passing the ball [7]. Grabara (2012), for example, compared body posture between soccer players and their untrained peer boys (11–14 years old), where upper body posture was assessed in transverse, frontal and sagittal planes. Soccer players demonstrated a more symmetrical pelvic lateral inclination angle. However, the 12-year-old soccer players had more significant asymmetry in the pelvis in the transverse plane. Soccer players' width symmetry of the waist triangles was more symmetrical, especially in 12- and 13-year-olds. A value of spinous process line deflection of more than 10 mm indicated spinal scoliosis. Soccer players had higher deflection (5.5%) than the untrained group (2.9%). The results revealed a 5–10 mm deflection in 22% of soccer players and 31% of the untrained group. In the sagittal plane, there were significant differences between the two groups. At the age of 11 and 14, soccer players demonstrated a higher γ angle, consequently increasing lumbar lordosis (β angle + γ angle) [14].

Recently, it was found that the upper thoracic and trunk inclination angles were significantly higher in soccer players in specific age groups (8–9, 10–11 and 12–13 years old) when compared with their untrained peers. In particular, in 8–9- and 10–11-year-olds, it was found that the lumbosacral and the upper thoracic angles were significantly larger in the soccer players. The researchers suggested that this possibly occurs due to the adopted running stance in soccer, which forces the trunk to lean forward. Such adoption may change the habit of body posture and become fixed over time, introducing a new postural pattern in the athlete [15]. Elite young soccer players were found to present functional deficits, particularly in deep squat and trunk stability tasks, as well as in asymmetry between the right and left sides of the spine [16]. For this reason, coaches and medical teams of soccer academies started emphasizing trunk stability improvement through specific training/exercise programs [16].

It is also well-documented that most soccer players have a dominant leg, which has been found to be a factor causing asymmetry in the strength and flexibility of the lower extremities [10,17–21]. The laterality in certain sports was associated with asymmetrical adaptations in bones and muscle circumference, as well as in flexibility and strength [17,22–24]. Therefore, functional skeletal asymmetries may increase as a result of the laterality of sports training [22]. Bishop et al. (2018) concluded that there is a complication of inter-limb asymmetries and that further research should be conducted focusing on understanding the mechanisms behind the occurrence of the inter-limb difference. Such an understanding will reveal valuable information to develop focused testing and intervention strategies to reduce inter-limb asymmetries [25].

However, although several studies have examined the body asymmetries in youth sports in relation to injury prevention, no studies so far have examined the effect of these asymmetries on soccer physical fitness parameters in young elite soccer players. Consequently, the purpose of the present study was to examine the effect of spinal asymmetries on specific parameters related to physical fitness in young International-level soccer players. Based on the above, it was hypothesized that spinal asymmetries might negatively influence physical fitness parameters in young male soccer players.

2. Materials and Methods

2.1. Participants

Fifty young International-level male soccer players (age: 15.4 ± 1.39 years; training age: 9.2 ± 1.82 years; weight: 66.5 ± 7.44 kg; height: 174.2 ± 6.74 cm), all active mem-

bers of the under 17 (U17) and under 15 (U15) Cyprus national teams, who train 5 days per week (~7.5 h) and participate in at least one official game per week, voluntarily took part in the study after being informed of the purpose and the potential benefits of the experimental procedure. The study was approved by the National Bioethics Committee (EEBK/EII/2017/39) and conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki). Following explanation of the experimental methods and procedures, parental and players' written informed consent were obtained prior to any assessment. All the young soccer players completed a medical history questionnaire. None of them used any medication or drugs which could influence the physical performance results, and no participant had any disease or musculoskeletal injury during the study period. Participants were not to engage in any strenuous exercise training or sports competition at least 48 h before the testing procedure.

2.2. Experimental Design

Figure 1 depicts the experimental design, including the order in which the experimental evaluations were executed. Testing procedures were performed in the same laboratory for all athletes under the same environmental conditions (~21 °C and ~60% humidity). To ensure that valid and consistent techniques were used during the testing procedure, four experienced researchers supervised all tests. All the measurements were completed in a two-week period. Measurements were performed on a single day for each participant in the same order and included: anthropometric characteristics, body composition, spinal asymmetry evaluation, lower body flexibility, countermovement jumps (CMJs) and single leg CMJs and lower body isokinetic maximum force (see Figure 1 below). The participants reported to the laboratory, during the morning hours (8:00–14:00), in groups of five. Each group stayed in the laboratory for around two hours to complete all evaluations. They were instructed to avoid any tea, caffeine and alcohol consumption for at least 48 h prior to physical fitness evaluations. One and a half hours prior to visiting the laboratory, all participants consumed a prescribed high-carbohydrate (CHO) meal (~90% CHO: ~10 g per kg of body weight), while during their stay in the laboratory, water intake was allowed ad libitum as previously described [26]. The CHO meal included: 1, 1.5 or 2 plain bagels (~52 g each) for the players whose body weight was between 50 and 59 kg, 60 and 69 kg and 70 and 80 kg, respectively; 2 tablespoons of honey (~35 g) and 1 medium banana (~30 g). All the participants were familiar with the testing protocol, as they had previously been evaluated during the season with the same testing procedures.

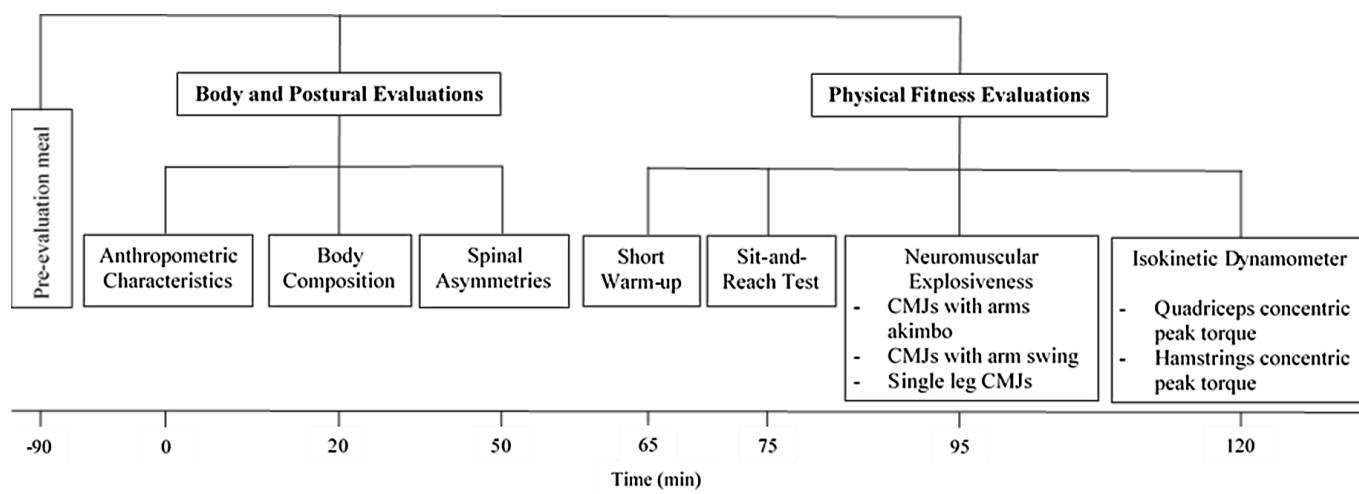


Figure 1. Schematic illustration of the experimental design with diagrammatic representation of the order from left to right that the anthropometrics, spinal asymmetries and physical fitness evaluations were executed.

2.3. Spinal Asymmetry Evaluation

All the spinal asymmetry evaluations were performed by an expert orthopedic surgeon and a highly trained sports kinesiologist. Thoracic kyphosis and lumbar lordosis were evaluated using an inclinometer (AcuAngle® Inclinometer, Baseline Evaluation Instruments, USA), as previously described [27]. Scoliosis (spinal rotation) was assessed with a scoliometer (Mizuho Osi®, Mizuho OSI Inc., Tokyo, Japan) as previously described [28]. Based on these evaluations, the participants were categorized into the “Normal” group (NG) or “Asymmetry” (AG) group (see in Section 3). The categorization for thoracic kyphosis and lordosis, as well as for scoliosis, was based on Van Blommestein et al. (2012) [27,29], respectively. In cases where a participant had more than one spinal asymmetry, the asymmetry with the highest asymmetrical degree was considered as the primary one, and it was categorized in the relevant group accordingly. Reliability was verified using the two-way random effect intraclass correlation coefficient (ICC) with 95% confidence intervals (CI) for the spinal asymmetry evaluation instruments (Table 1).

Table 1. Intraclass correlation coefficient for spinal asymmetries instruments.

	Intraclass Correlation (ICC)	95% Confidence Interval (CI)	p Value
Scoliometer	0.988	0.981–0.993	0.001
Inclinometer T1–T2	0.987	0.979–0.993	0.001
Inclinometer T12–L1	0.995	0.991–0.997	0.001
Inclinometer S2–S3	0.995	0.991–0.997	0.001

Spinous process of T1 = first thoracic vertebra, T2 = second thoracic vertebra, T12 = twelfth thoracic vertebra, L1 = first lumbar vertebra, S2 = second sacral vertebra, S3 = third sacral vertebra.

2.4. Anthropometrics and Flexibility Evaluations

Height and body mass were measured with a stadiometer and calibrated scale (Tanita Digital Scale, BC-545n, Southampton, UK) without shoes to the nearest 0.1 cm and 0.1 kg, respectively. The flexibility of the lower back and hamstrings was measured using the sit-and-reach test (Cranlea Medical Electronics, Bournville, Birmingham B30 2AH, UK) as previously described [30]. Two trials were performed, and the best one was used for further statistical analysis. Measurements were performed by the same investigator on all players. The ICC and the CV% for the sit-and-reach test were $r = 0.979$ and 2.71%, respectively.

2.5. Neuromuscular Explosiveness and Isokinetic Dynamometer Evaluations

Following a 15 min warm-up and 3–5 low- to medium-intensity CMJs, participants performed maximum CMJs (Optojump Next, Modular System, Microgate, Italy) for the evaluation of the neuromuscular explosiveness. The order of the jumps first included CMJs with arms akimbo (CMJ), followed by CMJs with arm swing (CMJas) and single leg CMJs (CMJR and CMJL). All CMJs were performed with 1 min of rest between trials and 5 min of rest between different jumps. All the participants were instructed to jump as high as possible.

Each participant started the jump procedure in the standing position, dropped into the squat position, and then immediately jumped as high as possible. The depth of knee flexion used during each CMJ was individually determined by each participant [31]. Participants were instructed to maintain their hands akimbo to avoid arm swing, to take off with the ankles and knees fully extended, and to land on the toes balanced on the same spot, while the CMJas then followed [31]. A maximum of four trials were performed for CMJ and CMJas, three trials were performed for CMJR and CMJL, and the best jump height was recorded for further analysis. The validity and reliability of all jumps were previously reported [32]. Thirty seconds of passive rest was allowed between trials and approximately 3 min between different jump-type tests.

Fifteen minutes following the CMJs, participants performed the lower body isokinetic dynamometer test (HUMAC NORM isokinetic extremity system, Stoughton, MA, USA). All participants were familiar with the isokinetic test since two familiarization trials were scheduled prior to the main evaluations. After a short warm-up on a stationary bicycle and with dynamic stretching as well as a warm-up on the dynamometer, participants performed a maximum of 3 concentric repetitions (quadriceps' and hamstrings' concentric peak torque). Briefly, the participants were seated comfortably on the isokinetic dynamometer chair in an upright position, with the backrest at 85°. Straps were used to ensure a stable position for the exercising leg and hips. The knee angle was set at 60° flexion (0° = full knee extension) as previously described [33]. The best peak torque value out of the three main trials performed by each participant was included in the statistical analysis.

2.6. Statistical Analysis

Following the normality of the distribution test (Kolmogorov–Smirnov), all the data were expressed as the median and interquartile range (IQR). Since all the data violated the assumptions for parametric analysis (i.e., equality of variance and normality of distribution), a non-parametric examination was carried out using a Mann–Whitney U-test for un-paired evaluations between the AG and NG for each asymmetry (i.e., kyphotic, lordotic and scoliotic postures). All the statistical analyses were performed using the SPSS software (version 20 for Windows; IBM SPSS Inc., Chicago, IL, USA). The effect sizes (ESs) of each fitness performance per spine asymmetry category were estimated according to the Rosenthal (1991) equation ($r = Z/\sqrt{N}$) [34]. The ESs were interpreted according to Cohen's criteria. A value of $r = 0.1$ was considered a small effect size, 0.3 represented a medium effect size and 0.5 a large effect size [35]. Statistical significance was declared at $p < 0.05$.

3. Results

Table 2 presents the spinal asymmetry groups' categorization and participants' anthropometric characteristics of each group, including the norms for each categorization.

Table 2. Spinal asymmetries groups' categorization and participants' anthropometric characteristics of each group.

Spinal Asymmetry		Normal		Asymmetry
Kyphotic Posture	Norms: 36–40° (N = 24)	Age: 15.93 ± 1.29 years	Norms: 41–60° (N = 26)	Age: 14.83 ± 1.29 years
		Height: 174.21 ± 7.18 cm		Height: 174.15 ± 6.45 cm
		Weight: 67.48 ± 7.29 kg		Weight: 65.60 ± 7.61 kg
Lordotic Posture	Norms: 26–29° (N = 30)	Age: 15.45 ± 1.40 years	Norms: 30–50° (N = 20)	Age: 15.23 ± 1.41 years
		Height: 173.33 ± 6.36 cm		Height: 175.45 ± 7.25 cm
		Weight: 65.72 ± 7.24 kg		Weight: 67.67 ± 7.76 kg
Scoliotic Posture	Norms: 0–4° (N = 34)	Age: 15.37 ± 1.41 years	Norms 5–7° (N = 16)	Age: 15.34 ± 1.41 years
		Height: 175.09 ± 5.87 cm		Height: 172.25 ± 8.18 cm
		Weight: 67.41 ± 6.98 kg		Weight: 64.58 ± 8.24 kg

Figures 2 and 3 present the CMJs and peak torque performance results as well as the CMJ reaction time performance and the sit-and-reach flexibility scores observed following the Mann–Whitney U-statistical test, which revealed the differences between the NG and AG. The performance in CMJs was lower for the AG compared to the NG ($U = 199$, $z = -2.195$, $p = 0.028$, $r = -0.31$) in kyphotic posture categorization. The AG performed better in the sit-and-reach flexibility test than the NG ($U = 196.5$, $z = -2.053$, $p = 0.040$, $r = -0.29$) based on lordotic posture categorization, although AG performance in the sit-and-reach test was lower compared to that of the NG ($U = 163.5$, $z = -2.260$, $p = 0.024$, $r = -0.32$) based on scoliotic posture categorization. The AG performed worse in the single

leg CMJ than the NG based on scoliotic posture categorization; right ($U = 144.5$, $z = -2.653$, $p = 0.008$, $r = -0.38$) and left ($U = 121.5$, $z = -3.131$, $p = 0.002$, $r = -0.44$). No significant difference was found between the AG and NG in CMJ reaction time and in concentric peak torque ($p > 0.05$).

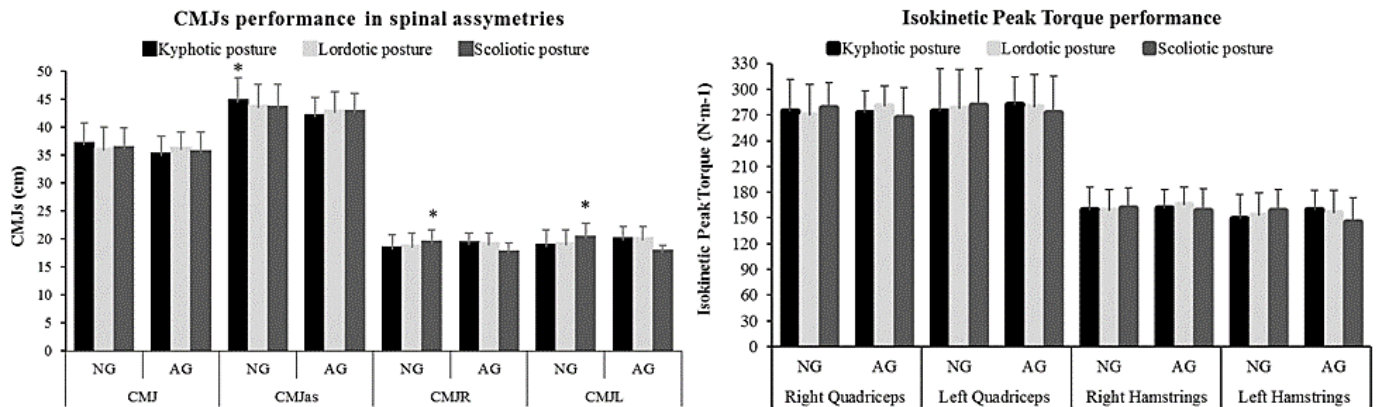


Figure 2. Median values and IQR for: Countermovement Jumps (CMJs) and peak torque performance in kyphotic, lordotic and scoliotic postures between normal (NG) and asymmetry (AG) groups. *: Indicates significant differences in CMJs performance between NA and AG. CMJ = Countermovement jump, CMJas = CMJ with arm swing, CMJR = CMJ with right leg, CMJL = CMJ with left leg, cm = centimeters, N = Newton.

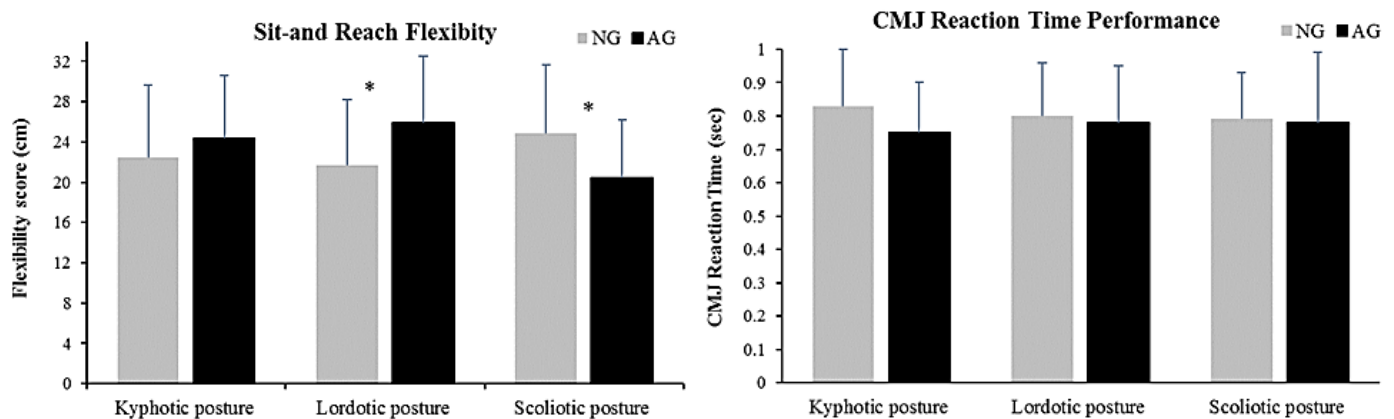


Figure 3. Median values and IQR for: Sit-and-Reach flexibility scores and CMJ reaction time performance in kyphotic, lordotic and scoliotic postures between normal (NG) and asymmetry (AG) groups. sec = seconds *: Indicates significant differences between NA and AG.

4. Discussion

The present study was the first to examine the effect of spinal asymmetries on soccer-specific physical fitness parameters in young International-level soccer players. The novel finding of the current study was that spinal asymmetries might negatively influence neuromuscular explosiveness performance and deteriorate the functional capacity of the hamstring and lower back flexibility in young International-level soccer players.

In the current study, the sit-and-reach flexibility and CMJ performance of the right and left legs were lower in the scoliotic posture AG compared with the NG. Both neuromuscular explosiveness and hamstring flexibility abilities were previously characterized as crucial components for soccer-specific performance [9,30] and injury prevention [36], respectively. It is possible that the inferior CMJ performance observed in the AG is due to the negative effect of scoliotic posture asymmetry on the hamstring and lower back flexibility. This may subsequently negatively influence hamstring muscle elasticity and motor coordination, which both contribute to improving lower limbs' neuromuscular power. It has previously

been found that muscular performance was increased following the application of regular hamstring flexibility training, which was able to improve peak torque generation [37] and simultaneously reduce the elastic component stiffness that both mechanistic actions contribute to by augmenting the utilization of elastic strain energy, therefore enhancing muscle contraction capability [28]. Indeed, it was recently also observed that a regular hamstring stretching training intervention improved hamstring flexibility, 35 m sprinting, countermovement jump and agility performance [30], as well as myofascial balance and pelvic symmetry, which may contribute in improving neuromuscular balance and contraction velocity [38]. In addition, considering the CMJ as a powerful movement combining several muscles of the upper and lower body musculature system, a decreased performance may be observed in the presence of scoliotic posture at any level of spinal asymmetry due to the muscle imbalance between the concave and convex sides [13,39,40]. It is, therefore, possible that scoliotic posture asymmetries induced a reduction in hamstring flexibility, which in turn may diminish neuromuscular explosiveness performance, and this is more evident when the jump is executed either with the left or the right leg alone.

It was also observed from the current study that CMJas performance was lower in the kyphotic posture AG compared with the NG. In the case of CMJas, where the trunk should be in an upright position during arms swing and flight phases, there is a potential restriction in performance since the mechanically involved joints are not moving within the normal range of motion and the muscles are imbalanced due to the postural malalignments [15]. Malmström et al. (2015) found that the biomechanical/biodynamical conditions of the arm and shoulder movements were negatively affected by the slouched posture, decreasing their movement range and velocity. Activity patterns of the axioscapular muscles changed, requiring additional muscle work to elevate the arm, the upper trapezius, the lower trapezius and the serratus anterior muscles [39]. All of the above partially dysfunctional musculoskeletal mechanisms may explain the inferior CMJas performance observed in the kyphotic posture AG compared to NG.

Unexpectedly, the present results also show that the lordotic posture AG performed better in sit-and-reach flexibility than the NG without, however, observing any other physical fitness differences in this categorization. In this case, the key question arising is: why does the higher hamstring flexibility observed in this lordotic AG not contribute to enhancing neuromuscular explosiveness, since, as was discussed above, better hamstring flexibility may contribute to improving neuromuscular explosiveness performance [30,38]? Since this anatomical asymmetry does not contribute to enhancing hamstring flexibility in a physical way, based namely on flexibility training interventions, it would not be expected to improve neuromuscular explosiveness performance by increasing peak torque generation and/or by reducing the utilization of elastic strain energy, which were both found to improve muscle contraction [37,38,41], as discussed above. The sit-and-reach flexibility test, for example, involves maximal trunk flexion with knee extension and ankle at 90° of dorsiflexion [42]. Lordotic posture is presented with the lumbar spine hyperextended, the pelvis is anteriorly tilted, the hip joints are flexed, the knee joints are slightly hyperextended and the ankle joints in slight plantar flexion [13]. Since, in lordotic posture, the hamstrings are elongated, this particular anatomical asymmetry possibly allows the player to score higher in the sit-and-reach flexibility test [13]. This, however, was only due to the anatomical asymmetry, without contributing to enhancing muscle contraction velocity or power performance. Consequently, based on the current results, lordotic posture per se may negatively affect neuromuscular explosiveness performance.

In the current experiment, we also examined the effect of spinal asymmetries on the quadriceps' and hamstrings' concentric peak torque performance. It was observed that kyphotic, lordotic and scoliotic spinal asymmetries did not influence quadriceps' and hamstrings' concentric peak torque performance, as measured with the isokinetic dynamometer, possibly due to the nature of the test. The isokinetic dynamometer separately measures the concentric or eccentric maximal strength of both quadriceps and hamstrings and, therefore, isolates the tested muscle group without being affected by other asymmetries

or muscle imbalances [43]. A different full-body performance test (i.e., mid-thigh pulls) involving both the upper and lower body may reveal significant differences in maximum strength compared to isokinetic leg extension and flexion. However, such a premise must be further examined.

The limitations of the current study were: (a) a larger sample size of young national soccer players could increase the power of the study. However, it is not a feasible task to locate a larger sample size of elite young active national players at once since every national team squad includes no more than 27 or 28 players, including the goalkeepers. So, in this study, we excluded the goalkeepers and evaluated all active members of the under 17 (U17) and under 15 (U15) Cyprus national teams during the period that the study was executed. (b) The mechanical properties of musculoskeletal and tendinous function, as well as the cellular, molecular and neural mechanisms associated with exercise performance parameters, should also be evaluated. (c) The current sports performance results should be treated with caution since a small number of players were initially diagnosed with more than one spinal asymmetry, and we do not know to what extent this could influence the results.

Practical Application

From a practical application point of view, the coaching and medical teams of soccer academies, in particular, may consider performing at least an annual evaluation of spine asymmetry identification. This may contribute to eliminating spinal asymmetry incidences through specific corrective exercise intervention programs. The purpose of these programs is to improve the long-term training development plan and to specifically enhance the neuromuscular explosiveness performance of young soccer players. In addition, in cases in which any kyphotic and scoliotic spinal asymmetries are identified, a specific lower back and hamstring flexibility intervention program should also be applied daily.

5. Conclusions

In conclusion, the current study revealed that kyphotic and lordotic posture may negatively influence neuromuscular explosiveness performance, while scoliotic posture may deteriorate sit-and-reach flexibility as well as the single right and left leg CMJ performance in young elite soccer players.

Author Contributions: E.T.: study design/methodology, spinal asymmetries evaluation, data collection, formal data analysis, writing—original draft preparation, writing—reviewing and editing. M.C.: study design/methodology, data collection, writing—reviewing and editing. A.A. and N.Z.: study design/methodology, data collection, formal data analysis, writing—reviewing and editing. M.T.: clinical and spinal asymmetries evaluation, writing—reviewing and editing. M.H.: conceptualization, study design/methodology, data collection, formal data analysis, writing—original draft preparation, writing—reviewing and editing, project administration. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was approved by the National Bioethics Committee (EEBK/EΠ/2017/39) and conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare no conflict of interest.

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