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Original Research

The effects of combined aerobic and resistance training program in Korean male youth soccer players

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Abstract

Background: This study analyzed the effects of short-term, off-season physical training on the core dynamic and thigh muscle function of youth soccer players. **Methods**: For two weeks during the off-season, middle-school soccer players (MSP, n = 75) and high-school soccer players (HSP, n = 104) participated in exercise training (five times per week). Their body composition, physical fitness, core dynamic balance, and isokinetic muscle function were compared before and after training. **Results**: Both groups showed significant ($p < 0.01$) decreases in body composition, and significant ($p < 0.01$) improvements in physical fitness (MSP, 1.02–1.15%; HSP, 1.05–3.76%). In terms of core dynamic balance, both groups showed a significant ($p < 0.01$) increase in back strength (MSP, 1.09–1.11%; HSP, 1.06–1.16%), and a significant ($p < 0.05$) decrease in the left-right difference (MSP, 0.70–1.43%; HSP, 1.00–1.09%) after training. For isokinetic muscle function at the knee joint, the MSP group showed significant improvement in flexors, whereas the HSP group showed significant improvements in both the extensors and flexors. The dominant *vs* non-dominant deficit decreased significantly in the MSP group for total work and average power per repetition of the flexors at 60 deg/sec and in the HSP group for peak torque and total work of the flexors at 60 deg/sec. The hamstring-to-quadriceps ratio increased significantly at 60 deg/sec on the dominant side in the MSP group. **Conclusions**: In youth soccer players, two weeks of physical training during the off-season improved both physical fitness and core dynamic balance, suggesting that this training is effective for injury prevention.

Keywords: soccer; off-season; adolescent; physical fitness; muscle function

1. Introduction

Soccer performance is determined by various factors, such as body composition [1], morphological attributes [2,3], technical and tactical skills [4,5], and mental and physiological characteristics [6]. Body composition, along with mental, physical, functional, and physiological characteristics, is one of the most important factor that can determine athletic potential and likelihood of success in a specific sport [1,7]. However, there is often a tendency to focus more on training technique and tactics than physical fitness [6]. Soccer is a sport that requires intermittent, repetitive, vigorous movements for a total of 90 mins (two halves of 45 mins each) in an effort to regain or retain possession of the ball and score goals. As such, it is difficult to efficiently exhibit technique and tactics if these are not supported by physical fitness. Considering the nature of soccer, which consists of many changeable activities, such as running, jumping, turning, and sprinting [8], a high level of physical fitness, comprising endurance, power, speed, and change of direction, needs to be maintained [9–11]. However, the soccer year is divided into season and off-season, and training to improve physical fitness during the off-season is typically entrusted to the athletes themselves [12]. Effective training is required by soccer players who experience a decline in physical fitness during this period due to a reduced volume of training [13].

Generally, elite youth soccer players show better performance than their non-elite peers in terms of physical ability [14,15], sprinting, and jumping [16,17]. Maintenance of superior physical ability through training is also very important for injury prevention. Therefore, many instructors and athletes are strongly motivated by the idea that only hard, intense training can produce good outcomes. For young soccer players, however, longer training time can increase the risk of injury [18]. Hamstring strain is the most common non-contact injury suffered by elite male soccer players. Although the causes are diverse, it is closely related to decreased muscle (hamstring) strength [19]. However, even athletes who maintain a high level of hamstring muscle strength show an increased risk of hamstring strain injury if they display an imbalance in their hamstring-to-quadriceps ratio (H:Q ratio) [20]. Thus, rather than physical fitness simply determined by absolute factors, such as high muscle strength, it is important to develop balanced physical strength in diverse areas. Balanced development of the body can prevent various ankle and knee injuries related to poor balance [21]. Therefore, to improve athletic performance and prevent injury in youth soccer players, it is crucial to provide training that is effective at improving physical fitness without disrupting physical balance. In addition, because growing youths show different levels of physical development depending on their age, it is important for training programs to consider the stage of development [22–24]. In this study, we classified youth soccer players by age and investigated the effects of short-term physical training during the off-season on muscle function and balance. In this way, we aimed to facilitate the development of off-season physical training programs for preventing injury and improving athletic performance in youth soccer players.

2. Materials and methods

2.1 Participants

A total 193 players from male soccer teams of six school (three middle schools and three high schools) were recruited. We excluded 14 players who were rehabilitating recent injuries (eight middle school players, six high school players), and the remaining 179 players (75 middle school soccer players [MSP; age, 14.28 $\pm$ 0.98 years] and 104 high school soccer players [HSP; age, 17.33 $\pm$ 0.84 years]) were included in this study. All participants engaged in physical training for 2 weeks during the off-season as part of an off-season management provided at a sports medical center. Physical training was performed five days per week, 6 to 8 weeks at the end of the season before going to pre-season training; each training session lasted for 150 mins, including warm-up and cool-down exercises. Physical training was conducted in an environment where temperature (20 $\pm$ 1 °C) and humidity (65 $\pm$ 2%) were controlled. The training program is shown in Table 1. Participants' body composition, physical fitness, core dynamic balance, and isokinetic muscle function were measured and compared pre- and post-training.

2.2 Body composition

Participants' height and weight was measured before breakfast using a weight and height scale (GL-150, G-Tech International co., LTD, Korea), and body mass index (BMI) was calculated using the equation "weight (kg)/height (m)^2". Percent body fat (% BF) [25] was calculated automatically using the equation of Jasksonand Pollock [26] by measuring the 3-site subcutaneous fat thickness at the chest, abdomen, and anterior thigh using the Skyndex Electronic Skinfold Caliper (Skyndex I Digital Skinfold Caliper, WY, USA). Lean body mass (LBM) was calculated using the Boer formula [27] as follows:

$$\text{LBM} = 0.407 \times \text{weight} + 0.267 \times \text{height} - 19.2.$$

The participants' ages and physical characteristics are shown in Table 2.

2.3 Physical fitness

To test participants' physical fitness, we measured muscular endurance, explosive power, and change of direction. Whole-body endurance was tested using the burpee test, in which participants repeatedly performed burpees for 1 min, and the total number of repetitions was recorded. Explosive power was tested using a standing long jump; the distance was measured with a tape during two repetitions, and the longest distance was recorded. Change of direction was tested using the sidestep test with an appropriate measuring device (WDT-8320, Worldsports Industry, Korea). Participants moved back-and-forth between two lines that were positioned at 1.2 m on either side of a central line for 20 s, and the number of times the participant crossed the central line was recorded.

2.4 Core dynamic balance

The dynamic test, which requires strength, flexibility, and proprioception, was performed using the Air Balance 3D (im-tech. Korea. The Air Balance 3D is based on the principles of the Star Excursion Balance Test [28], and is used for the diagnosis, evaluation, and training of physical balance (www.im-tech.kr). For taking measurements, the height of the footplate was adjusted depending on the participant's height, and the stabilization device was used to fix the participant's waist to prevent twisting of the torso. The participant folded their arms in an "X" across their chest, while standing straight and without bending at the waist. They only used their core muscles to tilt their body as far as possible during each of the eight positions indicated on a monitor in order to measure the peak range of motion (ROM). The eight positions that were measured were as follows: anterior (A0), posterior (P180), left-lateral (L90), right-lateral (R90), anterolateral left (AL45), anterolateral right (AR45), posterolateral left (PL135), and posterolateral right (PR135) (Fig. 1).

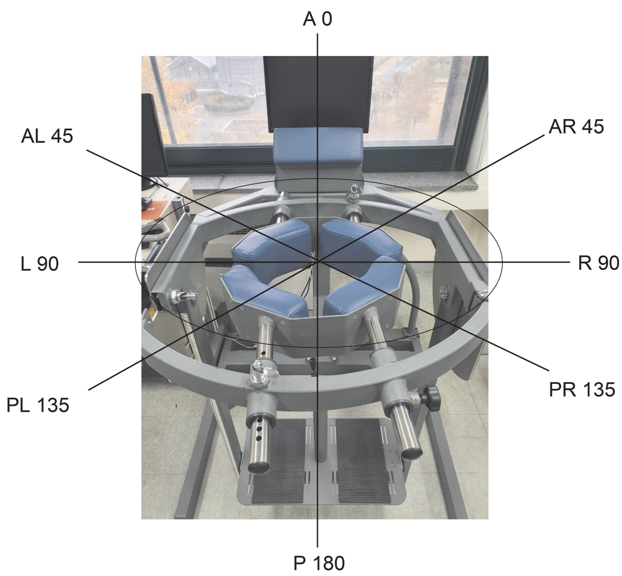

Fig. 1. Core dynamic balance test by Air Balance 3D. The grid displays directional terms. A0, anterior; P180, posterior; L90, left-lateral; R90, right-lateral; AL45, anterolateral left; AR45, anterolateral right; PL135, posterolateral left; PR135, posterolateral right.

Table 1. Training program.

Time	Contents	
10 min	Warm up and stretching Warm up: jogging Dynamic and static stretching: whole body	
30 min	Core training (interval and/or circuit) Upper abdomen: crunch and modified abdominal exercise (20 reps., 3–4 set, 30 sec. rest) Middle abdomen: transverse abdominis activation (20 reps., 3–4 set, 30 sec. rest) Lower abdomen: hip flexors cross-training (20 reps., 3–4 set, 30 sec. rest) Abdominal rotation and lower back exercise: bridge and dynamic plank exercise (1 min., 3–4 set, 1 min. rest)	
20 min	Functional lower limb training (squat, jumping *et al.*) (6–70% of 1RM, 20 reps., 3–4 set, 30 sec. rest)	
60–70 min	Interval and circuit training (80% HRmax or 1RM, 30 sec, 3–4 set, 1 min rest)	
	Aerobic interval exercise (80% HRmax, 30 sec., 3–4 set, 1 min. rest) Cycle Treadmill (10 deg) Step box Ladder coordination Rope, trembling, jumping	Resistance circuit exercise (80% 1RM, 30 sec, 1 min. rest) Leg extension (30 sec, 80% of 1RM) Leg curl Leg press Leg adduction: standing (cable) Double-leg calf raise Smith machine squat Wide squat Step box lunge jumping Lunge jumping
20 min	Functional lower limb training (step, ladder coordination, jumping, turn, acceleration and deceleration using rope) (6–70% of 1RM, 20 reps., 3–4 set, 30 sec. rest)	
10 min	Cool down Dynamic and static stretching	

Since better core strength, flexibility, and proprioception are associated with larger ROM, we used the measured ROM values to evaluate core dynamic balance [29]. In addition, the left-right core dynamic balance was evaluated by calculating the differences between positions opposite each other in the sagittal plane (L90/R90, AL45/AR45, and PL135/PR135).

2.5 Isokinetic muscle function

To test muscle function, a Testing & Rehabilitation System (CSMI-Humac Norm, MA, USA) was used to measure the peak torque (PT), deficit (dominant/non-dominant difference), and hamstring-to-quadriceps ratio (H:Q ratio) in the flexors (hamstrings) and extensors (quadriceps) of the knee joint. Measurements were taken with the participant seated and the rotational axes of the knee joint and dynamometer aligned. Restraints were applied to the thigh and shoulders to limit contribution of unwanted body segments to torque measurements. Using a long input adapter and adjusting arm, the length of the lower leg part and the adjustable axis were set appropriately, and the ankle was fixed. Thereafter, the joint ROM was set to 0–135 to prevent hyperextension or hyperflexion. Knee flexion and extension were tested at the same speeds of 60 deg/sec and 240 deg/sec. Before recording the measurement, participants performed practice trials (three submaximal, one maximal). The participants were given allotted at least 2 mins of rest after the practice trials. Consequently, measurements were obtained 5 times at 60 deg/sec and 20 times at 240 deg/sec. After flexion and extension exercises at each speed, participants rested for 2 mins. Among the analyzed variables, the PT and deficit were recorded as the values measured by the Testing & Rehabilitation System, and the H:Q ratio was calculated using the formula, "PT of hamstring/PT of quadriceps X 100".

2.6 Statistical analyses

The mean and standard deviation (SD) in each group were calculated using SPSS statistical software v27.0 (IBM company, NY, USA). Normal distribution of pre- and post-training and homogeneity of data was performed by Kolmogorov-Smirnov tests and Levene test, respectively. Paired t-tests were performed to analyze differences between pre- and post-training for each measured variable in each group. Independent t-tests were performed to compare the differences in isokinetic muscular function between the dominant and non-dominant sides. The statistical significance level for all tests was $p < 0.05$. Effects sizes (ES) were calculated using SPSS statistical softeware v27.0 (IBM company, NY, USA).

Table 2. Training effects for general characteristics of all participants.

	MSP			HSP		
	Pre	Post	ES	Pre	Post	ES
Age (yr)	14.28 ± 0.98			17.33 ± 0.84		
Hight (cm)	166.45 ± 8.45			175.70 ± 6.08		
BW (kg)	54.25 ± 9.87	53.98 ± 9.62*	0.339	67.43 ± 6.79	66.07 ± 6.42*	0.319
LBM (kg)	47.22 ± 6.09	47.21 ± 5.96	0.100	54.56 ± 4.07	54.60 ± 3.99	0.026
BF (%)	12.41 ± 3.33	11.75 ± 2.83	0.153	12.78 ± 2.09	12.25 ± 2.38*	0.416
BMI (kg/m^2)	19.43 ± 2.16	19.32 ± 2.06*	0.328	21.98 ± 1.67	21.37 ± 1.58*	0.325

Data are presented as means ± SD. MSP, Middle-school soccer players; HSP, High-school soccer player; ES, effect size; BW, body weight; LBM, lean body mass; BF, body fat; BMI, body mass index. *$p < 0.05$ vs. Pre by paired *t*-test.

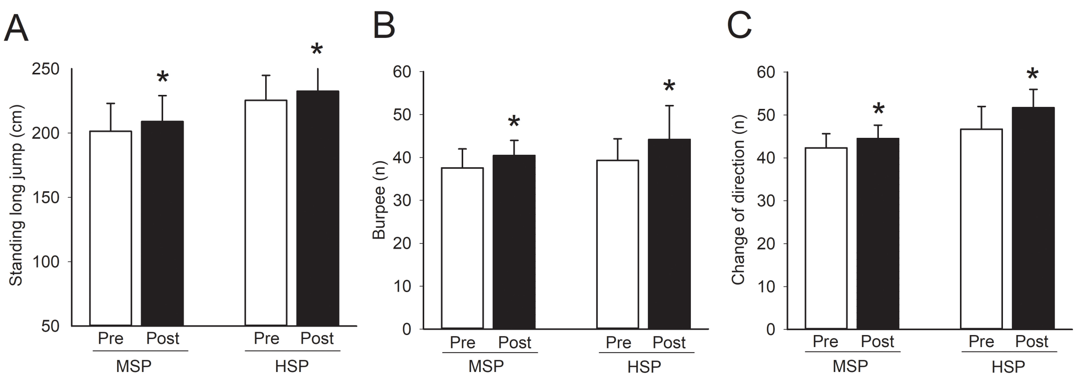

Fig. 2. Effects of 2-weeks off-season training on physical fitness in Korean male middle- and high-school soccer players. Standing long jump (A), Burpee's (B), change of direction (C) in MSP and HSP. Data are presented as means ± SD. *$p < 0.05$ vs. Pre by paired *t*-test. MSP, Middle-school soccer players; HSP, High-school soccer player.

3. Results

3.1 Body composition

When changes in body composition were analyzed after 2 weeks of off-season training, both the MSP and the HSP groups showed significant changes in BW, BF, and BMI (Table 2). Compared to pre-training, post-training BW decreased by 0.46 ± 1.02 kg (p = 0.001) and 0.35 ± 1.11 kg ($p < 0.001$), BF decreased by 0.95 ± 2.34% (p = 0.163) and 1.77 ± 3.12% ($p < 0.001$), and BMI decreased by 0.10 ± 0.30 (p = 0.002) and 0.11 ± 0.34 ($p < 0.001$) in the MSP and HSP groups, respectively.

3.2 Physical fitness

Power, change of direction, and muscular endurance were measured before and after two weeks of training using the standing long jump test, burpee test, and sidestep test. The MSP and HSP groups both showed significant improvements in their results for all three tests (Fig. 2). Compared to pre-training, post-training long jump test increased by 7.49 ± 9.43 cm (p = 0.022) and 7.02 ± 8.16 cm (p = 0.019), burpee test increased by 2.84 ± 4.20 and 4.79 ± 8.08 ($p < 0.001$ in both groups), and sidestep test increased by 2.13 ± 3.13 and 4.90 ± 4.90 ($p < 0.001$ in both groups) int the MSP and HSP groups, respedtively.

3.3 Core dynamics

Fig. 3 shows the results when core dynamic balance (strength, flexibility, and proprioception) and left-right balance measured using the Air Balance 3D. The MSP group showed no change in core dynamic balance anterior to the frontal plane (A0, AL45, AR45), but showed a significant increase posterior to the frontal plane (P180, p = 0.020; PL45, p = 0.007; PR45, p = 0.015; Fig. 3A). The left-right balance of the core muscles also improved significantly (p = 0.004), as the difference between PL135 and PR135 decreased (Fig. 3B). In the HSP group, core dynamic balance improved significantly in all positions except for A0 (P180, p = 0.027; other positons, $p < 0.001$; Fig. 3C). The left-right balance of the core muscles also improved significantly (p = 0.045), as in the MSP group, due to a decrease in the difference between PL135 and PR135 (Fig. 3D).

3.4 Isokinetic muscle function

Table 3 shows the absolute values for the PT in the MSP group. Relative values are not shown because there was almost no change in body weight, meaning that the statistical results were identical to the absolute values. First, in the extensors, there was a significant difference in the PT at 60 deg/sec between the dominant and non-dominant sides

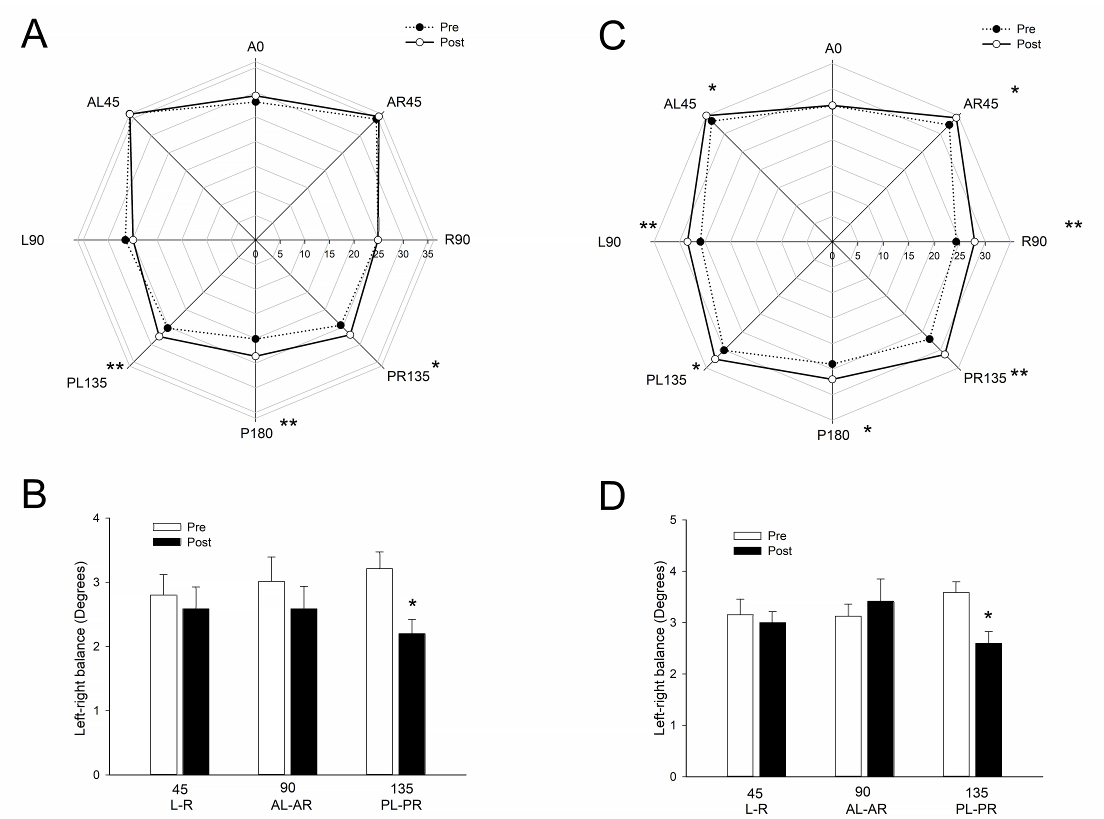

Fig. 3. Effects of two-weeks off-season training on ROM (A and C) and core dynamic balance (B and D) by Air balance 3D in MSP (A and B) and HSP (B and D). Data are presented as means ± SD. *$p < 0.05$, **$p < 0.01$ vs. Pre by paired *t*-test. MSP, Middle-school soccer players; HSP, High-school soccer player; ROM, range of motion.

pre-training (p = 0.031); however, there was no difference post-training. Indeed, the deficit between the dominant and non-dominant sides showed no significant differences for extensors. The flexors showed significant increases in PT at 60 deg/sec (p = 0.009) and 240 deg/sec ($p < 0.001$) on the dominant side. Upon comparing the dominant and non-dominant sides, there were no significant differences either pre- or post-training. However, the deficit, which is the difference between the dominant and non-dominant sides, showed non-significant decreasing trends in the PT at 60 deg/sec (p = 0.069).

Table 4 shows the absolute values for the PT in the HSP group. Between the pre- and post-training, the extensors showed significant increases post-training in the PT ($p < 0.001$) at 60 deg/sec on the non-dominant side and in the PT at 240 deg/sec on the dominant side. Upon comparing the dominant and non-dominant sides, there were significant differences for the PT at 60 deg/sec pre-training (p = 0.011), but no differences post-training. Nevertheless, in the deficit between the dominant and non-dominant sides, there were no significant differences in any of the measured variables for the extensors. The flexors showed significant increases post-training for the PT at 60 deg/sec (p = 0.013) on the non-dominant side and for the PT at 240 deg/sec (p = 0.013) on the dominant side. For the dominant and non-dominant sides, no significant differences occurred during pre- or post-training. However, the deficit between the dominant and non-dominant sides showed an overall decreasing trend post-training, and the flexors showed the PT at 60 deg/sec ($p < 0.042$) especially showed significant decreases.

Table 5 shows the results for the H:Q ratios pre- and post-training. The MSP group showed a significant increase in the H:Q ratio on the dominant side post-training ($p < 0.001$). Between the dominant and non-dominant sides at each time point, there was a significant difference in the MSP group pre-training (p = 0.017), with a higher H:Q ratio on the non-dominant side. However, there were no differences for the MSP group at 240 deg/sec or for the HSP group at either speed.

4. Discussion

The objective of this study was to develop a program to enhance physical fitness and physical balance for youth soccer players during the off-season to prevent injuries and improve athletic performance. To this end, we implemented a short, two-week training program during the off-season and analyzed its effects on body composition, physical fitness, core dynamic balance, and isokinetic muscle function of the knee joint.

Table 3. Absolute values of isokinetic peak torque, total work, average power, and endurance ratio on extensors and flexors of knee joint for middle school soccer players (MSP).

Values		Extensors			Flexors		
		Pre	Post	ES	Pre	Post	ES
60 deg/sec PT (Nm)	Dominant	129.46 ± 33.95	128.30 ± 36.86	0.074	73.35 ± 20.24	76.43 ± 23.12**	–0.262
	Non-dominant	118.40 ± 32.96#	119.49 ± 34.89	–0.062	70.96 ± 22.22	72.99 ± 22.99	–0.154
	Deficit	10.42 ± 10.43	10.09 ± 11.34	0.032	11.01 ± 11.96	8.62 ± 7.58	0.181
240 deg/sec PT (Nm)	Dominant	85.13 ± 23.95	85.84 ± 22.36	–0.067	53.45 ± 14.39	55.80 ± 14.88**	–0.345
	Non-dominant	82.32 ± 22.26	82.30 ± 22.41	0.002	52.13 ± 15.41	53.42 ± 14.37	–0.160
	Deficit	8.32 ± 7.43	7.68 ± 8.18	0.082	8.69 ± 7.08	8.91 ± 7.00	–0.23

Data are presented as means ± SD. PT, peak torque; ES, effect size. $^{**}p < 0.01$ vs. Pre by paired t-test, $^{\#}p < 0.05$ vs. Dominant by independent t-test.

Table 4. Absolute values of isokinetic peak torque, total work, average power, and endurance ratio on extensors and flexors of knee joint for high school soccer players (HSP).

Values		Extensors			Flexors		
		Pre	Post	ES	Pre	Post	ES
60 deg/sec PT (Nm)	Dominant	200.55 ± 36.91	202.60 ± 35.86	–0.116	103.90 ± 24.07	106.60 ± 20.95	–0.147
	Non-dominant	183.01 ± 39.64#	193.31 ± 38.96**	–0.385	98.91 ± 25.02	105.16 ± 21.17*	–0.271
	Deficit	7.30 ± 11.04	6.88 ± 10.02	0.031	9.61 ± 12.16	6.58 ± 9.84*	0.236
240 deg/sec PT (Nm)	Dominant	116.35 ± 20.55	123.68 ± 18.75**	–0.552	72.32 ± 13.81	75.21 ± 12.22**	–0.288
	Non-dominant	117.18 ± 38.51	121.61 ± 21.00	–0.125	69.03 ± 13.08	74.01 ± 13.28**	–0.400
	Deficit	5.61 ± 7.09	5.62 ± 7.05	–0.026	8.58 ± 8.06	6.34 ± 8.84	0.193

Data are presented as means ± SD. PT, peak torque; ES, effect size. $^{*}p < 0.05$, $^{**}p < 0.01$ vs. Pre by paired t-test, $^{\#}p < 0.05$ vs. Dominant by independent t-test.

Body composition is very important in soccer because an appropriate level of body fat helps the ordinal to move more efficiently during training and soccer game [30]. In our study, both the MSP and HSP groups showed significant decreases in BW and % BF. These changes could have been affected by various factors. BW and % BF show changes depending on the season, typically increasing during the off-season and decreasing during the season [31]. Since this study was conducted 6 to 8 weeks after the end of the season, the participants' self-care would have inevitably declined. In this context, it is likely that even 2 weeks of training would effectively improve body composition. Along with these changes in the body composition, both the MSP and HSP groups also showed increased physical fitness, irrespective of age.

For soccer matches, players need to possess high levels of physical fitness, determined by muscle strength, endurance, speed, and power, in order to display strong athletic performance over a long time without getting fatigued or injured. In particular, maximal strength development is not only the basis for power production [32] and short-distance sprint [33,34], but also reduces the incidence of injuries [35] and helps tolerate larger load during training [36]. Therefore, training programs are required to develop maximum power generation capacity [37]. In addition, soccer players require not only muscular strength development but also aerobic or anaerobic exercise capacity [38–40]. Resistance circuit-based training can improve strength and endurance at the same time [41], therefore, we employed a program that included this and aerobic or anaerobic exercise. Our findings demonstrated that even just 2 weeks of training during the off-season is effective for building the foundations of physical fitness. However, since this study only measured power, change of direction, and muscular endurance, it cannot be said clearly that it is an effective program for improving overall physical fitness. Additional analyzes of factors, such as agility, speed, and cardiorespiratory parameters are required.

In the event of insufficient physical stability and mobility, players' physical ability becomes impaired, and the risk of injury increases [42,43]. The core muscles that constitute the lumbo-pelvic-hip complex are not only the starting point for all movements but are also essential for maintaining stability [44–46]. Therefore, core dynamic balance and stability, and the ability to move the body freely in the desired direction, are essential for both performance and injury prevention in soccer players. The core dynamic balance and stability measured in this study showed no changes in locations anterior to the frontal plant in the MSP group, but improved significantly in the lower back muscles. In contrast, the HSP group showed improvements in all locations except A0, and especially showed improvements in the muscles posterior to the frontal plane. Alongside these improvements, the difference between PLL45 and PLR45,

Table 5. Hamstring-to-quadriceps ratio for dominant and non-dominant side by two weeks of training on middle and high school soccer players.

Group		60 deg/sec			240 deg/sec		
		Pre	Post	ES	Pre	Post	ES
MSP	Dominant	55.67 ± 8.66	59.48 ± 8.55**	–0.464	63.70 ± 9.30	65.43 ± 9.08	–0.100
	Non-dominant	58.34 ± 9.13#	59.55 ± 8.74	–0.162	63.80 ± 10.27	64.89 ± 11.48	–0.036
HSP	Dominant	53.56 ± 7.07	54.08 ± 6.44	–0.160	62.43 ± 7.44	61.24 ± 8.47	0.131
	Non-dominant	54.95 ± 13.09	55.30 ± 10.63	–0.073	60.82 ± 9.81	61.77 ± 9.79	–0.074

Data are presented as means ± SD. MSP, Middle-school soccer players; HSP, High-school soccer player; ES, effect size. $^{**}p <$ 0.01 vs. pre in same group, $^{\#}p < 0.05$ vs. dominant in pre.

which represents left-right difference (relative to the sagittal plane) in core dynamic balance, also decreased significantly, indicating the efficacy of training in at improving the left-right balance of the lower back muscles. Generally, healthy, untrained adults show ratios of trunk flexion to extension in the range of 0.7–0.9, while athletes tend to show a ratio within 0.5–0.7, due to increased trunk extensor strength [47]. Thus, our findings suggest that the two-week off-season training program was appropriate for increasing trunk extensor strength while also improving left-right balance. Imbalance in muscle performance parameters, such as torque production capability, work, power, and resistance, between the left and right sides of the body or between agonist and antagonist muscles increases the risk of injury [48–51], demonstrating that this program effectively provides basic training to improve performance and prevent injury through balanced development of trunk and core muscle strength in young soccer players.

Soccer consists of repeated movements, such as running, stopping, kicking, and tackling, which requires muscles strength in the legs, especially in the flexors and extensors of the knee joint [52]. However, misguided training can increase the risk of injury by creating imbalances between dominant and non-dominant sides or agonist and antagonist muscles [49–51]. In this regard, the measurement of knee joint muscle function could provide information about effective training for improving leg muscle strength while preventing imbalances. First, the PT, TW, and AP at 60 deg/sec and 240 deg/sec showed overall improving trends in both groups, and the flexors (quadriceps) especially showed a high degree of improvement. Moreover, the deficit between the dominant and non-dominant sides improved significantly for TW and AP at 60 deg/sec in the MSP group and for PT and TW at 60 deg/sec in the HSP group. Meanwhile, the H:Q ratio increased significantly post-training compared to pre-training at 60 deg/sec on the dominant side in the MSP group. Due to the increased H:Q ratio, the significant difference between the dominant and non-dominant sides, which was seen pre-training (55.67 ± 8.66 and 58.34 ± 9.13), disappeared post-training (59.48 ± 8.55 and 59.55 ± 8.74). A lower H:Q ratio is associated with a higher risk of injury [53], and the recommended range for healthy individuals is 50%–80% [54]. The results in our study were within this range, and were similar to the ratios of 55%–67% observed in elite, sub-elite, and amateur French soccer players [55]. On the other hand, our result is much lower than the ratios of 110% and 76% measured measured in Greek soccer league players [56] and Qatar Stars League players, respectively [57]. Therefore, although it is positive that the training program in this study improved the quadriceps more than the hamstrings, as shown by several study results, the program needs to be modified, such as including single-joint resistance exercise with a varying tempo of repetition [58], to more effectively develop the quadriceps.

This study had several limitations. LBM was analyzed using an equation, and trunk extensor and flexor strength could not be measured directly but were instead measured using a device for measuring isokinetic muscle function. Moreover, we were also unable to measure various indices of basic physical fitness, such as cardiovascular fitness. Therefore, in future studies, it will be important to measure body composition using dual energy x-ray absorptiometry, to measure all physical fitness variables related to athletic performance, and to measure trunk and core muscle function using an isokinetic device. In addition, since the ability to recover is important for injury prevention, studies analyzing plasma metabolites, such as creatinine, lactate dehydrogenase, and creatine kinase, are also needed. By using these methods, it would be possible to confidently demonstrate the effectiveness of this training program for short-term fitness improvement and injury prevention in the off-season.

5. Conclusions

In conclusion, among sports disciplines, soccer has a very high rate of non-participation in matches due to various injuries [59]. Therefore, in order to become elite athletes who can compete in top leagues around the world, health maintenance and injury prevention beginning at the youth stage is essential. To suggest a training program for these athletes, we applied a combined aerobic and resistance exercise program for two weeks during the off-season, and confirmed that participants showed improvements in body composition parameters, physical fitness, core dynamic balance, and isokinetic muscle function. These results support the use of this training for youth soccer players to not only to improve physical fitness but to possibly prevent injury.

Author contributions

SHK and DS designed the research study. BS performed the measurements. BS, DS and SHK processed the experimental data, performed the analysis and designed the figures. DS and SHK drafted the manuscript. All authors read and approved the final version of the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study adhered to the ethical standards of the Declaration of Helsinki. The experimental procedure and analysis were explained to the male athletes and coaches, and consent was obtained before continuing the experiment. The study was approved by the Institutional Review Board of Jeonbuk National University (JBNU 2021-05-004-002).

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Conflict of interest

The authors declare no conflict of interest.

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