Effects of a 12-Month Complex Proprioceptive-Coordinative Training Program on Soccer Performance in Prepubertal Boys Aged 10–11 Years

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Abstract

Boraczyński, MT, Sozański, HA, and Boraczyński, TW. Effects of a 12-month complex proprioceptive-coordinative training program on soccer performance in prepubertal boys aged 10–11 years. *J Strength Cond Res* 33(5): 1380–1393, 2019—The aim was to examine the effects of a series of on-field proprioceptive-coordinative (P-C) exercises on motor performance (MP) in prepubertal soccer players. Fifty-three male soccer players aged 10.1–11.8 years were randomized among 2 experimental programs receiving P-C training (P-CT; $n = 26$) or regular training (RT; $n = 27$). A control group (C; $n = 22$) consisted of age-matched (10.3–11.9 years) cohorts not involved in any regular physical activity. Both experimental groups completed an identical 12-month comprehensive soccer program except training in P-CT was modified to substitute small-sided conditioning games with 24 multimode P-C exercises with modulated exercise intensity (every 8–9 weeks based on predicted maximal heart rate [HR_{max}]). Pre-, peri-, and posttraining measures included anthropometry and 5 tests assessing soccer-specific MP: movement rhythm (turning the ball backwards–T1), motor adaptation (running with the ball around poles–T2), spatial orientation (running to sequentially numbered balls–T3), balance (single-leg static balance–T4), and kinesthetic differentiation of movement (landing the ball on a 2 × 2 m sector–T5). Repeated-measures analysis of variance revealed no significance between-group differences for age, anthropometry, and body-fat percentage at baseline. Significant main effects for group (P-CT vs. RT) were found in all tests (T1–T5) and main effects for time (group P-CT) in T3–T5, whereas a significant group × time interaction was observed only in T4 ($F = 2.98$, $p = 0.0204$). Post hoc tests indicated that P-CT attained significantly better results than RT at peritraining (by 26.4%; $p < 0.01$) and posttraining (by 31.9%, $p < 0.01$). Modulated exercise intensity had little effect on soccer performance (T1–T3, T5). Based on the results, it is recommended that the training of young soccer players be supplemented with the bilateral balance exercises and games used in the study. Furthermore, the suitability of monitoring HR in P-C exercises targeting the analyzed MP skills is questionable.

Key Words motor coordination abilities, skill development, youth soccer, exercise intensity

Introduction

Soccer constitutes an open-skill team sport whose performance is dependent on highly variable conditions. For this reason, soccer follows a highly complex and acyclic movement structure in which different components constituting soccer performance vary according to situational circumstances (38,46). There are still a number of uncertainties concerning the multidimensional facets (physiological, psychological, psychomotor, and biomechanical) of contemporary soccer, particularly in regard to designing an optimal training protocol (16,22,25). Although the importance of developing certain anthropometric and physiological characteristics is an unquestioned component of soccer training, there is a small but growing body of literature advocating the important role of coordination abilities and perceptual-cognitive processes, as the ability to efficiently execute complex movement patterns is an essential aspect of soccer performance (1,12,28,29,39,46). Hence, suggestions that training must focus not only on developing endurance, power, flexibility, and speed but also coordination are warranted, as the latter quality can improve anticipation of opponent actions, situation assessment, decision-making skills, modulation of changes in movement speed and direction, and advanced spatial-temporal body coordination in soccer-specific tasks such as passing, trapping, shooting, and heading (48,49,51).

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Coordination is a system-environment interaction with a sensory-motor coupling. It refers to a process in which the different movement system components involved in a specific motor action are combined in such a way that is efficient with respect to the intended goal (43). The individual abilities constituting coordination potential can be defined as motor coordination abilities (MCAs) (27–29). As targeted practice is needed to evolve these abilities (5), achieving proficiency in a given physical activity therefore requires training with a considerable MCA component for it to have a significant impact on technical and tactical performance (27–29). Considered in this framework, MCAs can serve as the foundation for integrating training in team sports such as soccer.

A common criticism of standard youth soccer training is the lack of integrating the more valuable aspects of modern training paradigms, particularly the quick adaptation of individual motor programs to specific game demands (2,40,46). This state of affairs may restrain the development of MCAs and other technical skills in young soccer players. We assume that the development of coordination and movement skills (through the application of generic and specialized training loads) is key to long-term athletic success and why it is important to continually monitor motor coordination level. This may enable efficacious training supervision as well as confirm the application of a given modality and load. The literature emphasizes the importance of prescribing contrasting training programs aimed at improving neuromuscular, coordinative, and athletic performance in younger age soccer players (16,28,29,33,46), particularly the application of comprehensive coordination training for those in the Junior F (6–8 years) and E (8–10 years) age categories (5).

A review of the literature revealed a paucity of information on the effects of such a diversified training intervention in young soccer players except for 2 studies (28,29). This is unfortunate, as research on the early introduction of training that integrates exercises developing proprioceptive mechanisms and neuromuscular coordination may not only provide data on how to enhance soccer performance but also significantly reduce the risk of injury at a later stages in one's athletic career (6,24,30). In addition, although longitudinal research is considered essential to uncovering the mechanisms that influence training adaptations through diversified training (7,18,20), the vast majority of investigations involving young soccer players have involved mainly short 3-, 4-, 8-, 12-, or 24-week interventions (18,26,32,42,47). Consequently, there remains a relatively small body of scientific knowledge on the long-term outcomes of enhancing MCAs in soccer training, resulting in practices that are more of the result of individual training experiences than scientifically based instruction.

Therefore, the aim of the study was to assess the effects of a proprioceptive-coordinative (P-C) series of multimode exercises in a regular soccer training program on soccer performance in prepubertal male soccer players. We hypothesized that the specificity of a 12-month on-field training regime with tailored generic and specialized training loads would elicit significant improvements in soccer performance when compared against a stand-alone regular soccer training program or an age-matched control of analogous fitness level.

Methods

Experimental Approach to the Problem

A single-center, parallel, partially group matched, controlled, and longitudinal design was adopted. The study was performed over a 12-month period, from September 2013 to October 2014 with a short (2-week) detraining period in August 2014. A repeated-measures design involving 3 groups of prepubertal men (2 training groups of soccer players and 1 control group) was used to determine the efficacy of a P-C training (P-CT) program integrated with regular soccer training relative to just the regular training program (RT). The efficacy of the training programs was evaluated by pre-, peri- and posttraining tests and filtered by comparisons with the control group. Baseline anthropometric, body composition and performance measurements were conducted 1 week before the intervention. A follow-up was completed after 6 months training (peritraining) and on completing the 12-month intervention (posttraining). Only participants who attended at least 85% of the training sessions and completed all 3 pre-, peri-, posttesting trials were included in the data analysis. Testing was integrated into the weekly training schedule of the participants.

Subjects

The study design was approved by the Józef Rusiecki Olsztyn University College Review Board and was conducted according to the guidelines and recommendations of the European Ethics Committees (Declaration of Helsinki, 2008). Additional approval for testing was provided by NA-KI Sports Training Facility officials. The parents or legal guardians of the subjects were informed about the purpose and procedures of the study and written consent was obtained. The subjects were also informed of the experimental aims and risks involved and told that they could withdraw from the study at any time.

In total, 75 prepubertal boys aged 10–11 years were recruited, all with normal nutritional status. The sample comprised 53 injury-free soccer players (age 10.1–11.8 years) attending a comprehensive soccer training program at the preselection stage and 22 untrained controls (age 10.3–11.9 years). The soccer players had at least 2 years of identical training experience (mean training period 2.4 $\pm$ 0.3 years) before the study. After baseline measurements, the soccer players were randomly allocated to receive either P-CT ($n = 26$) or RT ($n = 27$). The participants were instructed to follow their usual diet and asked to not participate in any other forms of physical training during the study duration. The control group (C) consisted of healthy age-matched

Table 1. Descriptive statistics (mean values and standard deviations) and differences in the anthropometric and body composition characteristics pre-, peri-, and posttraining (with specified main effects) between the experimental (P-CT and RT) and control (C) groups.*

		P-CT ($n = 26$)	RT ($n = 27$)	C ($n = 22$)	% Δ			Statistical significance of differences (main effects)
Parameter	Time point	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*	P-CT–RT	P-CT–C	RT–C	
BH (cm)	Pretraining	141.6 ± 7.2	141.0 ± 7.8	142.4 ± 6.6	0.4	0.6	1.0	Group: $p = 0.2287$; Time: $p = 0.0000$†; Group × Time: $p = 0.9734$
	Peritraining	144.7 ± 7.5	142.8 ± 7.5	144.9 ± 6.5	1.3	0.0	1.5	
	Posttraining	147.8 ± 7.4	145.2 ± 7.4	147.6 ± 6.6	1.8	0.1	1.7	
BM (kg)	Pretraining	35.3 ± 7.3	34.6 ± 7.4	36.1 ± 7.4	2.0	2.2	4.2	Group: $p = 0.5192$; Time: $p = 0.0013$†; Group × Time: $p = 0.9998$
	Peritraining	37.3 ± 7.9	36.6 ± 7.2	38.1 ± 7.3	1.9	2.1	4.4	
	Posttraining	39.9 ± 8.2	38.9 ± 7.1	40.5 ± 7.1	2.6	1.5	4.1	
BMI (kg·m^{-2})	Pretraining	17.5 ± 2.7	17.3 ± 2.6	17.5 ± 2.6	1.2	0.0	1.2	Group: $p = 0.7941$; Time: $p = 0.1125$; Group × Time: $p = 0.9901$
	Peritraining	17.7 ± 2.8	17.7 ± 2.4	18.1 ± 2.4	0.0	2.3	2.3	
	Posttraining	18.2 ± 2.8	18.4 ± 2.3	18.5 ± 2.3	1.1	1.6	0.5	
BF (%)	Pretraining	15.4 ± 4.1	15.6 ± 4.2	16.0 ± 4.7	1.3	3.7	2.5	Group: $p = 0.3182$; Time: $p = 0.9231$; Group × Time: $p = 0.9984$
	Peritraining	15.1 ± 4.4	15.3 ± 4.6	16.2 ± 4.3	1.3	6.8	5.6	
	Posttraining	14.8 ± 5.8	15.2 ± 4.0	16.7 ± 3.8	2.6	11.4	9.0	

*BF = body-fat percentage; BH = body height; BM = body mass; BMI = body mass index; C = control group; P-CT = proprioceptive-coordination training group; RT = regular training group.

†Statistically significant differences at significance level $\alpha = 0.05$.

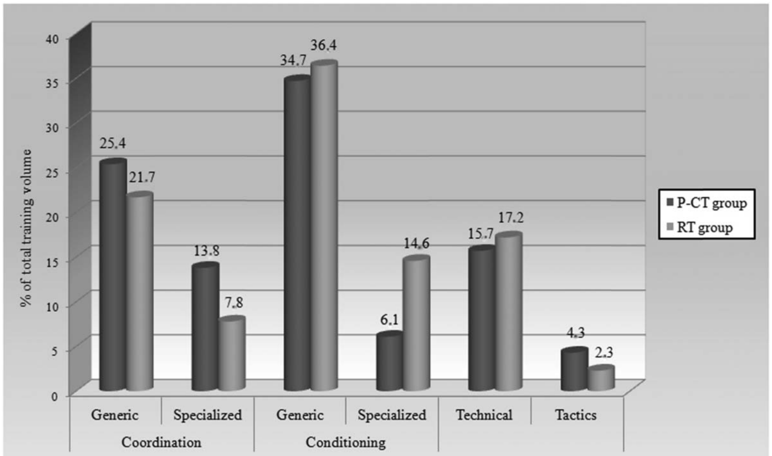


Figure 1. Training load differences between the soccer training programs of the experimental groups (P-CT and RT).

cohorts not involved in any regular physical activity although attending normal 45-minute PE classes (3 $h \cdot wk^{-1}$). None of the controls were skilled or had any extensive experience in soccer. The detailed physical characteristics of the study samples are summarized in Table 1.

Procedures

Training Protocol. Proprioceptive-coordinative training and RT received three 90-minute training sessions per week (3 $h \cdot wk^{-1}$). The training protocol implemented in both groups was based on the methodological and organizational guidelines developed by the Polish Soccer Association for youth soccer (Warsaw, 2010). These encompassed training methods aimed at improving generic and specialized coordination skills, speed, and individual technique through targeted drills and multiple variations of small-sided conditioning games (SSCGs). The selected SSCGs included 3 vs. 3, 4 vs. 4, or 5 vs. 5 with goalkeepers, and 2–3 ball touch drills played on a 25 × 35 m or 40 × 50 m field. A small-sided conditioning game was used because this method involves manipulating key constraints to facilitate rapid discovery of functional movement behaviors (12).

To control for differences in the training protocols applied in P-CT and RT, we adopted a criterion defining the "generic" or "specialized" characteristics of a given exercise. This allowed us to compare the conditioning and coordinative exercises, the core components of P-CT and RT training, between the 2 groups. Figure 1 presents the percentage (%) of total training volume devoted to each training component. In total, P-CT and RT groups completed 117 and 113 training sessions with a duration of 176 hours 25 minutes and 170 hours 15 minutes, respectively. In this regard, there was uniformity between P-CT and RT as to volume of generic exercise.

Training in P-CT was modified by adjusted training load and the substitution of SSCGs in the regular training program with a series of 24 multimode P-C exercises to aid the development of various MCAs. These exercises were administered in a random sequence and applied 30 minutes before soccer-specific practice. Twelve exercises were executed with the aim of shaping 5 MCAs important in soccer: movement rhythm, motor adaptation, spatial orientation, static balance, and kinesthetic differentiation of movement. The other 12 exercises involved: multidirectional forms of running, jumping, and skipping (20 m distance); single-leg balancing games; standing on 1 foot while catching and kicking the ball to a partner; mini-obstacle course of stepping over 4 balls, then jumping over boxes, and then 4 more balls; kicking balls of various weights to multiple targets at various distances (2–8 m); opposite arm circles (right hand circled forwards and the left backwards); jumping in place with 180° or 360° mid-air turns; balance exercises on a balance trainer; step-over running; series of jumps to one-legged standing; 90/180/360° hip turns using a wide stance; jumping and landing; and obstacle running (balls placed on the field with the participant jumping over them). Figure 2 presents a training schematic of 8 selected exercises to illustrate the procedures. Participants performed 2–3 sets of 6–8 repetitions for each exercise, with beginning exercise duration between 20–60 seconds and interspersed with 2–3 minutes breaks. Approximately 42% of total training time was devoted to recovery. Most of these exercises were performed with the ball and in dynamic conditions, corresponding to the requirements of coordination training in soccer as delineated by Tessitore et al. (46).

Exercise Intensity. Exercise intensity in the P-C exercises was modulated based on age-predicted maximal heart rate (HR_{max}) values, calculated for each participant using the formula: $208 - 0.7 \times$ age (45). Once a week, heart rate (HR) during a training session was monitored and collected using Polar Team System heart rate monitors (Polar Electro OY, Kempele, Finland). Heart rate data (collected every 5 seconds) were downloaded to a computer. Training intensity was progressively increased in each exercise every 8–9 weeks in 5 graded phases (phase 1: 120–135 $b \cdot min^{-1}$, phase 2: 135–150 $b \cdot min^{-1}$, phase 3: 150–165 $b \cdot min^{-1}$, phase 4: 165–180 $b \cdot min^{-1}$, phase 5: 180–195 $b \cdot min^{-1}$). Field

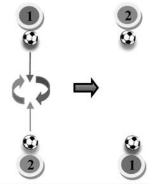
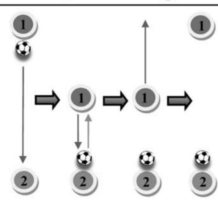
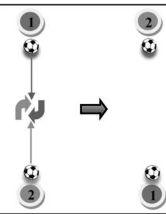
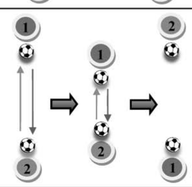
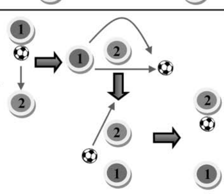
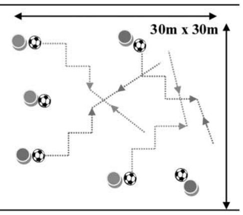
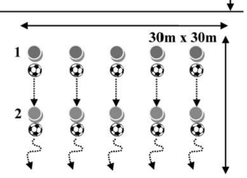
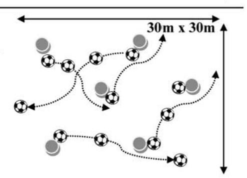
Description	Schematic
Two players (each with a ball) stand 10 m apart and begin dribbling towards each other. At the midpoint, separated by approximately 1 m, they perform a scissor move on the same side and continue to dribble to the opposite side. This is then repeated.	
Two players stand 10 m apart. Player 1 passes the ball on the inside of the foot to Player 2 and runs as fast as possible to Player 1. Player 2 performs a wall pass to Player 1 who again passes the ball to Player 2, who then begins running backwards to the starting point. Player 2 now has the ball and performs the same exercise with roles revered.	
Two players (each with a ball) stand 10 m apart. They dribble the ball towards each other using the same foot. At the midpoint, separated by approximately 1 m, they exchange the ball using a light pass with the inside of the foot. After the exchange, they continue using the same foot to dribble the ball at the opposing side. This is then repeated using the opposing foot.	
Two players (each with a ball) stand 6–8 m apart. Both simultaneously pass the ball using the inside of the same foot to intercept the ball (using the same foot) and dribble as fast as possible to the opposite end. The players repeated the protocol but with the opposing foot.	
Two players stand 4 m apart. Player 1 has possession of the ball while Player 2 assumes the plank position perpendicular to Player 1. Player 1 dribbles the ball in the direction of Player 2 and at a distance of approximately 1 m kicks the ball underneath Player 2 while jumping over Player 2. Player 1 intercepts the ball using the same foot until returning the starting point. The same exercise is repeated with roles reversed.	
A group of players (each with a ball) dribble the ball in different directions in a 30 x 30 m square. Each dribbles the ball forward using only one foot with four alternative touches on the inside and outside of the foot in a zig-zag and then three reverse touches to return to their starting point.	
A group of players (each with a ball) is partnered to dribble the ball in one direction in a 30 x 30 m square. Player 1 dribbles closely behind Player 2, dribbling with the same speed and direction. The ball is dribbled by using the inside and outside of the foot.	
A group of players (each with a ball) dribble in a 30 x 30 m square passing each other. Dribbling is allowed with any part of the foot. After a couple of forward dribbles the player must run up and sit on the moving ball without using his hands or feet, then stand up and continue dribble the ball at a faster pace.	

Figure 2. Diagram and description of 8 selected exercises used in the proprioceptive-coordinative training program of P-CT.

Figure 3. Test T1 assessed rhythmic ability by turning the ball backwards with the dominant leg.

dimensions, exercise speed, and rules were manipulated to determine the prescribed exercise intensities.

Chronological Age and Maturational Status. The chronological age was calculated as the difference between the date of birth and date on which the first testing session was conducted. The maturational status of the participants was determined (4 pubertal categories: prepubertal, early pubertal, pubertal, and postpubertal) using the modified Pubertal Maturational Observational Scale (PMOS). The PMOS scale has shown high reliability and can be used to differentiate between pubertal stages based on indicators of adolescent growth, axillary and leg hair growth, muscular development, presence of acne, and evidence of sweating during physical activities (13,36). The participants were classified as prepubertal (equivalent to Tanner Stage I).

Leg Dominance. Leg preference and laterality are usually used to express the preferential use of one leg in voluntary motor

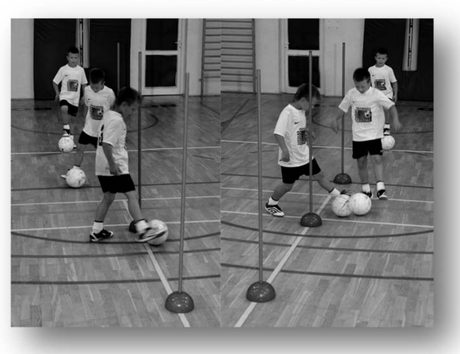


Figure 4. Test T2 assessed motor adaptation ability by running with the ball around poles on the dominant side.

Figure 5. Test T3 assessed spatial orientation ability by running to sequentially numbered balls.

acts (17,19). In response to a questionnaire, almost all participants (94.7%) classified themselves as right-leg dominant (1 player from P-CT, 2 from RT, and 1 from C were left-leg dominant). We used the term "dominant leg" for the leg used to manipulate an object (soccer ball in T1 and T2) and as the leg the participants preferred to use to kick the ball (T5). In the single-leg balance test (T4), the leg that was used to hold the ball was established as the "preferred leg" while the "nonpreferred leg" provided postural and stabilizing support. Thus, leg dominance in this test referred to the leg that was used for mobility while the nondominant leg contributed to support.

Anthropometry and Body Composition. Anthropometric measurements ascertained body height–BH (cm), body mass–BM (kg), body mass index–BMI ($kg \cdot m^{-2}$), and body-fat

Figure 6. Test T4 assessed single-leg static balance with the dominant leg.

percentage–BF (%). Body height and BM were measured with a calibrated WB-150 stadiometer (Tryb-Wag, Poland) to an accuracy of 0.1 mm and 0.1 kg, respectively. Body-fat content accurate to 0.1% was assessed by bioelectric impedance analysis using a MC-780U Multi Frequency Segmental Body Composition Analyzer (Tanita Corporation, Japan). All measurements were taken in the morning by an experienced anthropometrist and in compliance with the procedures recommended by the International Society for Advancement of Kinanthropometry (ISAK).

Performance Tests. Training effects were verified by analyzing the results of 5 performance tests used to assess MCA as developed by Ljach and Witkowski (27). A detailed description of each test is provided below. Testing conditions were standardized and conducted by the same group of researchers in an indoor facility to avoid the confounding effects of weather. A station format was used and testing order was randomized across the participants. Neither experimental groups (P-CT or RT) practiced these tests during training. The participants were allowed to complete 3 trials (interspersed with 45 seconds of rest), but at least one successful trial was required. The participants were instructed to complete the test as quickly and accurately as possible, and the trial was immediately terminated if the participant lost contact with the ball. All tests were performed by the dominant leg or dominant side. Before testing, a standard 8–10 minutes warm-up was executed involving a series of running, jumping, and dynamic stretching exercises (Figure 3).

Test 1 (T1). This test assessed movement rhythm or the ability to accurately execute a task with a given tempo or adequately modify movement timing because of changing conditions. The participant began the test with both feet on the ground and assumed a starting position on the command "get ready." On the command "start" the participant was required to roll the ball backward using the sole of their shoe and then using the same foot make contact with the ground. The goal was to implement this "touch and go" technique and keep the ball rolling backward. Timing was stopped the moment the participant placed their foot on the ground after contacting the ball 10 times. The result was the total time from start to finish (Figure 4).

Test 2 (T2). This test quantified motor adaptation or the ability to quickly amend a known performance to changing conditions. Three poles were set at 2.5-m intervals along a 10-m straight line. On the command "start," the participant began at one end and had to run and kick the ball entirely around the 3 poles using only the dominant leg (using any part of the foot was accepted) until reaching the finish line. The result was the total time required to circle each pole from start to finish (Figure 5).

Test 3 (T3). This test assessed spatial orientation or the ability to accurately recognize the orientation of the player to

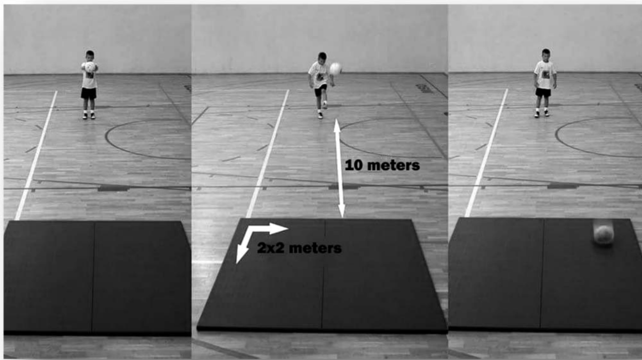


Figure 7. Test T5 assessed the kinesthetic differentiation of movement by landing the ball on a 2 × 2 m sector with the dominant leg.

a reference point and quickly execute a directed movement. Five numbered medicine balls were placed on the circumference of a semicircle with a 3-m radius. The balls were placed at 1.5-m intervals and arranged nonsequentially. From a starting position at the center of the circle, the participant was shown a number and had to immediately run to the numbered ball and touch it with the sole of either foot (the sequence of the numbered balls was kept hidden from the participant). The next number was shown and the participant had to run to touch the center ball and then the numbered ball. The result was the total time to run and touch each of the 5 balls (Figure 6).

Test 4 (T4). This test measured static balance as the ability to maintain a stationary unipedal position while executing a secondary balance task with the soccer ball. The participant began the test standing on 1 leg with both hands placed on the hips and with the other foot held out to hold the ball. When ready to start the test, the participant said "start" and was to hold the ball in this position for as long as possible. Time was measured until the participant dropped the ball, lost balance, or removed his hands from the hips. The best of 2 trials was recorded (Figure 7).

Test 5 (T5). This test was a measure of the kinesthetic differentiation of movement (proprioception) or the ability to accurately assess the position of the body relative to neighboring parts (spatial component), the tension used by the working muscles (strength component), and the movement speed (temporal component). A 2 × 2-m mat was placed on the ground. A line was marked at a distance of 10 m from the edge of the mat. The participant was to perform straight drop shot from the line with the aim of landing the ball on the mat. A total of 10 shots were allowed, in which a landed shot was awarded 1 point and a miss no points. The result was the sum of points.

Reliability and Validity of the Performance Tests. The data of the 3 groups were analyzed to assess the reliability and validity of the performances tests. One-way analysis of variance (ANOVA) was used to obtain the intraclass correlation coefficients (ICCs) of the measures. Confidence intervals at the 95% level were used to determine

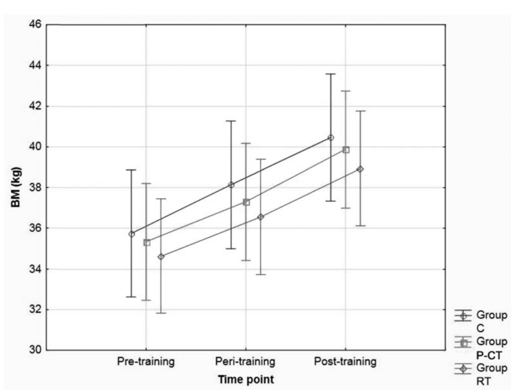


Figure 8. Pre-, peri-, and posttraining body mass (BM); mean values with errors bars representing 95% confidence intervals.

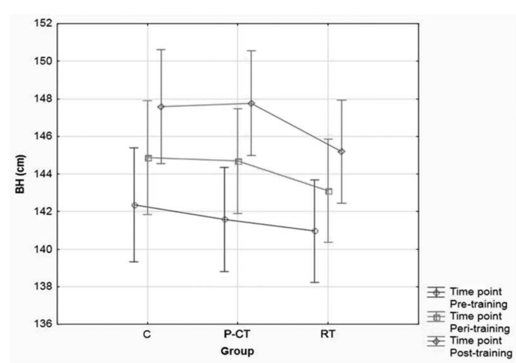


Figure 9. Pre-, peri-, and posttraining body height (BH); mean values with errors bars representing 95% confidence intervals.

the ICCs. The coefficient of variation (CV) was determined on the change in mean performance over consecutive pairs of trials for individual participants. This was established to reflect intrasubject reproducibility and expressed as the percentage of the subject's mean. As these tests were short in duration, an ICC value above 0.50 is considered sufficient for group diagnosis (44). Face validity was assumed since the tests assess specific elements of soccer play. In this study, we decided to determine the validity of the performance scores by a rank evaluation made by a coach. To that end, Spearman's rank correlations were used to assess validity, with a value above 0.30 treated as valid (44).

Statistical Analyses

Descriptive statistics (mean–M, standard deviation–*SD*) were calculated for all variables. The distribution of the data set in each group was screened for normality using the Shapiro-Wilk test. Because of the different sample sizes of the 3 groups, Levene's test was applied to confirm the homogeneity of variance. Training-related effects were assessed using 2-way (group × time) ANOVA with repeated measures to examine the differences for each variable between the 3 groups and at the pre-, peri-, and posttraining times. If a main effect was found (group, time, or group × time interaction), Tukey's test was applied post hoc to determine the significance of the differences for the group mean values. The Statistical Package for Social Sciences ver. 11.5 (SPSS, Chicago, IL, USA) was used for data processing. The alpha level was set a priori to 0.05 to indicate statistical significance.

Results

All participants in P-CT and RT met the minimum 85% attendance frequency for training and completed all the performance tests. No severe health problems or sport-related injuries occurred during experimental period.

Statistical testing confirmed the assumption of normality and the homogeneity of variance between the groups for all variables. Laboratory measurements of the physical characteristics of the experimental (P-CT and RT) and control (C) groups are presented in Table 1. There was no significant group × time interaction for any of the measures. Comparisons of the mean values revealed a significant main effect of time but not group for BM ($F = 6.85$; $p = 0.0013$) and BH ($F = 9.73$; $p = 0.0000$). This suggests that the groups were based on a homogenous sample.

Post hoc testing for BM and BH among the experimental groups identified 2 homogenous groups although this was not discernable, where mean BM and BH were not significantly different from peritraining compared with pre- and posttraining values. Significant pre- and posttraining differences in P-CT were found, although these changes were expected because of the 12-month duration of the study as the body undergoes dynamic growth during this phase of biological development (prepuberty). Despite the linear characteristics of the changes, we did not observe significant differences in anthropometry between RT and C. Figures 8 and 9 present the trends for BM and BH, respectively.

The reliability of the 5 performance tests (T1–T5) was characterized by ICCs of 0.59–0.81 (Table 2). Intrasubject variation varied between 8.4–14.7%. The highest ICC value was observed in the spatial orientation test (T3: ICC = 0.81, CV = 10.3%) and the lowest in the kinesthetic differentiation of movement test (T5: ICC = 0.59, CV = 14.7%). These results indicate that the performance tests show acceptable reliability. The test scores (T1–T5) demonstrated a validity coefficient of no less than 0.30, with the highest value in the movement rhythm test (T1: 0.54) and the lowest in the kinesthetic differentiation of movement (T5: 0.37). Thus, the applied performance tests met the assumed criterion of accuracy (rank evaluation of coordination made by a coach).

Table 2. Intraclass correlation coefficients (ICCs) for relative reliability and coefficients of variation (CVs) of the 5 performance tests (T1–T5).

Motor coordination ability	Test symbol	Test (variable)	ICC	95% confidence intervals	CV (%)
Movement rhythm (s)	T1	Turning the ball backwards with the dominant leg	0.72	0.63–0.80	8.4
Motor adaptation (s)	T2	Run with the ball around poles on the dominant side	0.77	0.71–0.83	7.2
Spatial orientation (s)	T3	Run to sequentially numbered balls	0.81	0.74–0.85	10.3
Static balance (s)	T4	Single-leg static balance with the dominant leg	0.64	0.53–0.72	12.8
Kinesthetic differentiation of movement (pts.)	T5	Landing the ball on a 2 × 2 m sector with the dominant leg	0.59	0.48–0.67	14.7

Table 3. Descriptive statistics (mean values and *SD*) and differences in motor coordination abilities (T1–T5) at pre-, peri-, and posttraining (with specified main effects) between the experimental (P-CT and RT) and control (C) groups.*

		P-CT ($n = 26$)	RT ($n = 27$)	C ($n = 22$)	% Δ			Statistical significance of differences (main effects)
Parameter	Time point	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*	P-CT–RT	P-CT–C	RT–C	
Movement rhythm (s) (T1)	Pretraining	10.5 ± 2.19	10.7 ± 1.33	13.2 ± 1.98	1.8	25.0	22.7	Group: $p = 0.0000$†; Time: $p = 0.3167$; Group × Time: $p = 0.9803$
	Peritraining	10.2 ± 2.14	10.7 ± 1.18	12.8 ± 1.87	5.2	26.0	19.8	
	Posttraining	9.9 ± 2.08	10.5 ± 1.28	12.7 ± 1.89	5.7	27.4	20.5	
Motor adaptation (s) (T2)	Pretraining	13.6 ± 1.86	14.8 ± 3.21	26.2 ± 4.65	8.7	92.1	76.8	Group: $p = 0.0000$†; Time: $p = 0.1319$; Group × Time: $p = 0.9581$
	Peritraining	13.3 ± 1.78	14.5 ± 3.00	25.4 ± 4.26	9.0	90.4	74.7	
	Posttraining	12.8 ± 1.86	14.2 ± 3.14	24.6 ± 3.77	10.9	92.4	73.5	
Spatial orientation (s) (T3)	Pretraining	17.8 ± 1.61	18.5 ± 1.61	19.3 ± 1.85	3.8	8.2	4.3	Group: $p = 0.0000$†; Time: $p = 0.0031$†; Group × Time: $p = 0.6699$
	Peritraining	16.9 ± 1.54	18.3 ± 1.56	18.8 ± 1.59	7.9	11.3	3.2	
	Posttraining	16.5 ± 1.68	18.1 ± 1.72	18.5 ± 1.29	9.7	12.2	2.3	
Static balance (s) (T4)	Pretraining	25.5 ± 10.17	25.7 ± 7.76	7.8 ± 4.47	1.0	69.6	70.6	Group: $p = 0.0000$†; Time: $p = 0.0423$†; Group × Time: $p = 0.0200$†
	Peritraining	28.3 ± 10.07	20.8 ± 7.10	8.9 ± 4.75	26.4	68.6	57.3	
	Posttraining	32.6 ± 9.46	22.2 ± 7.19	9.5 ± 4.67	31.9	70.9	57.4	
Kinesthetic differentiation of movement (pts.) (T5)	Pretraining	4.3 ± 1.46	3.8 ± 1.08	1.6 ± 0.91	11.6	62.8	57.9	Group: $p = 0.0000$†; Time: $p = 0.0001$†; Group × Time: $p = 0.1487$
	Peritraining	4.7 ± 1.26	4.0 ± 1.06	1.9 ± 0.83	14.9	59.6	52.5	
	Posttraining	5.7 ± 1.23	4.2 ± 1.18	2.2 ± 0.80	26.3	61.4	47.6	

*C = control group; P-CT = proprioceptive-coordination training group; RT = regular training group.
†Statistically significant differences at the significance level $\alpha = 0.05$.

Table 4. Post hoc comparisons for significant differences on the results of the single-leg static balance test (T4).*†

Variable		Mean value
Group	Time point	Static balance–T4 (s)
C	Pretraining	7.8[d]
C	Peritraining	8.9[d]
C	Posttraining	9.5[d]
RT	Peritraining	20.8[a]
RT	Posttraining	22.2[a,b]
P-CT	Pretraining	25.5[a,b,c]
RT	Pretraining	25.7[a,b,c]
P-CT	Peritraining	28.3[b,c]
P-CT	Posttraining	32.6[c]

*C = control group; P-CT = proprioceptive-coordination training group; RT = regular training group.
†a, b, c, d; mean values marked with the same letters in the column indicating no statistically significant differences (homogeneous groups).

The results of the 3 groups (P-CT, RT, and C) in the 5 performance tests at pre-, peri- and posttraining with specified main effects (group, time, and group × time interaction) are presented in Table 3. Regarding a significant main effect of group, only a few significant group findings were identified among the performance measures. Proprioceptive-coordinative training demonstrated better physical performance than RT and C in all tests except the movement rhythm test (T1), with no difference between the 2 experimental groups. A significant main effect was also present for time ($p \leq 0.05$) in P-CT in the spatial orientation (T3: $F = 5.94$, 5.1%) and kinesthetic differentiation of movement (T5; $F = 9.26$, 21.3%) tests. A significant group × time interaction was observed only in the single-leg static balance test (T4: $F = 2.98$, $p = 0.0204$), which is presented in Table 4.

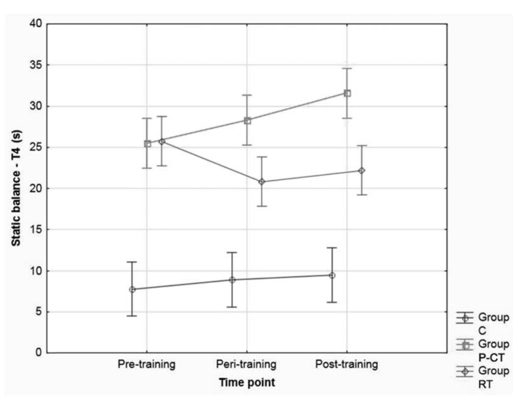


Figure 10. Pre-, peri-, and posttraining performance in the single-leg static balance (T4); mean values with errors bars representing 95% confidence intervals.

At pretraining, the experimental groups (P-CT and RT) did not significantly differ from each other ($p > 0.05$) while both showed superior performance compared with C by 69.6 and 70.6%, respectively ($p < 0.01$). In contrast, at peritraining, P-CT attained significantly better results than RT (26.4%; $p < 0.01$). At posttraining, the difference between the experimental groups increased to 31.9% ($p < 0.01$). The mean trend in the single-leg static balance test (T4) for the groups, showing significant time × group interaction effects (between P-CT and RT at pretraining), is illustrated in Figure 10.

Discussion

This study was designed to determine whether a set of 24 multimode on-field P-C exercises (3 $h \cdot wk^{-1}$ performed for 12 months) performed just before soccer-specific practice (instead of an SSCG) could significantly affect MCA considered crucial for soccer performance (movement rhythm, motor adaptation, spatial orientation, static balance, and kinesthetic differentiation of movement). In planning this study, we first wanted to avoid the influence of confounding factors such as pure biological development on the gains in individual MCA by adopting the present three-group model. In this regard, we did not observe any significant differences between the 3 groups in regard to anthropometry (BM, BH, BMI, and BF%), attesting to their relative homogeneity, so it is unlikely that these variables explained the differences we observed in the performance tests and were more likely the result of training-related effects. In addition, the increases in BH and BM were similar to those reported in the literature on age-matched men in Poland (15) and other countries (8).

Although longitudinal research on motor coordination and the development of soccer-specific skills in prepubertal soccer players is currently lacking, there are indications that the relationship between motor control and biomechanics could form a significant component of scientific investigation on talent identification and skill development (11). Ljach and Witkowski (28) and later Ljach et al. (29) provided a wide data set obtained from numerous cross-sectional and longitudinal studies (1-, 2- and 4-year experiments) on the development of MCA in soccer players across a wide age range (11–19 years). In their analyses of training effects on coordination skills, they assessed developmental variance in 7 soccer-based MCA using 17 indicators deemed to be most representative of motor performance (MP). Our study can be considered to complement the findings of Ljach and Witkowski (28) and Ljach et al. (29) for individuals aged 10 years. By implementing a longitudinal study and including such a younger sample of soccer players, our guiding aim was to further gain knowledge on the individual development of selected MCA and estimate the efficacy of a set of

P-C exercises (applied in P-CT) on the above. This approach was particularly justified by data indicating that the most favorable period for the development of MCA is between 6 and 12 years of age (28,29).

Cross-sectional analysis has indicated that soccer players are characterized by highly developed static and dynamic balance second only to gymnastic athletes (3,14). For example, Matsuda et al. (31) reported that soccer players have more stable 1-legged stance than basketball players and swimmers. However, the vast majority of studies conducted on soccer players analyzed bipedal balance. Because one-legged balance with a lifted leg has not been thoroughly studied in soccer players, we decided to measure single-leg static balance (T4) when choosing suitable performance tests. In this study, we found a significant group × time interaction for single-leg static balance ($F = 2.98$; $p \leq 0.05$). The significant differences between the experimental groups (P-CT and RT) first at peritraining (26.4%; $p \leq 0.05$) and later at posttraining (31.9%; $p \leq 0.05$) clearly show that the exercises used in P-CT are more efficacious than regular soccer training. These results suggest the important role of muscle sensation in the development of balance, in which correct posture is maintained by applied muscle tension. Most of the coordination and balance training exercises applied in the P-CT protocol were conducted with a weight-bearing position (single-leg stance). This stresses the role of proprioception as an important factor promoting functional stability in soccer (43). We may assume that the specialized exercises executed in P-CT increased the awareness paid to proprioceptive cues early in the training process. The large between-group differences in T4 could indicate a lack of equilibrium between hamstring and quadriceps strength as well as dominant versus nondominant side hamstring strength. This is particularly important as the normalization of strength imbalances may reduce the incidence of hamstring injury (9). Although the efficiency of a training regime in improving these variables has been confirmed, such as by Paterno et al. (34) who concluded that three 90-minute neuromuscular training sessions per week for 6 weeks improved single-limb stability in young female athletes, it is important to take into account interindividual variability in balance as a result of maturation and physical development. Some reports have indicated the variable development of balance, which continually accelerates to approximately 14 years of age only to briefly plateau and then continue to advance (20). Paterno et al. (34) also analyzed the effects of timing on balance ability, suggesting that coaches and therapists should involve balance exercises after rather than before sports training. Within the context of soccer, additional research is needed to determine whether balance ability is innate in soccer players or whether it is developed through specialized training. Such investigation should determine whether similar differences would have been found in a static balance test with the nondominant leg (and compare it with dynamic balance), as only the symmetric development of both legs could attest to the efficacy of the P-CT protocol.

With regard to the results of 5 performance tests used in this study, we found significant main effect for group (P-CT vs. RT) and time for P-CT in T5, which involved landing the ball on a 2 × 2-m mat. When compared with the sample of 11-year old boys from the Ljach and Witkowski (27) study, P-CT showed enhanced gains of 9.3% (dominant leg). It was determined at the study design stage that this type of testing modality (similar to the cross-pass) provides an optimal experimental setup for assessing kicking precision and variability (35). Kicking the ball a certain distance is a measure of technique and kinesthetic differentiation. It entails a complex sequence of movements, spanning multiple effectors, and thus relies on carefully coordinated movements timed to the order of tens to hundredths of milliseconds (4). When analyzing the results of T5, it should be noted that this test assesses the interaction of numerous coordination abilities. We believe that there are 2 motor variables that work to explain the strong link of proprioceptive muscle sensation with the MCA of kinesthetic differentiation of movement in such a task. In particular, the MCA of kinesthetic differentiation determines both movement precision and movement economy and strongly determines the level of MP. Because the training program of P-CT contained numerous soccer-specific exercises (on-field), kinesthetic differentiation of movement was practiced in most of the training tasks. Shaped in such a manner, this ability may have been responsible for the increased precision of kicks across the subsequent testing trials (pre-, peri-, and posttraining).

According to the literature, one of the defining characteristics of a motor skill is the rhythm that determines the timing between successive movement phases (43). The acquisition of a new motor task is coupled with the attainment of its inherent rhythm and plays a large role in its mastery (21). Research on the conditions necessary to obtain maximum performance in tests assessing unilateral backward leg movements has indicted the important role of "ball sensation," encoded in specialized memory structures (41). The memory model of such a movement is based on its mechanism, i.e., contra-receptors are activated by the lower extremity the moment when contact is made with the ball. This allows the athlete to feel the ball's hardness, flexibility, and mass, all of which are crucial factors in determining kicking precision (43,41). Therefore, this mechanism is bound with the very strict perception of ball speed and flight and the interaction between its mass, flexibility, and rotation. In our study, a significant main effect for group occurred in P-CT compared with RT (6.1%; $p \leq 0.05$), revealing faster movement execution in P-CT. Although not significant, improvement in P-CT between pre- and posttraining values fell within the percent change observed by Ljach and Witkowski (28), who also administered a 12-month training intervention in young soccer players with 5.5 years of training experience. They found that the indices of movement rhythm increased by 3.9–24.6% in the experimental group compared against 3.3–8.5% in the control group. Furthermore, on completing the 12-month training regime, the participants receiving P-CT also showed a performance level (in turning the ball backwards) similar to that reported by Ljach and Witkowski (27). We noted a difference of only 0.3% for the dominant leg (T1) in favor of the 11-year old boys from Ljach and Witkowski's study (27), although it needs mention that this difference falls within measurement error. Zachopoulou et al. (53) also observed that a specialized 10-week music and movement program contributed to the enhancement of rhythmic ability (and therefore improved motor coordination) in 72 preschool children regardless of sex. However, the authors stated that it is still unknown whether physical maturation has a larger effect than training in the learning certain rhythmic tasks. This is perturbed by the fact that rhythmic ability is usually characterized by high interindividual variation.

In terms of spatial orientation ability (T3, running to sequentially numbered balls), we found a significant main effect for group (P-CT vs. RT) and time in P-CT but no interaction. For this reason, the obtained results do not confirm the expected efficacy of the P-C exercises applied in P-CT. It should also be mentioned that there were no between-group differences in this test at pretraining. In addition, the lack of differences between RT and C for this ability is difficult to explain based on the collected data. The literature strongly emphasizes the individual spatial conditions of each sport (28). Recently, it was shown that spatiotemporal coordination in soccer is guided by informational game constraints (47). The physiological basis of spatial orientation lies in the strong relationships of independent analyzers, first visual and then kinesthetic, which create the overall structure of the sensorimotor system. Soccer has a number of specific requirements in this regard, as the changes in position occur within a particular "area of action" (on the field) with multiple orientation points (opponent, teammate, ball) and ever-changing situations (48,49). It should be noted that efficacious performance in tests T3 and T2 (running to sequentially numbered balls and running with the ball around poles, respectively) involves not only well-developed spatial orientation and motor adaptation but also considerable physical conditioning, particularly with regard to speed. However, based on the obtained results, we cannot assume that the application of the 24 multimode P-C exercises with increasing physiological load in group P-CT had a parallel effect on physical fitness. However, this has been confirmed in other studies, where an additional P-CT intervention increased not only coordination ability but also jumping power, throwing power, and flexibility, while significantly reducing the frequency and pattern of injuries (24). Contradictory results were obtained by Jullien et al. (23), who found that specific circuit training (performed 5 times per week for 3 weeks as part of a broader exercise program) designed to promote agility, coordination, and balance control did not improve performance in a short sprint or shuttle sprint with changes in direction. However, improvements were observed in an agility test. Other studies have posited the idea that the adaptation potential is lower for physical factors (e.g., maximal strength) and higher for coordination factors (e.g., perception) in trained subjects (37,52). It seems that athletes are exceedingly susceptible to coordinative adaptations because of this population's enhanced perceptive, anticipatory, and decision-making skills (52).

The results of our study do not fully confirm other reports in that several months of targeted soccer training in prepubertal boys shows significant improvement on soccer-specific qualities, the most predominate being coordination abilities. Taking into account the duration of such interventions, the literature shows that training programs in youth soccer require a minimum of 8–12 weeks to allow for neuromuscular, coordinative, and physiological adaptations in response to a training stimulus (10,50). Training programs of a shorter duration (6–8 weeks) did not always bring the expected level of progressive change to certain indicators (32). This study, besides being conducted over a 12-month period, systematically increased exercise intensity every 8–9 weeks, in which the first phase was performed at 120–135 $b \cdot min^{-1}$ and the last phase at 180–195 $b \cdot min^{-1}$. Given these modifications (controlled HR target zones), we hypothesized that the increased physiological strain produced by generic and specialized high-intensity exercises performed in the second half of the experiment (between the sixth and 12th month) would enhance the improvements in observed in the first half. Indeed, we found main effects for time in P-CT in T3–T5, although no significant effects were found in T1–T2 ($p > 0.05$). Moreover, apart from T4, no interaction effects were observed in all these performance tests. This was not anticipated, as the training adaptations to increased physiological load (exercise intensity) should have been translated into improved performance in the dynamic tasks involving running rather than those performed in static conditions, such as the single-leg balance test or kicking the ball on the 2×2 mat. Throughout the 12-month intervention, we observed slight improvements in P-CT but not enough to cause significantly different training outcomes, at least for the performance variables selected in this investigation. It seems clear that changes in on-field task constraints can influence and modify physiological, perceptual, and time-motion responses. Chang et al. (7) revealed that coordination-based exercises may specifically benefit prefrontal-dependent tasks in the still immature brains of young children by increasing the allocation of attentional resources and enhancing the efficiency of neurocognitive processing. Given the findings of our study and the aforementioned investigations, it seems reasonable to argue that training modality (including training duration and frequency) and/or other factors (age, prior experience) may have modulated the effects of P-CT on the tests measuring soccer performance. Children in particular may be profoundly influenced by the inherency of a planned and targeted training program because both environment and individual experiences may affect the developing brain at this stage in life (7).

Practical Applications

The practical approach used in this study yields data agreeing with the findings from studies that used much more sophisticated, time-consuming methods and apparatus to control the development of MCA and soccer skills in youth. The applied performance tests were reliable and stable over time. Although we found a number of significant main effects for group (P-CT vs. RT) in all of the tests measuring soccer-specific qualities (T1–T5) and main effects for time in spatial orientation (T3), static balance (T4) and kinesthetic differentiation of movement (T5) in P-CT, the superior efficacy of the P-CT protocol has not been fully confirmed. The beneficial impact of P-CT-based training (evident by the significant group × time interaction) was only in single-leg static balance performed with the dominant leg (T4), indicating this to be an appropriate training stimulus. This result confirms the findings of other authors on the high sensitivity of this ability during child development.

Our results support the concept of training coordinative potential in soccer players at the introductory sports level. Therefore, worthy of consideration is the introduction of certain methodological modifications to existing training programs for prepubertal male soccer players by including a selection of those P-C exercises most effective in improving MCA-related soccer performance. In this context, we suggest a single training session of bilateral exercises targeting balance ability including single-leg balancing games, standing on 1 foot while catching and kicking the ball to a partner; exercises using a balance trainer, and performing a series of jumps to 1-legged standing. At training outset, we would recommend low volume and low intensity so that technique may be first perfected. Apart from teaching proper technique, close supervision of exercise volume (by limiting exercise duration) is strongly encouraged to avoid the occurrence of injury.

Considering that a group × time interaction was observed only in the single-leg static balance test (T4), it can be surmised that the modulation of exercise intensity (every 8–9 weeks based on predicted HR_{max}) had little effect on the other MCA of movement rhythm, motor adaptation, spatial orientation, and kinesthetic differentiation of movement. The results call into question the suitability of monitoring HR in the P-C exercises targeting these MCA, despite some of the benefits from induced higher attentional control and executive function, as skill development is often mediated by cognitive rather than physiological factors. Thus, the results do not support the use of increasing exercise intensity (at least over 8–9 weeks stages) in the introductory-level training.

Finally, the adopted performance tests have the potential to be integrated in field test batteries for monitoring training progress in young soccer players, as they can be easily and inexpensively administered by coaches. We suggest future studies investigating the methods of enhancing soccer performance include other sets of exercises, perform parallel testing of dominant/nondominant limbs, assess soccer players of different age brackets, and examine the acquisition of coordination potential such as by describing the coordination modes for multiarticular actions as a function of skill. The applicative value of such an approach would be in the harmonious development of an individual coordination-fitness profile.

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