Preseason Integrative Neuromuscular Training Improves Selected Measures of Physical Fitness in Highly Trained, Youth, Male Soccer Players

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Abstract

Hammami, R, Negra, Y, Nebigh, A, Ramirez-Campillo, R, Moran, J, and Chaabene, H. Preseason integrative neuromuscular training improves selected measures of physical fitness in highly trained, youth, male soccer players. *J Strength Cond Res* XX(X): 000–000, 2022—This study examined the effects of an 8-week integrative neuromuscular training (INT) program, including balance, strength, plyometric, and change of direction exercises, on measures of physical fitness in youth male soccer players. Twenty-four male soccer players participated in this study. They were randomly allocated into an INT (n = 12; age = 15.7 ± 0.6 years, body height = 179.75 ± 6.54 cm, body mass = 78.20 ± 7.44 kg, maturity-offset = +2.2 ± 0.6 years) or an active control (CG, n = 12; age = 15.4 ± 0.8 years, body height = 178.4 ± 6.4 cm, body mass = 72 ± 8.3 kg, maturity-offset = +1.9 ± 0.7 years) group. Before and after training, tests to measure dynamic balance (Y-Balance test [YBT]), muscle strength (one repetition maximum [1RM]), muscle power (five jump test [FJT], single-leg hop test [SLHT], and countermovement jump [CMJ] height), linear sprint time (10 and 30-m), and change of direction with ball (CoD_{ball}) were performed. The analysis of covariance was used to test between-group differences (INT vs. CG) at posttest using baseline values as covariates. Significant, large, between-group differences at posttest were noted for the YBT (p = 0.016; d = 1.1), 1RM (p = 0.011; d = 1.2), FJT (p = 0.027; d = 1.0), SLHT (p = 0.04; d = 1.4), CMJ height ($p < 0.001$; d = 1.9), 10-m sprint ($p < 0.01$; d = 1.6), and CoD_{ball} ($p < 0.05$; d = 0.9) in favor of the INT group. Significant moderate-to-large pre-to-post changes were detected in the INT group for YBT, 1RM, CMJ height, SLHT, FJT, 10-m and 30-m sprint time, and CoD_{ball} test (d = 0.7 to 3.07, $p < 0.05$). No significant pre-to-post changes were observed in the CG ($p >$ 0.05), except for 10-m sprint time (d = 1.3; $p < 0.05$). Exposure to INT twice weekly is effective and time efficient to improve various measures of physical fitness in highly trained youth male soccer players.

Key Words: resistance training, football, human physical conditioning, youth sports

Introduction

Successful performance in soccer depends on a variety of physical and physiological factors, alongside technical, tactical, and psychological skills (5,33). More specifically, a player's level of physical fitness (e.g., balance, muscle strength or power, and change of direction speed [CoD]) plays a crucial role in accommodating the intense demands of training and competition in modern soccer (5,33,40). Indeed, measures of physical fitness, such as CoD speed (4) and muscle strength and power (31), can differentiate between soccer players of different competitive levels. Therefore, beginning to measure and develop physical fitness at an early age is of utmost importance for increasing the likelihood of competitive success in the future (17).

Generally, soccer is characterized by intense actions (i.e., sprinting, CoD speed, acceleration, and decelerations) as well as high impact and forceful bodily contact during training and competition (9,16), thus exposing players to the risk of injury (14). To offset this risk, integrative neuromuscular training (INT), which is a holistic training approach that integrates basic movements in addition to specific strength and physical conditioning exercises with or without external resistance, may be effective in decreasing injury incidence in youth athletes (15,20). Emery et al. (12) studied the effects of an in-season INT, including aerobic, agility, strength, and balance exercises, incorporated into the warm-up routine on injury prevention in female junior soccer players aged 11–16 years. The authors concluded that INT was effective in preventing sports-related injuries. In addition, Steib et al. (36) summarized the dose-response relationship of INT programs for injury prevention in youth athletes. The authors revealed that short bouts (10–15 minutes of INT), two-to-three times per week, with a weekly training volume of 30–60 minutes, had the largest preventive effect for lower extremity injuries in youth athletes.

Unlike injury prevention, the effects of INT on measures of physical fitness are less studied in the literature. The few available investigations indicate that INT programs induce large effects in muscle strength, small-to-moderate gains in muscle power, and moderate improvements in linear sprint time in youth athletes (31,32,40). The inherent advantage of INT is that it facilitates the targeting of many physical fitness qualities compared with a blocked approach, making it a time-efficient training method (30,31,36). In addition, INT requires limited and low-cost equipment and is more attractive to youth (13,30,31). These features make INT particularly well suited to be allocated during the preseason and in-season periods. Of note, most of the available studies addressed the in-season effects of INT programs on measures of physical fitness in youth athletes with a few studies on the preseason effects. For instance, Zouhal et al. (40) examined the effects of a 6-week in-season INT on CoD speed in youth male soccer players aged 17 years. The researchers reported greater improvements in CoD speed with turns for the nondominant (d = 0.89) and dominant (d = 0.96) leg sides in comparison with the control condition. In addition, Panagoulis et al. (31) examined the effects of an eight-week in-season INT on ball shooting speed, linear sprint time (10- and 20-m), CoD speed, jumping performance, and muscle strength in early adolescent soccer athletes. They reported significant improvements in 10- and 20-m sprint time (~15%), muscle strength (~10%), jumping ability (~6–9%), CoD speed (~3.5%), and ball shooting speed (~6.5%) after INT, whereas soccer training alone induced positive gains in 10-m sprint time (~4%) and ball shooting speed (~5%) with no changes in CoD speed and jumping performance and a deteriorated performance in 20-sprint time and muscle strength.

Although scientific evidence supports the usefulness of INT for injury resistance and physical performance improvement in youth, there is a dearth of studies that examine the effects of a preseason INT program on key measures of physical fitness in youth male soccer players. Therefore, more studies are needed to expand the rather limited existent literature. Considering that training approaches can substantially differ between in-season (e.g., focus on tactic technique) and preseason (e.g., focus on strength and conditioning), responses to INT coming from in-season studies should not be directly extrapolated to preseason ones. On this basis, this study aimed to examine the effects of the addition of an 8-week INT to the standard preseason soccer training schedule on measures of muscle strength and power, balance, linear sprint time, and CoD speed in highly trained youth male soccer players. Based on earlier studies conducted with youth male soccer players during the in-season period (30,31,40), we hypothesized that preseason INT would be effective for improving measures of physical fitness in highly trained male soccer players.

Methods

Study Design

A randomized, controlled, trial study design was applied to examine the effects of INT on measures of balance, muscle strength and power, linear sprint time, and CoD speed in highly trained youth male soccer players. The training program was conducted during the preseason period of the year 2021 (from September to November). Subjects of the INT group performed INT with 2 sessions per week for 8 weeks. However, subjects of the control group (CG) followed their standard soccer practice over the same duration. Baseline measurements were performed 4 days after the end of the familiarization session and included anthropometrics and physical fitness performance (i.e., balance, muscle strength, muscle power, linear sprint time, and CoD speed) assessments.

Subjects

The sample size estimation was computed using G*Power software (version 3.1.6) (33). Based on a previous intervention study on the effects of 8 weeks of INT on a proxy of muscle power (i.e., countermovement [CMJ] height) in adolescent male soccer players (30), an a priori power analysis, with a type I error rate of 0.05 and 80% statistical power was computed. The analysis indicated that for both groups together, 21 subjects would represent a sufficient sample with which to observe significant moderate effects of time (Cohen's d = 0.50) on CMJ height. Therefore, the required number of subjects in each group was determined to be 11. Considering the potential for subject attrition, a total of 24, youth, highly trained, male soccer players, from the same soccer team, were recruited to participate in this study. Subjects were randomly assigned to an INT (n = 12; age = 15.7 ± 0.6 years, height = 179.7 ± 6.5 cm, body mass = 78.2 ± 7.4 kg, maturity offset = +2.2 ± 0.6 years) or an active control (CG, n = 12; age = 15.4 ± 0.8 years, height = 178.4 ± 6.4 cm, body mass = 72 ± 8.3 kg, maturity offset = 1.9 ± 0.7 years) groups (Table 1). All subjects were regularly competing in the top-level national soccer division and had between 4 and 5 years of systematic soccer training experience. Of note, both groups followed the same soccer training program under the supervision of the same coaches. The CG participated in a regular soccer-specific training program over the 8-week intervention period with 5 training sessions per week lasting between 80 and 90 minutes each. The INT group conducted 2 weekly training sessions lasting 15 minutes each. The 2 sessions were performed after 15 minutes warm-up. The CG performed the same warm-up in addition to 15-minute passing drills. This made the overall exposition time identical between the 2 groups. Subjects' biological maturity level was estimated based on the maturity offset method using the prediction equation of Moore et al. (26). Before the start of the study, subjects were provided with a document detailing the experimental procedure alongside a parental consent request form. Parental consent and subject assent were obtained after a thorough explanation of the purpose, procedures, risks, and benefits of the study. The study was conducted according to the latest version of the Declaration of Helsinki, and the protocol was fully approved by the Ethics Committee of the Higher Institute of Sport and Physical Education of Ksar Said, Manouba University, Tunis, Tunisia, before the commencement of any assessments. None of the participating players had a history of musculoskeletal, neurological, or orthopedic disorders, over the previous 6 months, that might have impaired their ability to execute the prescribed tasks.

Table 1
Anthropometric characteristics of subjects from both the groups.*†

	INT (n = 12)	CG (n = 12)	p
Age (y)	15.73 ± 0.69	15.45 ± 0.88	0.38
Height (cm)	179.75 ± 6.54	178.47 ± 6.49	0.62
BM (kg)	78.20 ± 7.44	72 ± 8.33	0.06
BMI (kg·m^{-2})	21.38 ± 1.46	21.92 ± 2	0.46
MO (y)	2.22 ± 0.62	1.96 ± 0.77	0.38
APHV (y)	13.51 ± 0.40	13.49 ± 0.41	0.86
TE (y)	4.83 ± 1.70	5.58 ± 1.88	0.31

*INT = integrative neuromuscular training group; CG = control group; BH = body height; BM = body mass; BMI = body mass index; MO = maturity offset; APHV = years at peak height velocity; TE = training experience.
†Values are means and SDs.

Procedure

One week before the commencement of the study, one familiarization session, including all subjects, was conducted. During this period, all subjects were introduced to the different testing protocols, and subjects of the INT group received instructions on the proper technique of the different exercises that they would be undertaking in the intervention. The subject followed the same order during the pretest and the posttest. More specifically, they performed the dynamic balance test followed by the one repetition maximum (1RM), the jump tests, the sprint, and the CoD speed test. All subjects conducted a standardized 10-minute warm-up before testing, which consisted of submaximal running (e.g., skipping, hip in or out) and balance and landing exercises (e.g., forward or backward beam walking, single-leg stance on unstable devices). All tests were separated by a 5–10 minutes of break. Another rest period of 3 minutes was provided between trials of the specific tests. The better of 2 trials was used for further statistical analyses except for the 1RM test because they performed only 1 trial (Figure 1).

Anthropometrics. Subjects' body height and mass were collected using a wall-mounted stadiometer (i.e., Florham Park, NJ) and an electronic scale (i.e., Baty International, West Sussex, England), respectively. The sum of skinfolds was assessed using the Harpenden's skinfold calipers. Body measurements were conducted according to Deurenberg et al. (10) who reported similar prediction errors between adults and adolescents.

Dynamic Balance. Dynamic balance was assessed using the Y-Balance test according to a previously described protocol (19). A composite score (CS-YBT) was calculated and considered as the dependent variable using the following formula: CS-YBT (%) = ([maximum anterior reach distance + maximum posteromedial reach distance + maximum posterolateral reach distance]/[leg length × 3]) × 100.

Muscle Strength. Lower-body dynamic strength was assessed using the 1RM back squat test as described by Keiner et al. (21). Before attempting the 1RM, subjects performed 3 submaximal sets of 1–6 repetitions with a light-to-moderate load. Subjects then performed a series of single repetitions with increasingly heavier loads. The weight increments were dependent on the effort required for the lift and became progressively smaller as the player approached his 1RM. Failure was defined as a lift falling short of the full range of motion on at least 2 attempts, spaced at least 3 minutes apart. The 1RM was typically determined within 6–8 trials. Throughout all testing procedures, an instructor-to-player ratio of 1:1 was maintained, and uniform verbal encouragement was offered to all subjects.

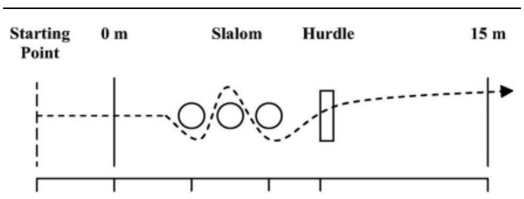

Figure 1. Schematic representation of the change of direction with ball test.

Muscle Power.

Five Jump Test The 5 jump test has been recommended for the measurement of lower-limb jumping ability and is considered to be soccer specific (7). From an upright standing position, with both feet flat on the ground, subjects tried to cover as much distance as possible with 5 forward bounding strides by alternating left-leg and right-leg ground contacts. The covered distance was measured to the nearest 1 cm using a tape measure.

Countermovement Jump Test During the CMJ, subjects started from an upright erect standing position and then performed a fast downward movement by flexing the knees and hips, which were immediately followed by a rapid leg extension resulting in a maximal vertical jump. Throughout the execution of the test, subjects maintained their arms akimbo. Countermovement jump techniques were visually controlled by the first author of the study. Jump height was recorded using an Opto jump photoelectric system (Microgate, SRL, Bolzano, Italy).

Single-Leg Hop Test For the single-leg hop test (SLHT), subjects started from an upright erect standing position. Afterward, they performed one maximal hop forward using only their dominant leg. The leg used to kick a soccer ball was identified as the dominant leg. Double arm swing was allowed during test performance. The maximal horizontal distance covered was measured to the nearest 1 cm using the tape measure.

Linear Sprint Time. Performance in the 30-m linear sprint test was measured using an electronic timing system (Brower Timing Systems, Salt Lake City, UT). In addition, split sprint time at 10 m was recorded. Subjects started 20 cm behind the starting line. They were instructed to start whenever they feel ready and to cover the 30-m distance as fast as possible. The photocell gates were placed 0.75 m above the ground.

Change of Direction With Ball. For the 15-m CoD speed test with ball (CoD_{ball}), players were instructed to perform 3-m straight running with the ball before the initial set of gates where they enter a 3-m slalom section marked by 3 aligned sticks (16-m of height) placed 15 m apart and then cleared a 0.5-m hurdle placed beyond the third stick (Figure 1). The subject then kicked the ball toward either of 2 small goals placed diagonally 7 m on the left and the right sides of the hurdle and ended with 7 m of a straight sprint (27).

Integrative Neuromuscular Training Program. The INT was undertaken for 8 weeks with 2 sessions per week, lasting 15 minutes each. The 2 INT sessions were performed after 15-minute warm-up. The INT protocol included balance on an unstable surface (i.e., BOSU), strength, plyometric, linear sprint, and CoD speed exercises (15). Each INT session included 5 exercises with 60–120 seconds of rest between sets and exercises. The training load of the implemented INT protocol was adjusted for exercise difficulty and intensity every 2 weeks. The volume of training remained constant for all exercises. Integrative neuromuscular exercises were conducted on the soccer pitch. A more detailed description of the program is displayed in Table 2. The CG performed 15-minute warm-up followed by 15-minute passing drill. Of note, training volume (i.e., total training exposure) was similar between the 2 groups. Qualified coaches and experienced sports scientists supervised both the groups. Throughout all training exercises, the instructor-to-player ratio of 1:1 was maintained.

Table 2

Description of the integrative neuromuscular training program.*

	Weeks 1–2	Weeks 3–4	Weeks 5–6	Weeks 7–8
Balance	Single-leg stance balance 3 sets of 5 reps	Single-leg stance balance, then controlling the ball around the body with the other leg 3 sets of 5 reps	Single-leg balance and overhead the ball 3 sets of 5 reps	Running 2 m and jumping before standing on single-leg stance passing the ball with dominant leg then nondominant leg 3 sets of 5 reps
Strength	Body mass half squat and body mass single-leg squat 2 sets of 10 reps Nordics hamstring exercises 1 set of 5 reps	Half squat and side lunges with medicine ball (2 kg) 3 sets of 8 reps Nordics hamstring exercises 2 sets of 5 reps	Bulgarian split squats and 4 directions' lunges with medicine ball (2 kg) 3 sets of 10 reps Nordics hamstring exercises 2 sets of 8 reps	Bulgarian squats and 4 directions' lunges with medicine ball (2 kg) 3 sets of 10 reps Nordics hamstring exercises 2 sets of 8 reps
Plyometrics	Standing long jump 2 sets of 10 reps	Side to side ankle hops over the hurdle 3 sets of 8 reps	Double-legged and one-legged lateral jumps over the hurdle 3 sets of 10 reps	Cone hops with 180° sidecuts. 3 sets of 10 reps
Change of direction	Preplanned lateral shuttle run of 3 m (right and left or left and right) back and forth, then pass the ball	Stop the ball (4 balls) after dribbling and following multiple changes in direction in a 4-m square. The total distance was 18 m	Touch cones placed in a hexagon (2-m side length) with preplanned order (N°1, N°2, N°3 and N°4) and then pass the ball The total distance was 20 m	Two-meter acceleration with ball then slalom with the ball between 3 cones and finally pass the ball, and after that performing a 5-m acceleration without the ball The total distance was 10-m

*In the last training session of each week, subjects tested whether they could have performed 2 more repetitions for each set or one more set. Once this is achieved, the absolute intensity or difficulty of exercise was increased.

Statistical Analyses

Data were tested for normal distribution using Shapiro-Wilk test. Between-group differences at baseline were tested using independent *t*-tests. Given that significant between-group differences were detected in some measures of physical fitness at baseline, training effects were further examined using the analysis of covariance (ANCOVA) model with baseline measurements entered as covariates. In addition, effect sizes (d) were determined by converting partial eta-squared from the ANCOVA output to Cohen d. To evaluate within-group and between-group pre-to-post performance changes, paired sample *t*-tests were applied (29). The effect size was determined from means, standard deviations, and correlation coefficients using the statistical software package G*Power (version 3.1.6). Effect size can be classified as small ($0.00 \leq d \leq 0.49$), medium ($0.50 \leq d \leq 0.79$), and large ($d \geq 0.80$) (8). Test-retest reliability was assessed with Cronbach model intraclass correlation coefficient (ICC) and coefficient of variation (CV). We considered an ICC over 0.90 as high, between 0.80 and 0.90 as moderate, and below 0.80 as low, and CV values were considered acceptable if <10% (39). For each ICC, the 95% confidence interval was calculated to take the sampling distribution into account. Data are presented as group mean values and standard deviation for the pretest and adjusted means and standard deviation for the posttest. The level of significance was established at $p \leq 0.05$. SPSS 20.0 was used for statistical analysis (SPSS Inc., Chicago, IL).

Results

All subjects received treatment conditions as allocated. Thus, 24 athletes completed the training program with an adherence rate of 93%. None reported any training-related or test-related injuries. Table 3 displays test data for all measures of physical fitness at preintervention and postintervention. There were no statistically significant baseline differences between the groups in chronological age, body height, body mass, maturity offset, and soccer experience.

Dynamic Balance

Regarding dynamic balance (i.e., CS-YBT), a significant between-group difference was found at postintervention ($p = 0.016$; $d = 1.13$ [large]) in favor of the INT group (Table 3). A significant pre-to-post change was detected in the INT group ($p < 0.001$; $d = 1.90$ [large]). However, no significant change was observed in the CG ($d = 0.40$ [small], $p = 0.244$).

Muscle Strength

For the 1RM back squat test, the ANCOVA model revealed a significant between-group difference at posttest ($p = 0.011$; $d = 1.21$ [large]) in favor of the INT group. In addition, the INT group achieved a significant pre-to-posttraining improvement in the 1RM back squat ($p < 0.001$; $d = 1.70$ [large]). However, no significant pre-to-posttest change was found in the CG ($p = 0.578$; $d = 0.18$ [trivial]).

Muscle Power

For CMJ height, the results indicated significant between-group differences at posttest ($p < 0.001$; $d = 1.93$ [large]) in favor of the INT group. Similar observations were reported for the FJT ($p = 0.027$; $d = 1.04$ [large]) and the SLHT ($p = 0.014$ d = 1.42 [large]). In addition, the INT group achieved significant pre-to-posttraining improvements in CMJ height ($p < 0.001$; $d = 2.40$ [large]), FJT ($p = 0.020$; $d = 0.80$ [large]), and SLHT ($p < 0.001$; $d = 2.30$ [large]). However, no significant pre-to-posttraining changes were found for CMJ height ($p = 0.166$; $d = -0.40$ [small]), FJT ($p = 0.725$; $d = 0.10$ [trivial]), and SLHT ($p = 0.060$; $d = -0.60$ [moderate]) in the CG.

Linear Sprint Time

Analysis of covariance results indicated a significant between-group difference at posttest for the 10-m ($p < 0.01$, $d = 1.69$ [large]) sprint time (Table 3). Pre-to-post training values increased

Table 3

AU16 **Group-specific baseline and posttest performances after 8 weeks of in-season integrative neuromuscular training on components of physical fitness in highly trained, youth, male soccer players.***

	Pre					Independent sample *t* test	Post					ANCOVA
	INT		CG				INT		CG			
	M	*SD*	M	*SD*	Diff (95% CI)	*p*	M	*SD*	M	*SD*	Diff (95% CI)	*p* (Cohen's *d*)
Dynamic balance												
CS-YBT (%)	96.06	4.89	104.78	4.26	8.7 (4.8 to 12.6)	0.001	103.28	0.61	100.68	0.61	2.6 (−4.6 to −0.5)	<0.05 (1.13)
Muscle strength												
1RM (kg)	52.75	4.84	61.00	7.92	8.2 (2.6 to 13.8)	0.005	59.65	0.66	56.84	0.66	2.8 (0.7 to 4.9)	<0.05 (1.21)
Muscle power												
CMJ (cm)	38.58	4.69	43.25	3.88	4.6 (1.0 to 8.3)	0.01	44.21	0.40	41.53	0.40	2.6 (1.4 to 3.9)	<0.001 (1.93)
SLHT (m)	1.89	0.25	2.06	0.20	0.1 (−0.02 to −0.3)	0.08	2.05	0.01	1.99	0.01	0.05 (−0.08 to −0.02)	<0.01 (1.42)
FJT (m)	12.45	1.24	12.58	1.31	0.1 (−0.9 to 1.2)	0.81	12.82	0.09	12.49	0.09	0.33 (0.0 to 0.62)	0.02 (1.04)
Linear sprint time												
10 m (s)	2.10	0.13	2.15	0.15	0.05 (−0.06 to −0.17)	0.30	1.97	0.01	2.03	0.01	−0.05 (−0.08 to −0.02)	<0.01 (1.69)
30 m (s)	4.47	0.17	4.36	0.16	−0.1 (−0.25 to 0.03)	0.10	4.34	0.02	4.41	0.02	−0.07(-0.1 to 0.1)	0.08 (0.79)
Change of direction												
CoD_{ball} (s)	3.73	0.15	4.18	0.35	0.4 (0.2 to 0.6)	0.005	3.83	0.03	3.95	0.03	−0.1 (−0.2 to −0.09)	<0.05 (0.97)

*M = mean; 95% CI = 95% confidence interval; *d* = Cohen's *d* (effect size); INT = integrative neuromuscular training group; CG = control group; ANCOVA = analysis of covariance; CS-YBT = composite score of the Y-balance test; 1 RM = one repetition maximum; CMJ height = countermovement jump height; SLHT = single-leg hop test; FJT = five jump test; CoD_{ball} = change of direction with ball.

significantly in both the groups (INT: $d = 3.07$, $p < 0.001$; CG: $d = 1.30$, $p < 0.05$). Likewise, a tendency toward a significant between-group difference at posttraining was found ($p = 0.080$; $d = 0.80$ [large]) for the 30-m sprint in favor of the INT group. In addition, the INT group achieved a significant pre-to-posttraining improvement in the 30-m sprint time ($d = 1.0$ [large], $p < 0.001$). However, no significant pre-to-posttraining changes were noted in the CG ($d = 0.0$ [trivial]; $p > 0.05$).

Change of Direction

Regarding the CoD_{ball} test, the results indicated significant between-group differences at posttraining ($d = 0.97$ [large], $p < 0.05$), in favor of the INT group. The INT group demonstrated significant pre-to-posttraining improvements in the CoD_{ball} test ($d = 0.70$ [moderate], $p < 0.05$). However, the CG failed to show a significant pre-to-post change ($d = 0.60$ [moderate]; $p > 0.05$).

Discussion

This study examined the effects of an 8-week INT program, which comprised balance, strength, plyometric, and CoD speed exercises, on various measures of physical fitness in highly trained, youth, male soccer players. The main findings indicated that 8 weeks of such training performed on a twice weekly basis resulted in improved measures of balance, muscle strength, muscle power, linear sprint time, and CoD speed performance in highly trained, youth, male soccer players. However, regular soccer practice induced no changes in any measures of physical fitness, except the 10-m sprint time.

Our results indicated improvements in dynamic balance following INT in youth male soccer players with such an improvement likely being the result of improved neuromuscular control (38). The INT program used in this study included postural control, strengthening, jumping, and CoD speed exercises with several variations mostly focused on knee flexor-extensor and hip extensor muscles. An earlier study by Pasanen et al. (32) evaluated the effects of 6 months of in-season INT, including sports-specific running technique, balance, jumping, and strengthening exercises, on balance performance in male soccer players. The results of this study indicated moderate improvements in subjects' sideways balance performance. This finding alongside that observed in this study seems to support the effectiveness of a whole-body multistation intervention training program for improving lower-extremity control. Although we did not measure the potential mechanisms associated with these changes, the dynamic nature of INT seems to place training stress on balance and equilibrium by promoting anticipatory postural adjustments (i.e., feedforward process) (19). Furthermore, the sensitivity of afferent feedback pathways can be improved with INT (37). Accordingly, the use of INT is recommended for youth soccer players to initiate adaptations in balance performance.

Our results indicated a large improvement in maximal dynamic strength (i.e., 1RM) after INT with no changes in the CG. This observation supports the notion that INT can stimulate adaptations in the contractile elements of the involved muscles. Dobbs et al. (11) demonstrated positive changes in back-squat performance in both prepubertal and postpubertal male subjects after 4 weeks of INT. Although the mechanisms responsible for these gains were not examined in our study, it is likely that changes were neuromuscular in nature and related to improved motor unit recruitment or synchronization and firing rate (13). In fact, high threshold motor unit recruitment and synchronization positively influence the production of maximal voluntary force in youth (31), and these mechanisms are likely responsible for the gain in 1RM performance noted in this study. In addition, it has been reported that INT improves lower-limb neuromuscular control and enhances movement efficiency (31). These changes could translate, at least to some extent, to improved force generation capacity in the lower limbs (31). Overall, our findings showed that preseason INT program is an effective approach to improve muscle strength in highly trained youth male soccer players.

In addition, we observed improved muscle power performance (CMJ, SLH, and FJT). This seems to support the notion that INT improves the efficiency of the stretch-shortening cycle in youth male soccer players (31). Our results are in line with those of Lloyd et al. (24) who demonstrated that a twice weekly INT program generated significantly greater gains in squat jump compared with a control group. Accordingly, we speculate that increases in jumping performance may have been stimulated by the enhanced neural drive to the agonist muscles involved in jumping, better intermuscular and intramuscular coordination, increases in muscle size and tendon stiffness, and alterations to single-fiber mechanics.

Our results further indicated improved sprint speed and CoD_{ball} performance following INT, with no changes in the CG, except 10-m sprint speed. Several studies have investigated the effects of other forms of INT on speed and CoD speed performance in youth team sport athletes (24,31,40). Zouhal et al. (40) demonstrated significant pre-to-post improvements in CoD speed performance after in-season INT with no changes in the control group. In this study, we evaluated the performance in 10- and 30-m sprinting speed, which respectively represents the initial and secondary phases of acceleration in sprint running (13,31). The effects of preseason INT on sprint speed may be related to increased neuromuscular activation (i.e., upregulation of firing frequency of motor units), reduced ground contact time, and stiffness of the musculotendinous tissue (31,34). Furthermore, the positive effects of preseason INT on CoD_{ball} suggest that this form of training may trigger positive adaptations to the stretch-shortening cycle (31). Thus, the significant CoD speed improvement after INT may be attributed to the greater SSC efficiency (i.e., rapid switch from eccentric to concentric muscle action) after INT, which is an important prerequisite to improve change-of-direction movements (40). In addition, it seems that the increase in the rate of force development and in the muscle power output following INT positively affects CoD speed performance. There is also evidence that eccentric muscle strength contributes to CoD speed performance, namely, during the deceleration phase (6). In this sense, it seems plausible to suggest that preseason INT that includes a combination of strength exercises and plyometrics, among others, might have enhanced eccentric muscle strength in youth male soccer players. The increased CoD_{ball} performance seems to be mainly the result of neural factors such as increased motor unit recruitment and firing frequency (22).

This study is not without limitations. To better understand the underpinning physiological mechanisms of the adaptations associated with preseason INT, tools and techniques such as electromyography (muscle activation) and ultrasound (muscle hypertrophy) should be used in future studies. In addition, we were unable to compare the effects of INT with single-mode plyometric or strength training, which is an important issue given the confounding influence of one training type on another in the manifestation of adaptations. This should be addressed in future research to identify the optimal proportion and combination for each mode of training during INT. Finally, 1RM was determined within 6–8 trials. With reference to the literature (18), the 1RM should have been determined in no more than 5 trials to avoid biased results as a result of the emergence of fatigue. However, fatigue (if any) could have affected both the preintervention and postintervention tests because the same procedures were applied in the same order. Therefore, any risk of a biased outcome between pretest and posttests would seem to be minimal.

Practical Applications

Our results indicate that the integration of 30 minutes of preseason INT, including dynamic stabilization, strengthening, jumping, and change of direction exercises, on a twice weekly basis, for 8 weeks, into routine soccer training, is an effective and time-efficient approach to improve diverse measures of physical fitness, including balance, muscle strength, muscle power, and CoD speed performance in highly trained, youth, male soccer players. Generally, pediatric fitness programs should prioritize multifaceted interventions such as INT to facilitate the learning of a wide range of motor skills and fitness qualities, all of which are necessary for soccer practice. Therefore, practitioners are encouraged to consider INT as an effective approach during the preseason period to target various components of physical fitness in male youth soccer players.

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References

1. Asadi A, Saez de Villarreal E, Arazi H. The effects of plyometric type neuromuscular training on postural control performance of male team basketball players. *J Strength Cond Res* 29: 1870–1875, 2015.
2. Barone R, Macaluso F, Traina M, et al. Soccer players have a better standing balance in nondominant one-legged stance. *Open Access J Sports Med* 2: 1–6, 2010.
3. Behringer M, Vom Heede A, Matthews M, Mester J. Effects of strength training on motor performance skills in children and adolescents: A meta-analysis. *Pediatr Exerc Sci* 23: 186–206, 2011.
4. Bloomfield J, Polman R, O'Donoghue P. Turning movements performed during FA Premier League soccer matches. *J Sports Sci Med* 6: 9–10, 2007.
5. Castagna C, D'Ottavio S, Abt G. Activity profile of young soccer players during actual match play. *J Strength Cond Res* 17: 775–780, 2003.
6. Chaabene H, Prieske O, Negra Y, Granacher U. Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. *Sports Med* 48: 1773–1779, 2018.
7. Chamari K, Chaouachi A, Hambli M, et al. The five-jump test for distance as a field test to assess lower limb explosive power in soccer players. *J Strength Cond Res* 22: 944–950, 2008.
8. Cohen J. *Statistical Power Analysis for the Behavioural Sciences*. Hillside, NJ: Lawrence Erlbaum Associates, 1988. pp. 23–97.
9. Dellal A, Chamari K, Wong DP, et al. Comparison of physical and technical performance in European soccer match-play: FA premier league and La Liga. *Eur J Sport Sci* 11: 51–59, 2011.
10. Deurenberg P, Pieters JJ, Hautvast JG. The assessment of the body fat percentage by skinfold thickness measurements in childhood and young adolescence. *Br J Nutr* 63: 293–303, 1990.
11. Dobbs IJ, Oliver JL, Wong MA, et al. Effects of a 4-week neuromuscular training program on movement competency during the back-squat assessment in pre–and post–peak height velocity male athletes. *J Strength Cond Res* 35: 2698–2705, 2021.
12. Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: A cluster-randomised controlled trial. *Br J Sports Med* 44: 555–562, 2010.
13. Faigenbaum AD, Farrell A, Fabiano M, et al. Effects of integrative neuromuscular training on fitness performance in children. *Pediatr Exerc Sci* 23: 573–584, 2011.
14. Faude O, Rößler R, Junge A. Football injuries in children and adolescent players: Are there clues for prevention? *Sports Med* 43: 819–837, 2013.
15. Fort-Vanmeerhaeghe A, Romero-Rodriguez D, Lloyd RS, Kushner A, Myer GD. Integrative neuromuscular training in youth athletes. Part II: Strategies to prevent injuries and improve performance. *Strength Cond J* 38: 9–27, 2016.
16. Gorostiaga EM, Llodio I, Ibáñez J, et al. Differences in physical fitness among indoor and outdoor elite male soccer players. *Eur J Appl Physiol* 106: 483–491, 2009.

17. Granacher U, Lesinski M, Büsch D, et al. Effects of resistance training in youth athletes on muscular fitness and athletic performance: A conceptual model for long-term athlete development. *Front Physiol* 7: 164, 2016.
18. Haff GG, Triplett NT; National Strength & Conditioning Association (US). *Essentials of Strength Training and Conditioning* (4th ed.). Champaign, IL: Human Kinetics, 2016.
19. Hammami R, Granacher U, Makhlouf I, Behm DG, Chaouachi A. Sequencing effects of balance and plyometric training on physical performance in youth soccer athletes. *J Strength Cond Res* 30: 3278–3289, 2016.
20. Herrington L. The effects of 4 weeks of jump training on landing knee valgus and crossover hop performance in female basketball players. *J Strength Cond Res* 24: 3427–3432, 2010.
21. Keiner M, Sander A, Wirth K, et al. Strength performance in youth: Trainability of adolescents and children in the back and front squats. *J Strength Cond Res* 27: 357–362, 2013.
22. Komi PV. Stretch-shortening cycle. *Strength Power Sport* 2: 184–202, 2003.
23. Lauber B, Gollhofer A, Taube W. What to train first: Balance or explosive strength? Impact on performance and intracortical inhibition. *Scand J Med Sci Sports* 31: 1301–1312, 2021.
24. Lloyd RS, Dobbs IJ, Wong MA, Moore IS, Oliver JL. Effects of training frequency during a 6-month neuromuscular training intervention on movement competency, strength, and power in male youth. *Sports Health* 14: 57–68, 2022.
25. Lloyd RS, Radnor JM, De Ste Croix MBA, Cronin JB, Oliver JL. Changes in sprint and jump performances after traditional, plyometric, and combined resistance training in male youth pre-and post-peak height velocity. *J Strength Cond Res* 30: 1239–1247, 2016.
26. Moore SA, McKay HA, Macdonald H, et al. Enhancing a somatic maturity prediction model. *Med Sci Sports Exerc* 47: 1755–1764, 2015.
27. Mujika I, Santisteban J, Impellizzeri FM, Castagna C. Fitness determinants of success in men's and women's football. *J Sports Sci* 27: 107–114, 2009.
28. Myer GD, Faigenbaum AD, Chu DA, et al. Integrative training for children and adolescents: Techniques and practices for reducing sports-related injuries and enhancing athletic performance. *Phys Sports Med* 39: 74–84, 2011.
29. Nogueira PA, Morra P, Martini E, Cavalieri AV, Henningson DS. Forcing statistics in resolvent analysis: Application in minimal turbulent Couette flow. *J Fluid Mech* 908, 2021.
30. Nunes ACCA, Cattuzzo MT, Faigenbaum AD, Mortatti AL. Effects of integrative neuromuscular training and detraining on countermovement jump performance in youth volleyball players. *J Strength Cond Res* 35: 2242–2247, 2021.
31. Panagoulis C, Chatzinikolaou A, Avloniti A, et al. In-season integrative neuromuscular strength training improves performance of early-adolescent soccer athletes. *J Strength Cond Res* 34: 516–526, 2020.
32. Pasanen K, Parkkari J, Pasanen M, Kannus P. Effect of a neuromuscular warm-up programme on muscle power, balance, speed and agility: A randomised controlled study. *Br J Sports Med* 43: 1073–1078, 2009.
33. Rebelo A, Brito J, Seabra A, Oliveira J, Krustrup P. Physical match performance of youth football players in relation to physical capacity. *Eur J Sport Sci* 14(Suppl 1): S148–S156, 2014.
34. Rimmer E, Sleivert G. Effects of a plyometrics intervention program on sprint performance. *J Strength Cond Res* 14: 295–301, 2000.
35. Schulz R, Langen G, Prill R, Cassel M, Weissgerber T. The devil is in the details: Reporting and transparent research practices in sports medicine and orthopedic clinical trials. *medRxiv*, 2021.
36. Steib S, Rahlf AL, Pfeifer K, Zech A. Dose-response relationship of neuromuscular training for injury prevention in youth athletes: A meta-analysis. *Front Physiol* 8: 920, 2017.
37. Taube W, Gruber M, Gollhofer A. Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiol* 193: 101–116, 2008.
38. Thorpe JL, Ebersole KT. Unilateral balance performance in female collegiate soccer athletes. *J Strength Cond Res* 22: 1429–1433, 2008.
39. Vincent WJ. *Statistics in Kinesiology*. Champaign, IL: Human Kinetics, 1995. pp. 71–72.
40. Zouhal H, Abderrahman AB, Dupont G, et al. Effects of neuromuscular training on agility performance in elite soccer players. *Front Physiol* 10: 947, 2019.