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Integrative neuromuscular training and detraining in pre-adolescent basketball players

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ABSTRACT

Youth sports participation can promote better physical activity levels and motor competence (MC) in young populations. However, it shows risks of injury and burnout. Integrative neuromuscular training (INT) is presented as a training alternative capable of reducing the incidence of injury and improving MC in young athletes. The aim of this study was to evaluate the effects of 6 weeks of individualized INT as a warm-up in preadolescent basketball players on their acceleration, change of direction (COD), vertical jump (CMJ) and dynamic unipodal balance (SEBT). Subjects (143.37 ± 8.75 cm, 40.66 ± 7.65 kg; 10.08 ± 0.27 years) underwent 20 minutes of INT three days per week during six weeks, where strength, change of direction speed, plyometrics, balance and coordination were trained. Assessments were performed before the intervention (P1), after the intervention (P2), and after 3 weeks of detraining (P3). At P2, significant improvements were obtained in COD test, CMJ, and in the posterolateral direction of the right leg and in the posteromedial direction of the left leg in the SEBT test. At P3, significant improvements were maintained for CMJ and SEBT. An INT warm-up can affect improvements in COD, CMJ and some directions of SEBT in pre-adolescent basketball players.

Keywords: Health, Sports science, Pre-adolescent, Team sports, CMJ, Change of direction, Balance, Acceleration.

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INTRODUCTION

Today's youth are weaker than previous generations, with a tendency towards motor incompetence and below desirable levels of physical activity (PA) (Faigenbaum et al., 2023; Bolger et al., 2021; Weaver et al., 2021). However, youth sports participation can be a potential tool for switching some of these outcomes, since it has shown to have a positive impact on PA levels, sedentary time, obesity in middle age, positive and healthy life trajectories, affective and psychosocial domains, academic and life skills, and motor competence (MC) and motor development (Coppens et al., 2021; Thompson et al., 2024; Yang et al., 2022).

Nevertheless, participation in youth sports, and particularly early specialization in youth sports, can give rise to negative outcomes, including injuries, burnout and/or dropout (Crane and Temple, 2015; Fort-Vanmeerhaeghe et al., 2016b; Thompson et al., 2024). This can happen due to the specialization of training programs, the lack of enjoyment, the perception of incompetence, the high and not well-matched demands of coaches and training or competition load, as well as the lack of a general fitness and MC base. Consequently, a negative trend in youth sports participation and PA levels can emerge (negative spiral of disengagement), whereby a reduced PA, due to injury or dropout, will decrease the fitness levels, potentially leading to functional limitations and less MC, than can possibly conclude in even less PA, poorer health, more injury odds and fear of movement (Crane and Temple, 2015; Faigenbaum et al., 2023; Fort-Vanmeerhaeghe et al., 2016a; Fort-Vanmeerhaeghe et al., 2016b; Myer et al., 2011b; Myer et al., 2013a; Thompson et al., 2024).

In this context, there is a variety of modes, methods and training strategies in the literature aimed at young athletes, with the goal of preventing injuries and enhancing both their MC and their general physical condition (Read et al., 2020). However, one protocol that is particularly well-represented in the literature is integrative neuromuscular training (INT). This is a multifaceted model of training that incorporates general (such as basic motor skills) and specific (such as tasks designed to improve motor control deficits) strength and conditioning activities. Its main elements (complementary and concurrent with each other) are strength training, stability training, core strength and stability training, plyometrics and speed/agility drills. The primary objectives of this training model are to enhance health-related and skill-related fitness components, increase resistance to injury, and improve performance in MC and sporting skills among youth (Fort-Vanmeerhaeghe et al., 2016a; Fort-Vanmeerhaeghe et al., 2016b; Myer et al., 2011a; Myer et al., 2013a; Myer et al., 2013b; Myer et al., 2015; Read et al., 2020). INT is presented as a feasible solution to sports related injuries, as it provides a training base that prepares young athletes for training and competition, helping to reduce neuromuscular deficits and increasing the MC of the youth. It is estimated that INT could reduce 15-50% of reported acute and overuse injuries in young people. This is mainly due to improved movement biomechanics and a trained and efficient neuromuscular system (Fort-Vanmeerhaeghe et al., 2016a; Fort-Vanmeerhaeghe et al., 2016b; Myer et al., 2011a; Myer et al., 2015; Myer et al., 2013a; Myer et al., 2013b).

INT has an intermittent nature, with periods of intense activity interspersed with intervals of rest and recovery, which resembles the natural form of movement and play observed in children (Fort-Vanmeerhaeghe et al., 2016a; Myer et al., 2015). This work was also developed as a counterpart to PA recommendations for young people, which emphasize 60 minutes of moderate to vigorous activity on most days of the week, which is not very motivating or adherent in this age groups (Myer et al., 2015). The evidence of the scientific literature reveals a multitude of positive effects associated with INT training. These effects may include improvements in fundamental movement skills (FMS) and MC, as well as health-related and skill-related fitness parameters. Furthermore, these interventions have achieved improvements in both pre-adolescent and adolescent subjects, with some studies using session times as low as 15 minutes, showing a significant efficacy of INT

(Faigenbaum et al., 2015; Faigenbaum et al, 2011; Faigenbaum et al., 2014; Font-Lladó et al., 2020; Nunes et al., 2019).

Young pre-adolescents are particularly susceptible to multifaceted work such as INT. These individuals are distinguished by high neural plasticity, which can enable them to benefit more socially, physically and mentally from this type of training. Furthermore, encouraging this type of activity at this age will facilitate future motor development during adolescence (Fort-Vanmeerhaeghe et al., 2016a; Fort-Vanmeerhaeghe et al., 2016b; Myer et al., 2011a; Myer et al., 2015; Myer et al., 2013a; Myer et al., 2013b). Given the potential benefits associated with INT and its crucial role in preventing injuries in young athletes, the objective of this study is to assess the impact of a six weeks structured and individualized INT program as a 20-minute warm-up in pre-adolescent basketball players. The effects were quantified in terms of acceleration and change of direction (COD) ability, vertical jump and unipodal dynamic balance.

METHODS

Subjects

A convenience sample of eight basketball players between 10 and 11 years old (two girls and six boys, 143.37 ± 8.75 cm, 40.66 ± 7.65 kg, 10.08 ± 0.27 years) was used for this study. Subjects competed in the 1st Mini basket Division category of the Galician Basketball Federation in Spain. All players belonged to the same team and had no training age in any general motor or fitness improvement program (such as INT or strength and conditioning) but had one to two years of basketball training and competition experience. The 8 followed the same training protocol (but individualized for each subject), the same assessments and the same technical-tactical basketball session organized by the coach. All relevant parties were informed of the procedures of the study. Parents and coach provided their consent, and the young participants admitted understanding and commitment. Any subject engaged in other sports. Any subject missed more than 4 days of practice (approximately 80% attendance). Furthermore, all participants were healthy and active preadolescents with no injuries or physical issues. This study adhered to the ethical principles of the Helsinki Convention and the local Investigational Review Committee approved the study.

Study design

This study comprised 11 weeks of intervention, with the first day of the first week designated as the pre-treatment assessments (P1). Seven days after, the training protocol commenced prior to the basketball training session. A total of six weeks (18 sessions) were administered to the subjects. The protocol was conducted before every team training session, with three team basketball practices per week. On weekends, the team competed in their respective league, performing their typical general basketball warm-up but not the INT one. Following the conclusion of the training program, the first post-treatment tests (P2) were conducted 72 hours after the final training session, with these assessments taking place in the 8th week. The second post-treatment tests, or post-detraining assessment (P3), were carried out three weeks later, after a period where participants resumed their regular basketball training sessions without an INT warm-up. The whole intervention period took place during the first half of the competitive season.

Protocol

The implemented INT protocol was created following evidence, recommendations, theoretical frameworks and tasks from similar interventions in the literature. The programme had a total of 18 sessions during 6 weeks, with a frequency of 3 non-consecutive days per week. The sessions were performed as a warm-up for the team's group basketball training, during the first 20min of the total 75 min of training. The INT components were body stability (lower limbs and core), strength, plyometrics, coordination and COD speed.

These were worked throughout the training week, in pairs, over 5 stations that formed the training circuit. Subjects performed 2 sets per exercise, or in other words, 2 laps of the circuit (Faigenbaum et al., 2015; Font-Lladó et al., 2020). The program attempted to follow an individualised and constant progression, marked by the technical competence of each subject. All the exercises of the different components had several levels of technical difficulty (Font-Lladó et al., 2020). The common approach for the creation of the exercise's progression was the progressive path from FMS and fundamental motor competence towards more advanced, complex and sport specific movement skills. Due to the sample age, it was still more close to the fundamental stage (Fort-Vanmeerhaeghe et al., 2016a). The same progressions, but in reverse, was used to set regressions if necessary to any subject at any station. The work to rest ratio of the circuit was controlled over time, working 30s at one station and resting 30s on the way to the next. In session 10, the work time was increased to 45 seconds.

Coordination was specifically worked prior to the start of the circuit, with a 5min general activation work, where the aim was to activate the subjects physically and psychologically. Working the coordination element at the start of the session can also be seen in other interventions in the literature (Faigenbaum et al., 2015; Faigenbaum et al., 2011; Nunes et al., 2019; Panagoulis et al., 2018). This moment is considered the most valuable part of the session for its development, as the central nervous system is not yet fatigued (Fort-Vanmeerhaeghe et al., 2016a). Coordination was worked with basketball drills and tasks. The elements of coordination used for its training can be seen in Table 1. Throughout the training intervention these tasks and drills were progressed implementing more or less coordinative elements. During the first sessions only 1 or 2 elements were introduced to the subjects (i.e.: rhythm and/or kinaesthetic dissociation), progressing to more elements with time and competence improvements (Fort-Vanmeerhaeghe et al., 2016a).

Strength occupied a prominent place in the protocol, being worked in, at least, 2 of the 5 stations. Body weight exercises and/or with small overloads, moderate speeds, basic exercises involving all the major muscle groups, adequate ranges of motion and movements that followed the athletic motor skills competencies (AMSC) were used. The AMSC are key fundamental movements that precede athletic movements, and the ones used for the strength training of this INT intervention were bilateral and unilateral lower body patterns, upper body pull and push (Faigenbaum et al., 2023; Fort-Vanmeerhaeghe et al., 2016a; Myer et al., 2013b; Read et al., 2020). Strength exercises progression is presented in Table 1. Strength exercises were also varied with regard to intensity and volume. Volume was adapted in exercises such as push-ups, that could be too challenging for some subjects. So instead of being guided by time, the exercise was prescribed with a minimum of 10 repetitions for the most basic push-up level, which could be increased in repetitions if a subject could perform it technically competent but could not jump to the next level of the progression. Intensity was also increased (i.e.: correct execution of squat pattern level 2 but incompetence on level 3) by altering resistance to the exercises, like overloading with medicine balls or using harder elastic bands.

In the case of plyometrics, progression was mainly guided by its intensity, which was based on the impact load of the exercise and its type of stretch-shortening cycle (SSC) (slow or fast) (Fort-Vanmeerhaeghe et al., 2016a). Again, subjects could only advance in the progression based on their technical competence in the exercise. Recommendations in the literature indicate that the optimal frequency of plyometrics is 2 days per week, leaving one day per week free of plyometric work, which was occupied with other INT element (i.e.: another strength or core exercise). The speed of execution was emphasized to be the maximum possible at all times (Faigenbaum et al., 2011; Font-Lladó et al., 2020; Fort-Vanmeerhaeghe et al., 2016a). The proposed plyometric progression is presented in Table 1.

Stability was worked on in two ways, as lower limb stability, and core control (Fort-Vanmeerhaeghe et al., 2016a). For the lower limbs the progression was based on the following criteria: 1. static balance (maintaining the centre of mass on a static base of support and a stable surface), and 2. dynamic balance (maintaining the centre of mass on a fixed base of support and under perturbations such as movement of other body segments or an unstable support surface). The progression also took into account the stability training variables such as the amplitude of movements, opened/closed eyes, the instability of the surface, the control of an object etc. (Fort-Vanmeerhaeghe et al., 2016a). In Table 1, the progression of lower limb stability can be observed.

On the other hand, core-centred control or stability has been worked following the next approach, from lowest to highest level of progression: 1. basic postural stability and conscious activation (i.e.: bird-dog, transverse abdominis work etc.), 2. stability and muscular endurance (isometric planks and bridges etc.) (Fort-Vanmeerhaeghe et al., 2016a). The progression of core training is presented in Table 1. COD speed training is based on closed and pre-planned situations and tasks with CODs (Fort-Vanmeerhaeghe et al., 2016a; Stewart et al., 2012). Within a progression for subjects of these ages, we have prioritized at the beginning the correct technical execution and learning of acceleration and COD mechanics, over agility training (Fort-Vanmeerhaeghe et al., 2016a). In Table 1 the progression for COD work is presented.

Table 1. INT elements and their respective exercises and/or progressions.

INT Elements	**Exercises and progressions**		
Coordination	Spatio-temporal orientation. Reaction. Rhythm. Kinaesthetic dissociation. Balance. Movement adaptation and transformation. Matching or combining movements.		
Strength	*Lower body*	Squat patterns	Squat to bench << Air squat << Overhead squat (wooden stick) << Overhead squat on instable surface.
		Hip-hinge patterns	Glute bridge << Hip-Thrust << Unilateral Hip-Thrust << Incline Hip-Thrust.
		Lunge patterns	Split Squat << Reverse Lunge << Forward Lunge.
	Upper body	Pushing	High incline push-up << Low incline push-up << Knee push-up << Push-up.
		Pulling	Horizontal band pull << Vertical band pull.
Core	Transverse abdominis (vacuum in supine position) << Reverse abdominis crunch << Clamshell << Bird-dog << Quadruped isometric plank.		
Lower limbs stability	Closed eyes bipodal positions (i.e.: closed eyes basketball shotting position) << Closed eyes single foot positions << Single foot stance + basketball moves (pass or shoot) << Bipodal stance on instable surface + basketball moves << Single foot stance on instable surface + basketball moves.		
Plyometrics	Bilateral horizontal CMJ << Bilateral vertical CMJ << Unilateral horizontal CMJ << Unilateral vertical CMJ.		
COD speed	Zigzag over 6 cones << Zigzag over 6 cones half forward and half backwards << T exercise (5x5x5m) forward sprints << T exercise with forward and lateral sprints << Zigzag and T exercises with basketball dribbling.		

COD = Change of Direction; CMJ = Countermovement Jump feedbacks play an imperative role in this type of INT program, which aims to improve and refine the motor skills of young and pre-adolescent children. For this reason, subjects were constantly provided with constructive and corrective feedback, both visual, verbal and tactile, as well as positive reinforcement regarding the execution of movements (Faigenbaum et al., 2015; Faigenbaum et al., 2011; Font-Lladó et al., 2020; Fort-Vanmeerhaeghe et al., 2016a; Myer et al., 2013a; Panagoulis et al., 2018). For promoting correct technique, signs and posters have also been used at most stations of the circuit, which showed the correct execution of the movement pattern performed.

Measurements

The subjects were tested 3 times. All of them were performed on Mondays at the usual training time and location. Subjects were explicitly asked to avoid any strenuous exertion on the day before the assessments and throughout the day of the assessments. The tests measured subjects' anthropometric characteristics (height and weight) at P1, their 5 and 10 m acceleration ability and COD ability at P1 and P2, and their vertical jumping ability and their balance at P1, P2 and P3. Due to bad weather conditions and for safety reasons, the ground of the facility was not in a suitable condition for the acceleration and COD tests to be carried out in P3, so no results or evaluations are available for this time point.

Anthropometry was assessed with height and weight. For weight, they were asked to stand barefoot on a digital scale. Height was measured, also barefoot, with a tape measure attached vertically to a wall, keeping their head in the "*Frankfort plane*". Subjects were tested on their acceleration ability in two different 5- and 10-metre sprint times. Both tests had three attempts. Three minutes rest were given between attempts and trials. Only the best of the three values, for each test, was taken for analysis. The two assessments were done in a straight sprint, separated by two black lines on the ground. A photocell system (Witty model, Microgate; Italy) measured the time. The distance between the receiver and the transmitter was 1.3m, facing each other at a height of 0.35m. After the evaluator said "*OK*", the subjects started the sprint 1m behind the first photocells. This prevented them from cutting off the signal prematurely. They were also told to run as fast as they could and not to stop until they reached the end (Noyes et al., 2012; Stewart et al., 2012).

COD ability was measured using the Pro-agility (or 5-10-5) test, which is commonly used for COD assessments, with evidence of effectiveness and reliability (Gillen et al., 2018; Lockie et al., 2016; Sahin et al., 2018; Stewart et al., 2012). Subjects started at an initial line from which they sprinted in a linear fashion towards another line 4.57m in front, touching it with their right hand, turning to their left 180° and running 9.14m to the furthest line, touching it with their left hand and turning 180° again to run a further 4.57m back to the initial line (Gillen et al., 2018; Lockie et al., 2016; Sahin et al., 2018; Stewart et al., 2012). COD was also tested with the photocell system, using the same methodology as acceleration assessment for standardization. It was compulsory to touch the lines with the hands. If the subjects did not do so, the attempt was counted as null and had to be repeated immediately. A total of 3 attempts and 3 min rest between them was given to the subjects. The best of the three attempts was taken for analysis.

Vertical jump was assessed with a countermovement jump (CMJ), a typical test in the assessment of lower body strength and power (Gillen et al., 2018; Lockie et al., 2016; Brooks et al., 2018), with high reliability (Gillen et al., 2018). The MyJump2 app for Android was used on a mobile device (240fps slow motion and 720p resolution). This app has been shown to be highly valid, reliable and effective for measuring vertical jump (Bogataj et al., 2020; Brooks et al., 2018; Sharp et al., 2019). Subjects were unable to perform any type of pre-step or arm swing assistance (hands on hips), starting the jump with feet shoulder-width apart, legs extended and trunk upright facing forward. They were instructed to perform a downward movement as fast as possible, followed by an upward movement as fast as possible in order to jump as high as possible. The movement was recorded at a distance of 1.5m and at a sufficient height to identify the take-off and landing phases (Bogataj et al., 2020; Brooks et al., 2018; Gillen et al., 2018). To obtain jump height the app applies the formula ‘$h = t^2 \times 1.22625$’, where h represents the height of the jump (in metres) and t the flight time measured in seconds (Sharp et al., 2019). Two attempts were performed per subject, with a minimum rest of 2 min between each attempt, only using the higher jump for further analysis.

Subjects' dynamic balance was measured using the Star Excursion Balance Test (SEBT), which is a reliable and valid assessment that has evidence in the literature for young basketball players (Gribble et al., 2012;

Gribble et al., 2013; Plisky et al., 2006). The test was performed with both legs of the subjects, starting first with the left leg on the floor, and being barefoot at all times. Subjects had 4 training attempts towards each of the 3 test directions (anterior, posteromedial and posterolateral). The anterior line was 135° apart from the other two posterior directions. The posterior directions were 90° apart between them. After the training attempts, the subjects had 3 attempts to touch as far as possible with the most distal part of their free foot in the 3 marked directions. At all times the hands had to be on the hips and the supporting foot aligned with the most distal part of the first toe and the most posterior part of the heel with the line marking the anterior direction. The first toe should be centred at the junction of the three lines marking the 3 directions. Subjects were given 1 minute rest between trials and the test and 2 minutes between one leg and the other. An attempt was invalid and had to be repeated if the subject moved the supporting foot from its determined position or lifted it, if the contact on the ground with the free foot was not a light touch on the line but a support and weight transfer could be appreciated, if the trunk movement was uncontrolled, if the hands moved from the hip and/or if approaching the free foot again to the initial position failed to reach the standing position and the balance was lost on the way (Gribble et al., 2012; Gribble et al., 2013; Munro and Herrington, 2010; Plisky et al., 2006; Robinson and Gribble, 2008). Only the highest raw score for each direction was recorded for subsequent analysis.

Prior to each assessment, an *ad hoc* warm-up was performed, based on other existing interventions in the literature for tests and trials similar to those in this study (Bogataj et al., 2020; Brooks et al., 2018; Stewart et al., 2012). It consisted of 10 minutes of basketball court movements (jogging, front, side and backward movements), skipping, calisthenic strength movements (splits and squats), short-distance sprints, submaximal jumps and dynamic stretches.

Statistical analyses

Statistical analysis was performed using SPSS statistical software for Macintosh (version 21.0, Chicago, IL, USA). Data are presented as mean and standard deviation. To assess the effects of the intervention programme on the different variables, different paired-samples t-tests were performed comparing pre-test and post-test values. Additionally, Cohen's d was also calculated as a measure of effect size. Values of *d* between 0-0.2, 0.2-0.5, 0.5-08 and >0.8 were classified as trivial, small, moderate and large, respectively (Cohen, 1988). The level of statistical significance was set at $p < .05$.

RESULTS

The mean values for each of the variables analysed at P1, P2 and P3 are shown in Table 2. No significant changes were observed after the intervention in the 5m and 10m sprint tests. A significant improvement in the Pro-agility test values was observed at P2 ($p = .017$; $d = 0.81$ large). Due to logistical problems and safety of the sample, no data can be provided in P3 for the 5m and 10m tests as well as for the Pro-agility. A significant improvement in vertical jump was observed at P2 ($p = .002$; $d = 0.55$ moderate) and was also maintained at P3 after the cessation of the protocol ($p = .031$; $d = 0.43$ small). In relation to the SEBT, a significant decrease in the anterior right leg score was observed at P2 ($p = .032$; $d = 0.28$ small), recovering to baseline values at P3. A significant increase in the posterolateral score of the right leg was observed at P2 and P3. Finally, in relation to the left posteromedial score, a significant increase was observed in P2 and P3 with respect to P1 values ($p = .021$; $d = 0.37$ small). The other directions of both legs in the SEBT test did not show significant effects in any assessment with respect to P1.

Table 2. Descriptive data of the measured variables according to the respective assessments at P1, P2 and P3.

Variables	P1	P2	P3
5m sprint (s)	1.156 ± 0.065	1.125 ± 0.069	
10m sprint (s)	2.077 ± 0.126	2.060 ± 0.145	
Pro-agility (s)	5.647 ± 0.279	5.435 ± 0.240*	
Vertical Jump (cm)	21.961 ± 4.526	24.546 ± 4.828*	23.696 ± 4.831*
SEBT anterior right leg (cm)	55.166 ± 9.200	50.655 ± 6.942**	56.762 ± 7.413
SEBT posteromedial right leg (cm)	76.711 ± 9.9005	79.744 ± 10.698	85.112 ± 7.503
SEBT posterolateral right leg (cm)	71.311 ± 10.900	79.766 ± 9.390*	83.175 ± 9.207*
SEBT anterior left leg (cm)	53.744 ± 9.071	44.355 ± 9.373	55.412 ± 6.090
SEBT posteromedial left leg (cm)	73.966 ± 9.789	81.188 ± 11.503*	89.820 ± 7.671*
SEBT posterolateral left leg (cm)	73.533 ± 7.889	77.777 ± 10.663	81.825 ± 8.496

*SEBT = Star Excursion Balance Test; P1 = pre-treatment assessment; P2 = post-treatment assessment; P3 = post-detraining assessment; * = significant differences with pre-treatment (p < .05); ** = significant differences with pre-treatment and post-detraining (p < .05).*

DISCUSSION

This study measured the effects of 18 sessions of programmed and individualized INT training in pre-adolescent basketball players on their acceleration ability, COD, vertical jump and dynamic balance. The main findings were that acceleration ability did not show significant differences after the intervention, the Pro-Agility test was significantly improved after the intervention, and the vertical jump showed significantly better values after the training protocol, maintaining these effects after 3 weeks of detraining. With regard to the SEBT, only the posterolateral direction of the right leg and the posteromedial direction of the left leg demonstrated significant improvements following the intervention, with these values remaining stable following detraining. Conversely, the anterior direction of the right leg exhibited a significant decline following training, returning to baseline values three weeks after the cessation of the intervention.

With regard to acceleration ability in 5 and 10 metres, no discernible enhancements were observed subsequent to the implementation of the INT protocol. When considering the nature of the training program, which incorporated both strength and plyometric components, it is reasonable to posit that improvements in sprinting capacity could be anticipated, given the established associations between muscle strength capacity and running speed (Fort-Vanmeerhaeghe et al., 2016a). Moreover, similar interventions have been documented in the literature, where linear speed, primarily assessed over short distances associated with acceleration, has been enhanced (Hewett et al., 2006; Lloyd et al., 2016; Panagoulis et al., 2018). These investigations have justified the results with increased neuromuscular activation, improved ground contact time, and increased muscle stiffness, which is expected in multidisciplinary neuromuscular training programs. Nevertheless, and in a similar vein to the findings of this study, Noyes et al. (2012) observed that a multidisciplinary neuromuscular intervention did not result in significant enhancements in 18-meter sprint performance in adolescent female basketball players. However, the authors attributed this outcome to the fact that the measurement was conducted with a manual digital stopwatch, which is not optimal for short distances like those. Also, it is suggested in the literature that training specificity may play an important role in the assessments results after a neuromuscular intervention (DiStefano et al., 2010; Faigenbaum et al., 2011). If we take into account that the only speed training performed by the subjects was the COD training, the specific distances and lineal paths assessed in the acceleration tests may not be very similar to the COD tasks performed in the INT.

The COD and vertical jump test have shown significant improvements following the INT intervention. These results could be explained by the high-intensity nature of plyometric and strength work of neuromuscular interventions, which has been shown to increase muscle strength and power (Fort-Vanmeerhaeghe et al., 2016a; Hewett et al., 2006). Furthermore, INT work can enhance core strength and stability, as well as neuromuscular control, potentially leading to optimal force production and movement efficiency due to the subjects' improved and mastered MC (Faigenbaum et al., 2011; Nunes et al., 2019; Panagoulis et al., 2018). The ability to jump and change direction requires plyometric ability, which can be achieved with increased muscle strength and improved SSC (Fort-Vanmeerhaeghe et al., 2016a). Furthermore, the pro-agility test is influenced by the ability to accelerate, decelerate and change direction. Therefore, positive muscle adaptations and efficiency in the use of the SSC could improve the results of this test (Fort-Vanmeerhaeghe et al., 2016a; Panagoulis et al., 2018). Again, the principle of task specificity with respect to the tests implemented may have had an influence (DiStefano et al., 2010; Faigenbaum et al., 2011). In this intervention, the plyometric tasks were composed of repeated CMJs, both vertical and horizontal, and the COD tasks had a large number of accelerations, decelerations and CODs.

Similar to our study, there is evidence in the literature of similar cases where significant improvements were achieved in COD capacity (Faigenbaum et al., 2011; Sahin et al., 2018) and/or muscle power measured through a jump (Faigenbaum et al., 2011; Faigenbaum et al., 2014), or specifically through a vertical CMJ, after an integrative neuromuscular intervention (Lloyd et al., 2016; Noyes et al., 2012; Nunes et al., 2019; Panagoulis et al., 2018). In the case of the CMJ, significantly better performances were observed after detraining, similar to Nunes et al. (2019). These authors found significant increases in the CMJ test in male and female volleyball players of 12.8 ± 0.7 years of age, after 12 weeks of INT, which was maintained after 8 weeks of detraining. The authors remarked that due to the age of the subjects and to the relatively short time elapsed, they could not associate this maintenance of performance with the subject's biological maturation. The authors attributed these results to the adaptations obtained with their INT intervention, being more effective than other types of traditional training.

Regarding the dynamic balance of the subjects assessed with the SEBT, a significant improvement of the results could be expected, as balance and stability training are associated with improvements in proprioceptive sensibility, joint stability, feedforward control mechanisms, and sensorimotor coordination strategies for the stabilization of the centre of body mass (Fort-Vanmeerhaeghe et al., 2016b). In the posteromedial and posterolateral directions of the left and right legs, respectively, we did observe significant improvements post-intervention. This is in agreement with other similar studies that also obtained improvements in balance, whether dynamic or static, measured with the SEBT or other balance assessment tools (Benis et al., 2016; DiStefano et al., 2010; Filipa et al., 2010; Tsukagoshi et al., 2011). These adaptations could be justified in the relationship between core strength, plyometric work and its dynamic nature, and increased strength (and its increased muscle activation, improved neuromuscular properties, and motor skills) with improved dynamic balance, improved neuromuscular control, and proprioception (Benis et al., 2016; Faigenbaum et al., 2011; Filipa et al., 2010; Fort-Vanmeerhaeghe et al., 2016a; Fort-Vanmeerhaeghe et al., 2016b; Tsukagoshi et al., 2011). Lastly, the maintenance of significantly higher values after detraining can be explained, similarly to the CMJ, by a positive adaptation of an effective INT intervention, as has been previously evidenced (Nunes et al., 2019). However, we should not deny the learning effect that may accompany this test and that may have affected the results obtained (Robinson and Gribble, 2008). This is something we could not control for, and future studies should assess whether there are differences in the effects of INT on balance and/or stability depending on the test applied.

However, these significant improvements have not occurred in all test directions. There are cases in the literature that have also failed to find improvements in balance after a neuromuscular intervention (DiStefano et al., 2010; Faigenbaum et al., 2011; Faigenbaum et al., 2014; Granacher et al., 2011). These studies justified the absence of significant modifications mainly in a possible insufficiency in the magnitude of the load, represented by the small load volume that characterise this type of interventions. Also, Granacher et al. (2011) explained the nonsignificant changes after a specific 4 weeks balance training in 6.7 ± 0.5 years old children due to the young age of the subjects. These authors stated that balance strategies may not be sufficiently presented under 7 years of age, and that the specific training may not be effective enough due to an immaturity of the postural control system. However, in the present study, the subjects are above 7 years old.

Specifically for the anterior direction, similar studies can be found in the literature where significant improvements have not been shown, but with significant better values in other SEBT directions (Benis et al., 2016; Filipa et al., 2010). Nevertheless, in the present study, a significant reduction in the performance of the anterior direction of the right leg was observed after the INT. One potential explanation we offer, although purely speculative, is the potential improvement in the frontal plane knee control after the INT intervention, which could improve body and segmental neuromuscular control (Fort-Vanmeerhaeghe et al., 2016b). This improvement by body neuromuscular control strategies could have reduced the knee displacement over the height of the feet, thus decreasing the total distance achieved. During the INT intervention correct hip-knee-ankle alignment was emphasised, which could have increased this control of the knee in the frontal plane, with the intention of avoiding knee valgus. Yet, after the three weeks of detraining, baseline values were restored, which could be due to a negatively affected neuromuscular knee control strategy in the frontal plane, or again, due to the possible learning effect that may be associated with this test (Robinson and Gribble, 2008).

Finally, if we take into account that there is evidence in the literature that longer INT intervention times could imply greater training effects (Nunes et al., 2019), this could also have affected the results achieved, being 6 weeks and 20min per session not enough training stimulus to provide significant changes for some of the assessed variables.

This study has certain limitations that should be highlighted. The first limitation is the absence of a control group. The second limitation is the small number of subjects representing the selected sample, with only 8 young people participating. Also, as stated before, the lack of a detraining assessment data on COD and acceleration test limits the overall understanding of the training intervention effect. Anecdotally, we share what Granacher et al. (2011) expressed, as it may be that the necessary attention and effort required for the correct performance of tasks was not given at all times by the children, since it was perceived that the maximum effort and attention was given when looking directly at the performance of a subject or remaining close to them. Regarding the SEBT, due to not being able to perform anthropometric measurements of the lengths of their body segments, it was not possible to normalise the distances achieved in each direction by representing them as a percentage of their leg length, something recommended to make the test more reliable, since a greater leg length could translate into greater distance achieved (Gribble et al., 2012; Munro and Herrington, 2010). Finally, some of the proposed tasks and drills may be specific to the sport of basketball, due to the motor patterns and situations proposed in the exercises. This means that the intervention and results obtained may not be representative of other similar populations and/or different sports.

CONCLUSIONS

The individualized and team performed INT program of this study seemed to be safe, effective, time and material efficient, and a worthwhile method of conditioning and motor learning in preadolescent basketball players. The main findings of this study indicate that 18 sessions of 20 minutes of INT during 6 weeks were enough to significantly increase COD ability, vertical jump performance, and unipodal dynamic balance in some directions of the SEBT, maintaining significant better values after 3 weeks of detraining for the vertical jump assessment and the SEBT. However, acceleration, and the majority of the SEBT directions, did not show any significant changes, suggesting that training specificity and total load magnitude of an INT program can possibly play an important role in some fitness parameters of preadolescent basketball players. Nevertheless, it is important to note that the results of this study should be interpreted with caution due to its limitations.

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