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RESEARCH

Fitness parameters in young football players are affected by training load and somatic-anthropometric variations

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Abstract

Purpose This study aimed at investigating relationship between variations in fitness parameters, variations in somatic-anthropometric parameters and training load variables in Italian elite soccer players during pre/mid and post-puberty.

Methods Thirty-six Italian elite young soccer players (Under-14, U14: 18; Under-17, U17: 18) participated in study. Their somatic-anthropometric and fitness parameters were assessed and training load (Session-RPE) was monitored during 119 days in the sporty season.

Results During the observational period meaningful variation in CMJ and 30-15IFT emerged in U17 and only in CMJ in U14. Meaningful correlations emerged between variations in CMJ and variations in numerous somatic-anthropometric parameters in U17 but only variations in ARM-GIRTH in U14. Meaningful correlations were found between variations in 30-15IFT and only variations in SUP-SKIN in U17, training load during match in U14 and U17 and training load during session training only in U17.

Conclusions During puberty, variation in fitness parameters are affected by variations in somatic-anthropometric parameters and training load parameters differently between U14 and U17. Variations of body shape have more influence in U17, match load more influence in U14 and intensity of training influence only in U17. This study offers new interpretations about the effect of anthropometric and somatic parameters, as well as on training dose (volume, intensity and typology) on the variation of fitness parameters during puberty.

Keywords Youth · Talent · Soccer · Training · Puberty

Introduction

Training during childhood and adolescence is a hot topic and several articles studied it deeply [1–9]. One of the most interesting arguments is the *trigger hypothesis* or *windows of opportunity* that can be summarised with the following phrase: *"critical/sensitive periods for accelerated development of motor performance based on a suitable training stimulus during appropriate maturational time period"* [2]. These periods seem to be influenced by several factors, first by the level of biological maturation of the subject [2, 4, 6, 7]. Nevertheless, the window of opportunity concept is today largely criticized because it is not supported by strong evidence. Same authors consider that there are no *critical periods* outside of which in not possible catch-up maximal trainability for particular motor ability, rather it is possible to observe *sensitive periods* characterized by peak of improvement for specific motor ability results combined between maturation and training [10–13]. Is important to consider that this period is motor ability dependent and characterized by large inter individual variability [10]. Geithner and colleagues have shown that although peak VO_{2max} improvement in youth occurs on average coincident with peak height velocity (PHV), 32% of subjects manifest peak VO_{2max} improvement in the pre-PHV period and 55% in the post-PHV period [14]. As already pointed out by Van Hooren and colleagues [10], during the pubertal period, it is not possible to consider performance improvement exclusively PHV dependent but rather the result of the combination between maturation of each biological system (bones, muscles, tendons, cardiovascular system, etc.) and training stimulus [3,

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15–17]. Therefore, it appears essential to be able to estimate the maturation level of the players during their childhood. Puberty is "*a dynamic period of development marked by rapid change in body size, shape, and composition, all of which are sexually dimorphic. It is characterized by the greatest sexual differentiation since fetal life and the most rapid rate of linear growth since infancy"* [18]. This period is characterised by a high inter-individual variability, associated with ethnic belonging and to environmental stimuli, as well as by intra-individual variability linked to timing of growth and maturation [18, 19]. This variability has the name of "*time-spreading effect"* [20]. Currently, the parameters used as valid indicators of puberty analysis are skeletal age, age at peak height velocity, current height expressed in terms of percentage of the adult height and secondary sex characteristics [21]. These authors state that these parameters are not interchangeable because they are estimations of different aspects associated with the puberty period. In male population it is considered that puberty starts averagely at 12 years of age and after reaching the peak growing around at 14 years of age [20]. During youth, aerobic power (VO_2max) increases in relation to age even if it is influenced by anthropometric variations (body mass, height) [20] and somatic variations [22]. Physical maturity level might affect VO_2max during puberty. A VO2max improvement of about 150% was recorded from 8 to 18 years of age in male subjects [23]. Two reviews concluded that it is possible to improve aerobic fitness in a range between 6.1% and 7.7% in male children (pre-pubertal) and between 7.6% and 8.6% in adolescents (circum-pubertal) [23, 24]. Fitness level during childhood and puberty is age-independent, while training intensity is proposed as one of the main dependent factors (> 85% HR Max) [23, 24]. Currently, there does not exist a shared opinion on physiological parameters that are crucial for neuromuscular adaptations during puberty [1, 2, 9, 24, 25]. There were reported improvements in strength parameters in youth trained males during childhood and adolescence, from 5.3% to 87%; these improvements are related to the effect of multifactorial causes [2]. Considerable improvements have been identified from 1.5 years before peak high velocity (PHV), with pick approximately 0.5–1.0 years after PHV [5], and in relation to leg length and to muscle mass [26]. A recent meta-analysis has been concluded that it is possible to achieve improvements in strength both in prepubertal subjects (Tanner stage 1) and mid/post-puberty (Tanner stage 2–4/5), albeit with double increments as regards the more physically mature individuals (ES: 0.81 vs 1.91) [9]. Increases in strength would seem to be linear during the period of childhood and adolescence [9]. These differences could be exclusively the result of conventional escalation of dose training during the period of puberty as proposed by British Association of Sport and Exercise Sciences [7]. The youth physical development (YPD) proposed by Lloyd et al. [3] underlines the importance of specific training typology and dose based on individual physical maturity level [27]. Granacher and colleagues, in a recent scoping review [27], concluded that neuromuscular training effect in superior in pre-pubertal subjects, dependent to neuromuscular ability (muscular strength vs muscular power vs muscular endurance vs athletic performance) but, in general, more sensitive to free weight and isotonic contractions. A training period of more than 8 weeks, more than one session at week, more than 1 set per exercise, 8–15 repetition per set and training intensity over than 60% of individual maximal intensity are necessary for resistance training program to improve neuromuscular ability in youth non-athletes [9, 25]. Instead, a training period of more than 23 weeks, 5 sets per exercise, 6–8 repetitions per set, a training intensity of 80–89% of individual maximal intensity, and 3–4 min rest between sets is necessary for resistance training programmes to improve muscle strength in youth athletes. However, Behringer and colleagues [28] underline that intensity of 60% of individual maximal intensity is sufficient, but necessary, for improving motor performance skills like jumping, running and throwing in youth. Training process is able to change the body composition, fitness capacity and task performances [5], without altering the maturation processes [28]. However, it is currently difficult to discriminate between the improvements to be attributed to the training process and to be attributed to the growth and maturation processes [4, 7]. In accordance with Van Hooren and colleagues [10] neuromuscular training effect is dependent on neuromuscular ability (acceleration vs maximal velocity vs squat jump vs RSI), training typology (plyometric training vs traditional strength training vs combined training) and maturational status (pre-PHV vs post-PHV) [29]. In detail, Radnor and colleagues underline that only 20% of subjects improve in all neuromuscular ability asses and that, in general, pre-PHV subjects are more sensitive to plyometric training and post-PHV more sensitive to traditional strength training. Therefore, not all subjects at the same maturational status and that train with the same stimulus, improve their performance at the same rate.

Pearson and colleagues underline that maturation is a confounding variable for talent identification and major influencer for variations of anthropometric and fitness characteristics in team sports in general [30]. Other authors underline this aspect also in soccer context [31, 32] and in Italian youth soccer context [33]. A lot of studies in soccer context, proved that maturity status influences selection [32, 34], physical performance [35], technical performance [16] but not tactical performance [36], physical fitness [37], playing position [38] and training load [39]. However, Ali Hammami and colleagues [40] demonstrate that soccer-training season was able to provide maturation-free improvement in anthropometric and performance characteristics in young soccer players during the training season, while Nobari and colleagues [41] underline that during soccer-training season maturation status and accumulated training load influence improving of only neuromuscular performance in young soccer players. The same authors concluded that *"coaches should consider adapting the training stimuli to the specific characteristics of the players (namely, maturation status) as well as not interpreting changes in fitness exclusively focusing on the training, but also weighing the maturation process."* Bidaurrazaga and colleagues [31], monitoring young soccer players for 4 years between 10 and 14 years of age demonstrated that development of fitness is not linear and influenced to maturity status. Early mature young soccer players were characterized, in general, by better performance in neuromuscular performance (CMJ, 15 m sprint and agility) but lesser improvement than late mature soccer players. Deprez and colleagues [42] monitoring young soccer players for 4 years between 12 and 16 years of age, demonstrated that maturity and body shape have limited influence on aerobic performance (Yo-Yo Intermittent Recovery Test Level 1). In detail, aerobic performance showed a high stability over first 2 years (12–14 years of age) and a moderate stability over four years, observing that young soccer players with lower aerobic performance are characterized by greater improving than average and high performers during puberty (235,7%, 86,8%, 62,2%, respectively). The authors underline that 47.6% of the players were moving to a higher or lower aerobic performance group.

Thus, late mature soccer players are able to catch up and also, outperform early mature athletes during growth, underlining the importance of understanding the influence of growth in improving performance during puberty [43]. With an interesting study, Wrigley and colleagues [32] demonstrated that the rate of improvement in physical performance of academy soccer players (CMJ, 10 m sprint, 20 m sprint, agility, repeated sprints, Yo-Yo Intermittent Recovery Level 2) between 11 and 16 years old over the course of 3 sporty seasons, is greater than to age matched non-academy players. These difference were independent of baseline fitness and changes in maturity status, emphasizing the important influence of training stimulus for soccer motor capabilities development during puberty.

This study has the aim to deepen the current knowledge on the topic and give new evidence to discriminate between the training effect and the growth effect in improving fitness parameters of young soccer players during puberty period. In detail, our aim was to evaluate variations in the somatic-anthropometric variables, training load and fitness parameters in young football players and correlation between the respective variations over time.

Methods

Participants

This study enrolled 36 young male football players of the Italian second division during 2014/2015 sporty season. 14 volunteers were enrolled from U14 category (AGE: 13.2 ± 0.3 years, HEIGHT: 162.2 ± 7.4 cm, WEIGHT: 49.9 ± 8.0 kg, BMI: 18.5 ± 1.7 kg/m^2, PHV 13.7 ± 0.5) and 14 from U17 category (AGE: 16.2 ± 0.3 years, HEIGHT: 178.8 ± 5.9 cm, WEIGHT: 67.3 ± 3.9 kg, BMI: 21.1 ± 1.4 kg/m^2, PHV 13.8 ± 0.4).

Interventions

Players participated in two test sessions during training days. First test session (T0) was done at start season, after 10 days of adaptation. Second test session (T1) was done after 119 days (December and January). Typical microcycle was comprised of 3 or 4 sessions to week (~ 90 min) on outdoor synthetic turf pitch of official dimensions (105 × 60 m) between 16:00 PM to 17:30 PM and 18:00 PM to 19:30 PM and 1 match with two times of 35 min and 40 min, respectively, for U14 and U17. In general players carried out 1 metabolic training and 1 resistance training. The remaining training time included technical-tactical sessions.

Somatic-anthropometric parameters

Anthropometric and somatic measures were performed in line with ISAKK protocol [44]. *Chronological age (AGE)* was calculated in decimal unit, subtracting birth date from test session date [45]. *Height (H)* was measured to the nearest 0.1 cm using a stadiometer (Seca 213, SECA Precision for Health, Benson Avenue Chino, USA). *Body weight (BW)* was measured to the nearest 0.1 kg using an electronic scale (PS5008, Laica SpA, Barbarano Vicentino, VI). *Body Mass Index (BMI)* was calculated to the nearest 0.1 kg/m^2. *Sitting Height (H-SITTING)* was measured to the nearest 0.5 cm using an extensible metre with subject in seated position on a rigid box (40 cm) adjacent to the wall. *Legs Length (L-LEGS)* was calculated to the nearest 0.5 cm subtracting *H-SITTING* from *H* [44–46]. *Calf girth (CALF-GIRTH)*, and *contract arm girth (ARM-GIRTH)* were measured to the nearest 0.5 cm using an extensible metre on the right side. *Humerus diameter (HUMERUS-DIAM)* and *femur diameter (FEMUR-DIAM)* were measured to the nearest 0.1 cm using bone calibre (Gima SpA, Gessate (MI)), on right side. *Fat Mass* was calculated in two ways: using Slaughter's equations *(%FM)* [47, 48] and using sum of skinfolds *(ΣSKIN)* [49]. We measured *triceps skinfold*

(TRI-SKIN), sub-scapular *skinfold (SUB-SKIN)*, supra-iliac *skinfold (SUP-SKIN)* and *medial calf skinfold (CALF-SKIN)* to the nearest 0.1 mm using a skinfold calliper (Harpenden, Baty International, Burgess Hill, UK), on right side. Level of Endomorphism *(ENDO)*, Mesomorphism *(MESO) and* Ectomorphism *(ECTO)* was calculated using *Carter & Heath's equations* to the nearest 0.1 point [50]. Physical maturity was estimated using *Age from peak height velocity* (APHV) [51] and *Percentage of predicted mature height* (%H-MAX) [31, 52–56].

Training load parameters

Internal training load was recorded through rating perceived exertion (RPE) CR-10 Borg's scale [40, 57] that is a valid and reliable scale to estimate the intensity of a session [58]. *Training load (TL)* was calculated using session-RPE proposed by Foster [59–61]. RPE was recorded after training or match [62, 63] showing CR10 scale to the volunteer in a private interview answering this question *"What was the mean intensity of your session?"*. To better recognize different intensity between sessions, in the first ten sessions, the coach discusses and compares ratings of previous sessions with players. *Total training load (TOT-TL)*, *training load of only training sessions (TR-TL)*, *training load of only matches (MA-TL)* [40, 64], *RPE average value of only training sessions (TR-RPE)*, *RPE average value of only matches (MA-RPE)* [33], *number of training sessions of each player (complete or incomplete) (TR-NUM)* [16, 65], *number of matches of each player (complete or incomplete)* (MA-NUM) [65] and *sum of played minutes of matches (MINUTES) were calculated* [16, 66]. Ten training sessions and/or matches were utilised for familiarisation on CR10 scale.

Fitness parameters

Leg power was estimated with Counter-movement *Jump (CMJ)* with hands on the hip [67]. CMJ was measured to the nearest 0.1 cm using an accelerometer (WE-g, BTS SpA, Garbagnate Milanese (MI)). After warm up [68–72], each volunteer performed three jumps with 30 s of rest between jumps. The best jump was recorded; a typical error of the accelerometer was previously calculated to be 1.1 cm (CV: 2,3%). CMJ was demonstrated to be independent of body shape in children [73] and has a good estimate of lower limb power in young soccer [74]. Furthermore, jumping ability was demonstrated to be a significant predictor of future contract status [75]. Aerobic fitness was estimated using *30–15 Intermittent Fitness Test (30-15IFT)*, an intermittent and incremental running test. Velocity of the final completed stage was recorded to the nearest 0.5 km/h. [76, 77]. After warming up, players had to complete as many stages as possible. Continuous encouragement was provided during testing to stimulate the athletes to really reach their maximum performance. 30-15IFT has good relationship with $VO2_{max}$, 10 m sprint, CMJ, ability to recover between effort [76] and anaerobic ability [78, 79], more sensitive to change [77] and more sensitive to individualize metabolic training than other aerobic fitness tests [76]. However, during youth development, fitness parameters are strongly unstable [42] and influenced by maturation [30, 74].

Statistical analysis

Shapiro–Wilk test was performed for the evaluation of normality (assumption) of statistical distribution. The effects of time (T0 and T1) on Somatic-anthropometric parameters and on fitness parameters were evaluated by the Wilcoxon test. The statistical differences among the variables associated with the training dose in the two categories were analysed using the Mann–Whitney Test. The level of significance was set at $P < 0.05$. Standardized effect sizes (ES) were calculated with Cohen's d for pairwise comparison, classified as follows: 0–0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; 2.0–4.0 very large effect, and > 4 nearly perfect [80]. Magnitude-based inferences (MBI) were calculated to assess the practical significance of changes as proposed by Hopkins [80]. Inference was calculated to establish whether the true differences were lower, similar or higher than the smallest worthwhile changes (SWC) (0.2 multiplied by the between-subject SD, based on Cohen's ES principle). For 30-15IFT was used SWC reported by Buchheit and colleagues [78]. For CMJ was used SWC calculated by our group with more than 300 athletes of the same youth sector soccer team (unpublished data). If SWC was in lower than instrumental sensitivity, the latter was used as SWC. For H, H-SITTING, L-LEGS was used instrument sensitivity (0,5 cm). For CALF-GIRTH and ARM-GIRTH was used instrument sensitivity (0,5 cm). For HUMERUS-DIAM and FEMUR-DIAM was used instrument sensitivity (0,1 cm). Quantitative chances of higher or lower differences were evaluated qualitatively as follows: < 1%, almost certainly not; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possible; 75–95%, likely; 95–99%, very likely; > 99%, almost certain. If the chance of having higher or lower values than the smallest worthwhile difference was > 5%, the true difference as assessed as unclear [80]. The data analysis was performed using a modified statistical Excel spreadsheet [81, 82]. The linear regression between CMJ and 30-15IFT, and the other independent variables (BW, H, BMI, H-SITTING, L-LEGS, %H-MAX, APHV, CALF-GIRTH, ARM-GIRTH, HUMERUS-DIAM, FEMUR-DIAM, TRI-SKIN, SUB-SKIN, SUP-SKIN, CALF-SKIN, %FM, ΣSKIN, ENDO, MESO, ECTO) and dependent variables (TOT-TL, TR-TL, MA-TL, TR-RPE, MA-RPE, TR-NUM, MA-NUM, MINUTES) was evaluated. The following intervals were proposed by Cohen to interpret these values: $q < 0.1$, *no effect; $0,1 \leq q < 0,3$, small effect; $0,3 \leq q < 0,5$, medium* effect; $q \geq 0,5$, *large* effect. Since no *p*-value is associated with Cohen's method, the only statistic reported is the effect size *q* [83, 84].

Statistical analysis was performed by GraphPad Prism 6 (GraphPad Software, Inc., USA).

Results

Median and standard deviation, p-value, effect size of all parameters at T0 and T1 are reported in Table 1. Magnitude-based inferences are also reported for somatic-anthropometric and fitness parameters in Table 1. Only significant magnitude correlations between variations in somatic-anthropometric parameters and variations in fitness parameters and correlations between training load parameters and fitness parameters are reported in Table 2. Meaningful variations emerged between T0 and T1 in BW, APHV, ARM-GIRTH, FEMUR-DIAM, SUP-SKIN, ΣSKIN, ENDO and CMJ in U14 and U17, in H, H-SITTING, %H-MAX and CALF-SKIN in U14, while variations were found in BMI, APHV, L-LEGS and 30-15IFT in U17. All training load parameters were different between U14 and U17 except in TR-RPE. However, only FEMUR-DIAM in U14 (ES 1.10) while BW (ES 0.72) and SUP-SKIN (1.33) in U17 show moderate variation within somatic-anthropometric parameters. Within fitness parameters, U14 shows moderate variation both in CMJ (ES 0.89) and 30-15IFT (ES 0.94), while U17 only in 30-15IFT (ES 1.67). However, MBI proves practical meaning only for H-SITTING *(Likely small)*, %H-MAX *(Likely small)*, APHV *(Almost certainly small)*, FEMUR-DIAM *(Almost certainly moderate)* and ENDO *(Almost certainly small)* in U14 and for FEMUR-DIAM *(Possibly small)* and 30-15IFT *(Almost certainly large)* in U17. Meaningful correlations emerged between variations in CMJ and variations in BW (r^2 0.25, *Small*), BMI (r^2 0.31, *Medium*), CALF-GIRTH (r^2 0.42, *Medium*), SUB-SKIN (r^2 0.41, *Medium*), TRI-SKIN (r^2 0.38, *Medium*), SUP-SKIN (r^2 0.28, *Small*), %FM (r^2 0.45, *Medium*), ΣSKIN (r^2 0.43, *Medium*), ENDO (r^2 0.48, *Medium*), MESO (r^2 0.30, *Medium*) and ECTO (r^2 0.25, *Small*) in U17 and variations in ARM-GIRTH (r^2 0.43, *Medium*) in U14. Meaningful correlations were found between variations in 30-15IFT and SUP-SKIN (r^2 0.28, *Small*) only in U17. Furthermore, meaningful correlations emerged between variations in 30-15IFT and MINUTES in U14 (r^2 0.43, *Medium*) and U17 (r^2 0.26, *Small*), MA-NUM (r^2 0.34, *Medium*) and TR-RPE (r^2 0.48, *Medium*) in U17 and MA-TL (r^2 0.41, *Medium*) in U14.

Discussions

In literature it seems that only another study investigated the relationship between variations in fitness parameters, variations in somatic-anthropometric parameters and training load variables in soccer players during pre/mid and post-puberty [57]; thus data recorded are difficult to compare with other studies. Our study offers new interpretations about the effect of anthropometric and somatic parameters, as well as on training dose (volume, intensity and typology) on the variation of fitness parameters during childhood and adolescence. In detail, our study investigates the influence of growth (variation of somatic-anthropometric parameters) and training stimulus (training load parameters) on variation of fitness (fitness parameters) during puberty.

As reported by Lloyd et al. [4] 3 months are sufficient to observe variations in somatic and fitness parameters during childhood and adolescence. Comparing studies of Beunen and colleagues [20] and Philippaerts and colleagues [8], it emerges that youth athletes (in this case soccer players) have anticipated the peak of improvements in different motor tasks, with respect to youth non-athletes. These improvements are more pronounced even after PHV. These results point out the importance of training during puberty [1, 8, 20]. Anthropometric parameters shown in this study were generally lower than those observed by Perroni and colleagues in amateur young Italian soccer players [85]. H, BW and BMI was lower in U14 (H, 168 ± 0,06 cm vs 162,24 ± 7,39; BW, 56,58 ± 8,54 kg vs 49,86 ± 7,96 kg; BMI, 19,95 ± 1,87 kg/m2 vs 18,53 ± 1,69 kg/m^2) and BW and BMI was lower in U17 (BW, 68,06 ± 9,36 kg vs 66,82 ± 3,89 kg; BMI, 22,12 ± 2,37 kg/m2 vs 21,02 ± 1,36 kg/m^2) than elite young soccer players assessed in our study [85]. Maturational status assessed [51] in accord with Philippaerts and colleagues [8] and Cumming and colleagues [56], respectively, for analysis of PHV and %H-MAX. U14 results pre/mid-puberty (− 0,6 years to PHV and 87,4% H-MAX), whereas U17 results post-puberty (+ 2,3 years from PHV and 98,4% H-MAX) at T0. Since PHV appears generally at the moment of 92% H-MAX [21], with caution, results of this study can be generalized to soccer players pre/mid-puberty and post-puberty.

After a period of 119 days during sporty season, variations emerge in BW, APHV, ARM-GIRTH, FEMUR-DIAM, SUP-SKIN, ΣSKIN, ENDO and CMJ in each group, in H, H-SITTING, %H-MAX and CALF-SKIN only in U14 and in BMI, LEG-LENGTH and 30-15IFT only in U17. Only FEMUR-DIAM and both CMJ and 30-15IFT shown significant and moderate effect size in U14 and only in BW, SUP-SKIN and just 30-15IFT in U17. Therefore,

Table 1 Median and standard deviation, p-value, MBI and rating of all parameters, at T0 and T1

Variable	U14		*p*	ES	MBI (%)	Rating	U17		*p*	ES	MBI (%)	Rating
	T0	T1					T0	T1				
Somatic-anthropometric												
Body weight (kg)	50.3 ± 8.0	50.5 ± 8.5	***	0.02	81/13/6	*Unclear*	67.2 ± 3.9	70.1 ± 4.1	**	0.72	71/18/12	*Unclear*
Height (cm)	163.5 ± 7.4	164.3 ± 7.0	***	0.11	93/7/0	*Likely trivial*	178.0 ± 5.9	181.0 ± 6.2		0.50	53/35/12	*Unclear*
Body mass index (kg/m2)	18.6 ± 1.7	19.1 ± 2.0		0.27	60/20/20	*Unclear*	21.0 ± 1.4	20.9 ± 1.6	**	0.07	59/24/18	*Unclear*
Sitting height (cm)	83.5 ± 4.6	84.5 ± 4.8	***	0.21	93/7/0	*Likely small*	93.5 ± 2.8	93.0 ± 2.8		0.18	24/29/47	*Unclear*
Leg length (cm)	79.5 ± 3.4	78.8 ± 3.0		0.22	40/27/33	*Unclear*	86.0 ± 3.9	87.0 ± 4.1	***	0.25	76/18/6	*Unclear*
% Predicted mature height	87.4 ± 3.0	88.9 ± 2.8	***	0.52	100/0/0	*Likely small*	98.4 ± 1.1	98.4 ± 1.1		0.00	53/35/12	*Unclear*
Age at peak height (ages)	−0.6 ± 0.7	-0.2 ± 0.7	***	0.57	93/7/0	*Almost certainly small*	2.3 ± 0.5	2.5 ± 0.5	**	0.4	88/6/6	*Unclear*
Calf girth (cm)	34.0 ± 2.2	34.3 ± 2.3		0.13	47/33/20	*Unclear*	37.0 ± 1.7	37.5 ± 1.9		0.28	47/41/12	*Unclear*
Contract arm girth (cm)	24.5 ± 2.0	25.3 ± 2.1	**	0.39	67/27/7	*Unclear*	28.3 ± 1.1	28.0 ± 1.0	**	0.28	12/24/65	*Unclear*
Humerus diameter (cm)	6.3 ± 0.4	6.5 ± 0.4		0.50	47/40/13	*Unclear*	6.8 ± 0.3	6.9 ± 0.3		0.00	41/53/6	*Unclear*
Femur diameter (cm)	9.3 ± 0.4	9.8 ± 0.5	***	1.10	100/0/0	*Almost certainly moderate*	9.6 ± 0.4	9.8 ± 0.4	***	0.50	75/25/0	*Possibly small*
Calf skinfold (mm)	9.7 ± 4.4	9.2 ± 4.2	***	0.12	7/0/93	*Unclear*	7.7 ± 2.2	7.6 ± 1.8		0.05	19/31/50	*Unclear*
Subscapular skinfold (mm)	7.2 ± 2.4	7.4 ± 2.4		0.08	40/13/47	*Unclear*	8.4 ± 1.6	8.4 ± 1.8		0.00	10/13/69	*Unclear*
Triceps skinfold (mm)	9.2 ± 4.9	8.9 ± 4.3		0.06	33/20/47	*Unclear*	7.7 ± 3.5	7.8 ± 3.9		0.03	50/38/13	*Unclear*
Suprailiac skinfold (mm)	6.6 ± 3.0	5.7 ± 2.4	***	0.33	7/13/80	*Unclear*	9.4 ± 2.3	6.2 ± 2.5	****	1.33	6/0/94	*Unclear*
% Fat mass	15.0 ± 5.8	14.2 ± 5.2		0.14	40/20/40	*Unclear*	12.0 ± 4.2	12.2 ± 4.6		0.04	44/25/31	*Unclear*
Sum skinfolds (mm)	33.7 ± 13.3	31.4 ± 11.8	***	0.18	0/27/73	*Almost certainly trivial*	33.8 ± 7.3	31.2 ± 8.4	**	0.33	6/19/75	*Unclear*
Endomorphism	2.4 ± 1.0	2.2 ± 0.8	**	0.22	0/60/40	*Almost certainly small*	2.5 ± 0.7	2.1 ± 0.8	**	0.53	6/13/81	*Unclear*
Mesomorphism	4.1 ± 0.9	4.3 ± 0.9		0.22	60/20/20	*Unclear*	3.7 ± 0.8	3.6 ± 1.0		0.11	56/6/38	*Unclear*
Ectomorphism	3.5 ± 1.1	3.6 ± 1.1		0.09	33/20/47	*Unclear*	3.7 ± 0.8	3.5 ± 1.0		0.22	25/19/56	*Unclear*
Training load												
Total training load (au)	14,528.0 ± 3494.9						22,984.5 ± 3403.5		****	2.45		*Very large*
Match training load (au)	2052.0 ± 1092.1						4072.5 ± 1595.9		***	1.48		*Large*
Training training load (au)	12,872.0 ± 2695.5						18,410.5 ± 2973.9		****	1.95		*Large*
Training number	40.5 ± 7.4						63.0 ± 7.3		****	3.06		*Very large*
Match number	12.0 ± 3.1						16.0 ± 4.8		**	0.99		*Moderate*
Match minutes (min)	599 ± 226.8						746.0 ± 315.0		*	0.54		*Small*
Average match RPE (au)	4.3 ± 0.9						4.9 ± 1.0		**	0.63		*Moderate*
Average training RPE (au)	3.6 ± 0.2						3.5 ± 0.4			0.32		*Small*
Fitness												
Countermovement jump (cm)	39.0 ± 4.9	44.0 ± 6.2	**	0.89	73/7/20	*Unclear*	48.5 ± 5.2	51.2 ± 7.3	*	0.43	59/6/35	*Unclear*
30–15 intermittent fitness test (km/h)	18.0 ± 0.9	19.0 ± 1.2		0.94	67/8/25	*Unclear*	20.0 ± 0.9	21.5 ± 0.9	****	1.67	100/0/0	*Almost certainly large*

Significant changes have been showed: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, **** = $p < 0.0001$

Table 2 Correlations between fitness parameters (CMJ and 30-15IFT) and somatic-anthropometric parameters or training load parameters

Variabile	U14				U17			
	r^2 (CMJ)	*q*	r^2 (30-15IFT)	*q*	r^2 (CMJ)	*q*	r^2 (30-15IFT)	*q*
Somatic-anthropometric								
Body weight (kg)					0.25	*Small*		
Body mass index (kg/m2)					0.31	*Medium*		
Calf girth (cm)					0.42	*Medium*		
Contract arm girth (cm)	0.43	*medium*						
Subscapular skinfold (mm)					0.41	*Medium*		
Triceps skinfold (mm)					0.38	*Medium*		
Suprailiac skinfold (mm)					0.28	*small*	0.28	*Small*
% Fat mass					0.45	*Medium*		
Sum skinfolds (mm)					0.43	*Medium*		
Endomorphism					0.48	*Medium*		
Mesomorphism					0.30	*Medium*		
Ectomorphism					0.25	*Small*		
Training load								
Match training load (au)			0.41	*medium*				
Match number							0.34	*Medium*
Match minutes (min)			0.43	*medium*			0.26	*Small*
Average training RPE (au)							0.48	*Medium*

only in H-SITTING, %H-MAX, APHV, FEMUR-DIAM and ENDO in U14 and in FEMUR-DIAM and 30-15IFT in U17 emerged significant practical variations. Opposing variations emerged in ARM-GIRTH. Nevertheless, this is in accord with Rogol and colleagues [18], which observed that in coincidence with PHV there is maximum increase of muscular mass in superior limbs. Worsening emerged in our study can be due to low training for muscles of the trunk and superior limbs during the observational period. Femur (FEMUR-DIAM) and humerus (HUMERUS-DIAM) diameter variations confirm actual evidence. Baxter-Jones and colleagues [86] after a longitudinal study on individuals of age 8 to 30 years concluded that 33% and 39% of bone mineral content of adults, respectively: total bone mineral content and femoral neck bone mineral content is formed around the PHV (± 2,5 years) in Caucasian population. The same group of researchers [87] also demonstrated that physical activity has an osteogenic positive effect on peak bone mineral content velocity (PBMCV) of total bone and femoral neck. Bone mineral content velocity maintains higher also 1-year post-PBMCV, respectively, of 9% and 7%. Furthermore, numerous studies [88–92] demonstrated that in pre-pubertal individuals, soccer physical activity causes significant changes only in bone areas stressed during activity. Although these studies used different assessments with respect to our study, significant changes appear only in FEMUR-DIAM both in U14 and U17 and greater variation chance in pre/mid puberty (U14) than post puberty (U17), in accordance with previous studies. Significant differences in all training load parameters (from moderate to very large ES), except in TR-RPE (small ES), support BASES hypothesis [7] that trainability in youth (U14) is generally underestimated by coaches and their staff. Nevertheless, small and not significant differences in TR-RPE between U14 and U17 suggest that this underestimation is mostly attributable to training volume and training methodology, instead of training intensity. In line with our results, Valente-dos-Santos and collaborators [17] observed that, in professional youth soccer players of age between 11 and 17 years, development of functional capacity (repeated-sprint ability), is influenced by maturity (skeletal maturity), body shape (fat mass) and annual volume of training.

Specially interesting is the different sensitivity to change in CMJ and 30-15IFT. Although Philippaerts and colleagues [8] stated that peak of improvement of aerobic capacity occurs around PHV, Beunen & Malina [20] affirm that muscular endurance is negatively correlated to change in body weight in early maturity individuals agd 12–13 years because it is not associated with complete maturity of muscles and hence in improvement of relative force. However, this different sensitivity can be attributed also to not-sufficient training to show significant changes. Finally, linear regressions between changing in fitness parameters and changing in somatic-anthropometric parameters and training load parameters show that different motor tasks react differently to changes in somatic-anthropometric and training load parameters.

These results are in line with the hypothesis that growth [30] and training [32] can be determinant for performance improvement in youth. In detail, U17 shows significant positive correlations between variations in CMJ and several somatic-anthropometric parameters (BW, BMI, LEG-GIRTH, SUB-SKIN, TRI-SKIN, SUP-SKIN, %FM, ΣSKIN, ENDO and MESO) and significant negative correlation with ECTO. Instead, variations in 30-15IFT show significant positive correlations with training load parameters in U14 and U17 categories. However, variations in 30-15IFT in U14 are positively related only with training load parameters during the match (MA-TL and MINUTES), whereas in U17 variations in 30-15IFT are related also with training load parameters inherent to training session (TR-RPE). Nevertheless, in U17 significant linear regressions show that variations in 30-15IFT are positively related with TR-TL and SUP-SKIN but negatively related with MA-NUM and MINUTES.

Gil-Rey and collaborators [57] have shown that in Spanish young soccer players (Under 18), both elite and non-elite, variation in aerobic fitness (time to exhaustion in Université de Montreal track test [93]) was associated with in accumulated training and match session-RPE (our TOT-TL) during 9 training weeks (r = 0.67; CI (95%): 0.37 to 0.83, *most likely very large*) but only partially with neuromuscular performance (CMJ and 5 m Sprint). Authors, like in our study, demonstrated that about 50% of the variation in aerobic fitness, but not neuromuscular performance, can be explained by training load. Our results, unlike Gil-Rey and colleagues, underlines that only training stimulus provided by match (MA-TL and MA-NUM) would appear positively correlated to variations in aerobic fitness in pre/mid puberty soccer players (U14), as shown in literature in elite adult soccer players [64], but negatively correlated to variation in aerobic fitness in post puberty soccer players (U17). Significant negative correlation between MINUTES and variation in 30–15 IFT in U17 may depend on different training backgrounds between starters and non-starters. Unpublished data underline that, in general, starters had training background in the professional youth soccer sector while, in general, non-starters had training background in the sub-elite youth soccer sector. In U17, positive correlation was demonstrated with only training stimulus provided by training (TR-RPE) and variation of body shape (SUP-SKIN). We hypothesize that these differences are caused by possible differences in baseline fitness and study duration (9 weeks vs 17 weeks). With similar objectives to this study, Malina and colleagues [46] concluded that CMJ is related with stature and physical maturity (Tanner's Stage) and that aerobic fitness (yo-yo intermittent endurance test) is related with physical maturity and training experience in young soccer players age 13–15 years. These results confirm part of our results.

In conclusion, it is possible that the effect of training stimulus provided by training sessions improves its association with variation of aerobic fitness with age, from no-association in pre/mid puberty soccer players to about 50% in post puberty soccer players. However, current knowledge suggests the effect of other factors and the presence of substantial individual characteristics (between-players) to explain variation in fitness parameters in youth soccer players and the importance of genetic heritage, baseline fitness and years of training [6, 31].

The current study presents some limitations: in present study we consider a small sample so future research should include a larger sample to confirm and reinforce our results [80, 84]. Additionally, future research should monitor both internal, external and gym-based training load to add more information about the discriminating factors that affect variation of fitness parameters. Furthermore, other sport specific variables, like playing position, periodization and methodology and contextual variables, like ranking and team philosophy, could be explored to add additional information to try to explain variation of fitness parameters during soccer season in young soccer players [39, 94].

Conclusions

Young soccer players in U14 and U17 categories are sensitive to change in some somatic-anthropometric and fitness parameters in about 4 months. It is important to underline different sensibility in changing concerning the body shape and proportions (body mass index and ratio of sitting height and leg length) and performance in aerobic intermittent fitness tests. This, however, may be affected by adolescence awkwardness, typical in this period of growth and training experience as previously highlighted [95]. Most interesting, but not surprising, is the significant difference in training load parameters, except average intensity perceived during session training, higher in U17 category [34]. Relationships between performance variations and somatic-anthropometric variations and training load parameters are task-specific both in U14 and in U17. In particular, lower limbs power variation is more affected to somatic-anthropometric parameters in U17 than U14, while aerobic fitness variation is more affected to training load parameters during match both in U14 that U17 and to average intensity perceived during training session only in U17. Results underline the importance of training sessions during puberty, especially during adolescence.

In conclusion, in young soccer players, variations of somatic-anthropometric parameters are more able to explain the improvement of neuromuscular fitness (CMJ) in post puberty (U17) than pre/mid puberty (U14); match load parameters are able to explain improvement of aerobic fitness (30-15IFT) only in pre/mid puberty (U14), while intensity of training (TR-RPE) load is able to explain until the 48% of improvement of aerobic fitness (30-15IFT) only in post puberty (U17). Thus, the evaluation and selection process of young male soccer players during puberty must consider many aspects, like sensibility in changing of parameters themselves [96].

Practical applications

During puberty, variations in fitness parameters are affected by variations in somatic-anthropometric parameters and training load parameters differently between U14 and U17. Soccer trainers must consider the different relationship between fitness performance variations and somatic-anthropometric parameter variations in pre/mid puberty and post puberty soccer players. This study highlights that, in sub-elite youth soccer players U17, development neuromuscular fitness is sensitive to variations of somatic-anthropometric parameters, while development aerobic fitness is sensitive to training and match load, in both U14 and U17. In practical term, this study demonstrated that variations of somatic-anthropometric parameters is able to explain until 48% of improving neuromuscular fitness (CMJ) only in post puberty soccer players (U17), while match load parameters is able to explain until the 43% of improving aerobic fitness (30-15IFT) in pre/mid puberty young soccer players (U14). Training load is able to explain until the 48% of improving aerobic fitness (30-15IFT) only in post puberty soccer players (U17).

Author contributions GS tested all participants, GS and MI wrote the main manuscript text, GS prepared Table 1 and 2. All authors reviewed the manuscript

Declarations

Conflict of interest Giacomo Schillaci and Marco Ivaldi declare they have no conflict of interest.

Human and animal rights All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

Informed consent Written informed consent was obtained from the parents of all participants.

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