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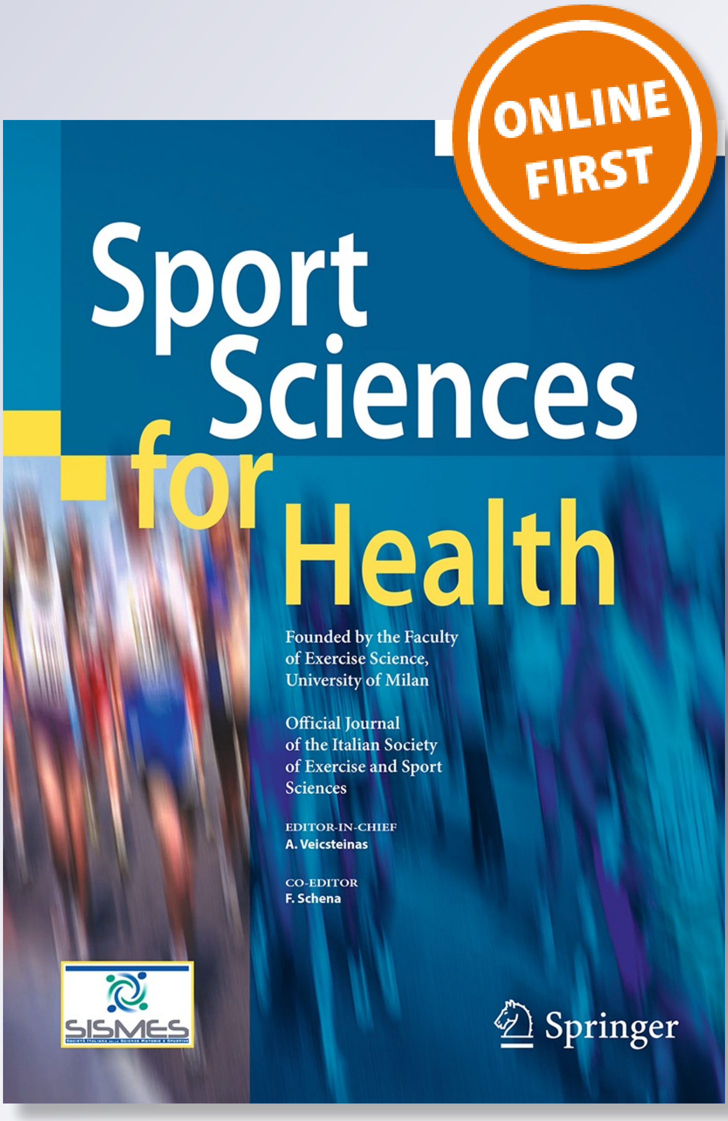

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ORIGINAL ARTICLE

Joint mobility/muscular chain elasticity in a cohort of 9- to 11-year school children exposed to a specifically designed professionally guided training

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Abstract

Purpose Joint mobility is a fundamental part in physical activity program for children, but a scientific characterization of the methods to improve the articular mobility in healthy children is still poor. The aim of this study was to investigate whether joint mobility/muscular elasticity were related to a merely active lifestyle or could be significantly improved in the presence of a collective, easy-to-perform, but specifically designed and professionally guided program.

Methods Specific functional and anthropometric parameters were single-blind tested on 277 children (aged 9–11 years). 148 were randomly assigned to a physical education program specifically designed to increase elasticity and supervised by professionals (treated group), while 129 (control group) continued their usual physical activity at school, with no specific program.

Results Specific tests were performed and showed a significant improvement of joint mobility compared to non-specific physical activity in 9- to 11-year children. As a secondary end-point, this program was effective also in children of overweight/obese BMI category.

Conclusions These results, building on those from this and other groups, should orientate decision-makers in the area of physical exercise for primary school children towards specifically designed programs based on demographic and anthropometric data.

Keywords Articular mobility · Healthy children · Physical activity at school · Musculoskeletal system · Elasticity

Introduction

The relationship between physical activity and health has been reported for centuries. The World Health Organization (WHO) guidelines recommend for children and youth at least 60 min of moderate–vigorous-intensity physical activity (MVPA) daily [1]. However, some authors reported a synthesis of data from WHO Member States estimating that the majority of people (aged 13–15 years) do not meet these guidelines [2]. Thus, the established health benefits of regular MVPA and the reported suboptimal activity levels of youth indicate a need for increased participation in Physical Activity at school.

Physical activity programs for children usually include joint mobility exercise. However, the scientific characterization of articular mobility in healthy children in different ages is still poor [3]. In fact, only recently it has been described that healthy Korean females present hypermobility of joints decreasing in adult age [4]. Generally, joint mobility is measured using a universal goniometer and indicated as joint range of motion (ROM). The ROM is expressed in degrees by aligning the arms of the device with specific bony landmarks on the joint. The most

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commonly used reference values for joint ROM are those published by the American Academy of Orthopaedic Surgeons (AAOS) [5].

Taking into account that joint structure has at least two more complex determinants (i.e., articular mobility and muscular chain elasticity) [6], the purposes of our research were: (1) to investigate whether the functional parameters of joint mobility (as representative of both components) in a cohort of 9- to 11-year healthy children without movement difficulties could be improved by a specific and professionally guided exercise program; (2) to study if the BMI could be related to the changes of joint mobility skills.

Participants and methods

Participants

300 children aged between 9 and 11 years were recruited and 277 were included in all the analyses. In particular, 148 (M/F = 70/78) were randomly assigned to the treated group (treated), while 129 (M/F = 60/69) to the control group (ctrl). Participants were allocated in the groups using a simple randomization process in a 1:1 fashion. None of the participants reported any movement difficulty. Exclusion criteria were: the presence of a progressive neurological, genetic, or metabolic disorder. Briefly, anthropometric measurements were focused on BMI and Fat Mass (FM). BMI was calculated as body weight divided by squared height (kg m^{-2}). FM was obtained by bioelectrical impedance analyser (BIA) (InBody 230; Biospace, Seoul, South Korea) based on multifrequency segmental bioelectrical methods as previously described [7, 8]. All measurements were made by two independent qualified technicians. An Harpenden stadiometer (Holtain, UK) was used to measure height and InBody 230 was used for weight.

As BMI for children is age and gender specific the classification was based on a percentile basis [9, 10]. Therefore, classification was:

- Normal Weight (NW) (5th–85th percentile) with a BMI comprised between 14.1 and 18.5 kg m^2 for males and 13.9–18.9 kg m^{-2} for females.
- Overweight (85th–95th percentile) with a BMI comprised between 18.6 and 20.9 kg m^{-2} for males and 19.0–21.7 kg m^{-2} for females.
- Obese (>95th percentile) with a BMI >21 kg m^{-2} for males and >21.8 kg m^{-2} for females.

Methodology

The trained personnel measuring the anthropometric characteristics of the participants was blinded to the initial randomization and protocol of physical activity program. Both groups treated and control routinely practiced physical activity at school as scheduled by the Ministry of Education. The program of Ministry of Education was organized as follows: 2 h/week of exercises and games for training general articular mobility and coordination. The specific program performed by treated group lasted twice/week for 8 months; it consisted in the maximal repetition number of flexion–extension of the ankles to be performed in 10 min in the sitting position (keeping a 90° fixed flexion of the hip). The training was proposed after 10 min of warming up activity (free running at low intensity) at the beginning of the lesson. The program proposed here was collective, minimally demanding and required no specific equipment. During the same time period, control group was allowed to perform their habitual physical activities, with no specific program.

By "professional guide" we refer to physical activity teachers with a university level degree in physical activity sciences.

At the beginning and at the end of the study, ctrl and treated group members were subjected to anthropometric measurements and to joint mobility tests as follows.

Tests

Three different tests were performed using the compass apparatus represented in Fig. 1, consisting of two hinged rigid elements (A, B) that allow to measure, beside anatomical lengths, the joint ROM. The compass was positioned with the pivot corresponding to the hip joint and the two arms as follows: the first arm (A) was used to measure the angular deviations of the back of the subject respect to the vertical line; the second arm (B) was used to measure the angular deviations of the legs from the vertical line. For the purpose of reading the results, the tests have been numbered and all the measurements were expressed in degrees. A schematic representation of the performed tests is shown in Fig. 2.

Test #1: Shoulder/Posterior muscular Chain Mobility Test (S/PC MT test) (Fig. 2a, b). By this test, performed in the sitting position, we measured the degree of shoulders maximal extension as representative of the elasticity of the upper posterior muscular chain. Legs were extended, with 90° dorsiflexion of the ankle. The 90° dorsiflexion of the ankles is critical to the physiological relevance of this test, as it stretches the posterior muscular chain (i.e., subjects with a short upper posterior muscular chain will be unable to reach the full extension of shoulders when ankles are dorsi-flexed). The 90° flexion of the hip represents the position in which the leverage load is absent since the trunk is perpendicular to the ground in the sitting position. Ideally, in this position, hamstring/calf resistance (middle/low posterior muscular

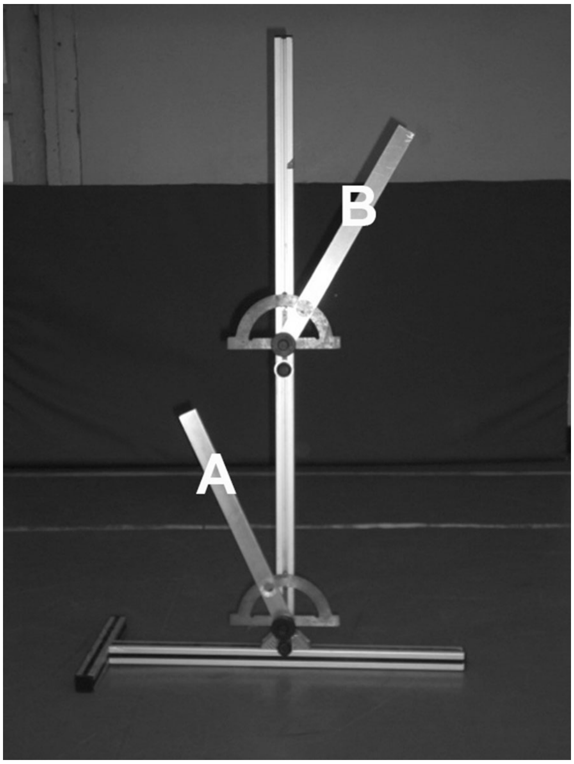

Fig. 1 Apparatus for test measurements: two hinged (arms) and one fixed (pivot) elements are shown. The fixed element was aligned with hip joint. The first arm (**a**) was used to measure the angular deviations of the back of the subject respect to the *vertical line*; the second arm (**b**) was used to measure the angular deviations of the legs from the *vertical line*

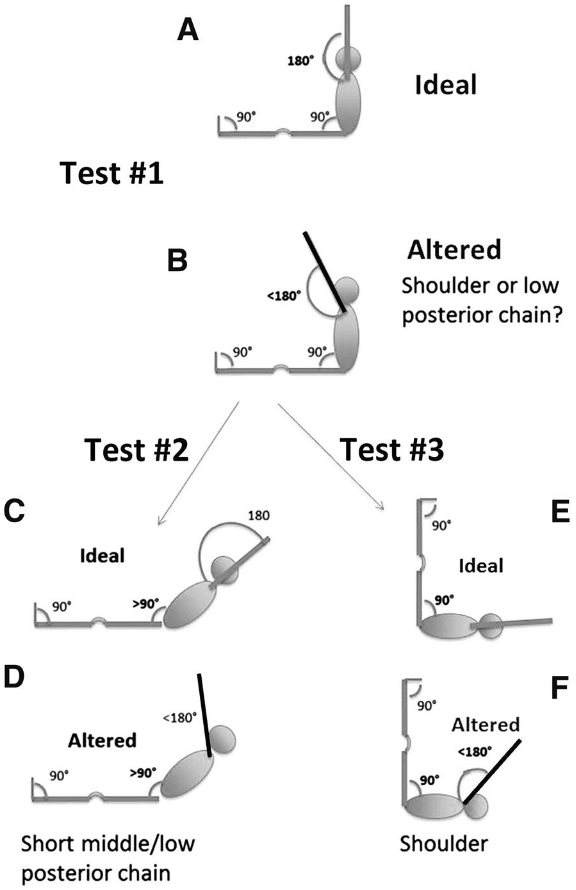

Fig. 2 Scheme of the test positions**.** **a** Ideal position in test #1 (Shoulder/Posterior Chain mobility test, S/PC MT). The ankles are dorsi-flexed and arms form 180° angle with trunk. **b** Schematic representation of a person presenting an alteration in shoulder mobility or low posterior chain. Ankles are dorsi-flexed and arms form <180° angle with the trunk. **c** Schematic representation of test #2 ideal. ankles are dorsi-flexed, legs and trunk form an angle >90°. The arms form 180° angle with trunk. **d** Schematic representation of a person presenting an alteration in middle/low posterior chain (test #2 altered). Ankles are dorsi-flexed, legs and trunk form a >90° angle and the arms form an angle <180° with the trunk. **e** Schematic representation of test #3 ideal. Supine position, ankles are dorsi-flexed, legs and trunk form 90° angle. The arms form 180° angle with trunk. **f** Schematic representation of a person presenting an alteration in shoulder joint mobility (test #3 altered). Supine position, ankles are dorsi-flexed, legs and trunk form 90° angle. The arms form an angle <180° angle with the trunk

chain) is perfectly counter-balanced by abdominal tension. The 90° dorsiflexion of the ankles is critical to this test, as it stretches the posterior muscular chain.

The measured value is the angular difference between the ideal maximal extension of the shoulder (180°, Fig. 2a ideal) and the real one (<180°, Fig. 2b altered). Smaller is the difference, better is the result since it indicates that the ankles dorsiflexion does not impair the shoulder maximal extension. Figure 2b shows an altered result of the test, in which, however, it is not possible to discriminate between shoulder and posterior muscular chain mobility problems. To this purpose test #2 and test #3 have been designed.

Test #2: Posterior muscular Chain Mobility Test (PCMT test) (Fig. 2c, d). This test, performed in the sitting position, is representative of the elasticity of the middle/low posterior muscular chain (hamstrings/calf). The >90° flexion of the hip represents the position in which the leverage load is present since the trunk is not perpendicular to the ground. Ideally, in this position, hamstring/calf resistance (middle/low posterior muscular chain) should balance the abdominal tension and compensative flection of arms is needed to help defective posterior muscular chain activity. Thus, when the subject perform >90° flexion of the hip with dorsi-flexed ankles and extended knees, the arms should form an angle of 180° with the trunk (Fig. 2c ideal). If there is a short lower posterior chain she/he will not be able to extend the arms that will form with the trunk an angle <180° (Fig. 2d altered).

Test #3: Shoulder Mobility Test (SMT test) (Fig. 2e, f). This assay was performed to evaluate shoulder mobility in the absence of posterior muscle chain involvement. In Fig. 2e (ideal) it is shown a representative scheme of the ideal result of the test #3: in the supine position the arms should form with the trunk an angle of 180° when ankles are dorsi-flexed. Closer to 180° is the angle between shoulder and trunk, better is the result. When the arms suffered of limited mobility/elasticity they form an <180° angle with the trunk (Fig. 2f altered)

Statistical analysis

First, data was analyzed for normality and stratified for age, genders and weight status. Multivariate analysis of variance (MANOVA) was conducted considering two genders, two school classes and two weight status (normal weight and overweight/obese). Since MANOVA was statistically significant we performed One-way ANOVA and χ^2 test for each variable. We applied Bonferroni adjustments to the statistical significance level [2 school classes × 2 weight status × 2 conditions (control and treated)] for each analysis. Thus, statistical significance was set to $p = 0.05/8 = 0.006$. Gender was not considered in the adjustments because we could not observe any statistically significant difference in the tests between boys and girls. Effect size was indicated by eta-squared (η^2). Range of the effect was considered small (0.02), medium (0.13), large (0.26).

Results

The anthropometric variations of the subjects during the test periods in the two groups are reported in Table 1. The proportion of normal weight (NW), overweight (OW) and obese (OB) was not significantly different between the two groups and in the two classes both at the beginning and the end of the test period (Table 2).

Table 1 Variations of the anthropometric parameters during the test period in the two groups

	IV class (9 years old)		
	Treated group (treated) ($N = 70$)	Control group (ctrl) ($N = 60$)	p
Δ Height	6 (0.8)	5 (1.2)	ns
Δ Weight (kg)	4.7 (2)	4.5 (2)	ns
Δ FM (%)	2.0 (3.2)	2.3 (7.2)	ns
Δ BMI	0.9 (0.8)	1 (0.9)	ns
	V class (10–11 years old)		
	Treated group (treated) ($N = 78$)	Control group (ctrl) ($N = 69$)	p
Δ Height	6.5 (1.2)	6.1 (2.1)	ns
Δ Weight (kg)	4.5 (2.3)	4.3 (2)	ns
Δ FM (%)	2.2 (7.2)	0.6 (6.4)	ns
Δ BMI	0.7 (1)	0.7 (0.9)	ns

FM fat mass, *N* number of children, *data* expressed as means (standard deviations) are the difference between the value obtained at the end of the study vs the beginning, *p* was by Anova test

Considering the test S/PC MT (#1), mean initial values of treated group (9-year children, 4th class) and control group were 13.6° (±10°) and 13.0° (±9.5°), respectively. In 10- to 11-year children (5th class) initial value of treated group was 8.0° (±9.3°) while for control group was 7.3° (±9°). We could observe a significant reduction in the difference of the shoulder/trunk angle respect to the ideal 180° in treated groups in 9-year children (4th class) (Fig. 3a; $^{*}p = 0.00003$, $F = 40$, $\eta^2 = 0.2$) and in 10- to 11-year children (5th class) (Fig. 3b; $p = 0.00001$, $F = 30$, $\eta^2 = 0.1$). This suggested that the maximal extension of the shoulder was significantly ameliorated (closer to the ideal 180°) by the proposed program. Similar results were obtained with the overweight/obese sub-population in both classes: for the 4th class ($p = 0.00002$, $F = 19.86$, $\eta^2 = 0.14$); for the 5th class ($p = 0.00006$, $F = 53.24$, $\eta^2 = 0.2$) (data not shown).

To understand if this amelioration was related to a change in the muscular chain elasticity or in the shoulder joint mobility, we moved to the analysis of test PC MT#2 (for muscular chain elasticity) and SMT #3 (for shoulder joint mobility). For test #2 mean initial values of the treated and control group (9-year children, 4th class) were 15.25° (±7.4°) and 14.35° (±5.6°), respectively; for test #3 values of the treated and control group were 18.05 (±9.45) and 20 (±11.4), respectively. For 10- to 11-year children (5th class), initial values of the treated and control group were: 14 (±6.6) and 13 (±6) for test #2, respectively; 14.4 (±8.6) and 13.5 (±8) for test #3, respectively.

While for test #2, we could not observe any significant difference between control and treated groups, test #3 results evidenced a significant amelioration in both school classes: for 9-year children (Fig. 3a 4th class; $^{**}p = 0.0002$, $F = 3.89$, $\eta^2 = 0.1$) and for 10- to 11-year children (Fig. 3b 5th class; $^{\wedge\wedge}p = 0.0055$, $F = 3.89$, $\eta^2 = 0.01$). As for test #1, similar results were obtained considering the overweight/obese sub-population in both classes. In fact the analysis of test #3 outcomes revealed a significant amelioration for the 4th class ($p = 0.0002$, $F = 15$, $\eta^2 = 0.07$) and for the 5th class ($p = 0.001$, $F = 6.57$, $\eta^2 = 0.05$) although with a small effect size (data not shown).

Discussion

Girls and boys from treated group showed better results at the end of the program as compared to the beginning, showing that the complex of the intervention was effective. More in detail, the results indicate that the program

Table 2 Stratification of the study groups in BMI classes before and after the study period

	IV class (9 years old)				V class (10–11 years old)				*p*
	Total	NW	OW	OB	Total	NW	OW	OB	
Before									
Treated group (treated)	70	53	13	4	78	62	12	4	ns
Control group (ctrl)	60	45	12	3	69	55	12	2	ns
After									
Treated group (treated)	70	47	19	4	78	60	15	3	ns
Control group (ctrl)	60	41	17	2	69	56	11	2	ns

NW normal weight, *OW* over weight, *OB* obese

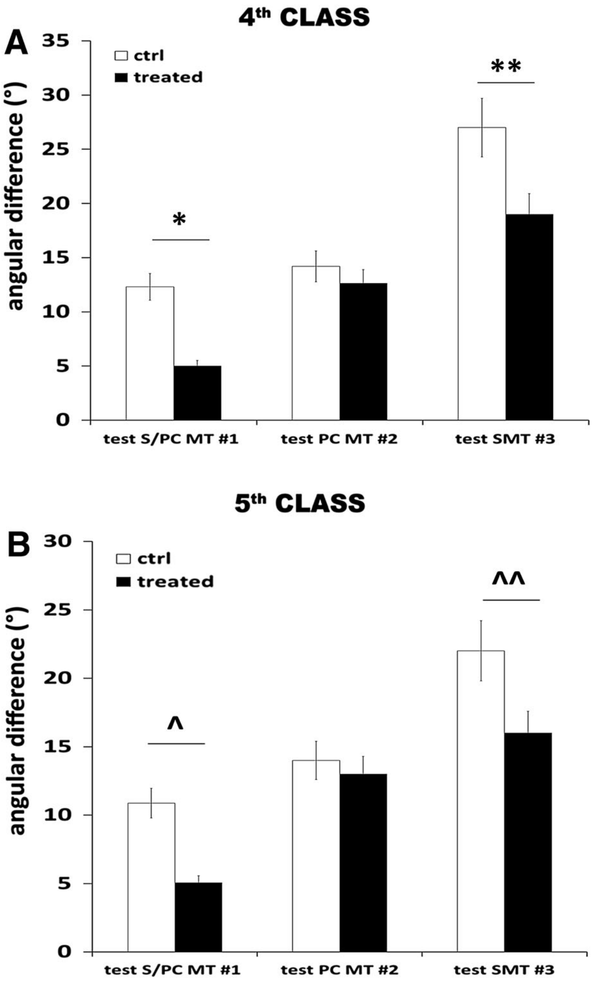

Fig. 3 Tests #1–3 differences in the 4th and the 5th class. **a** Angular differences between control (ctrl, *white bar*) and treated (*black bar*) groups of the 4th class in the three tests: S/PC MT #1 (Shoulder/Posterior Chain Mobility test); PCMT #2 (Posterior Chain Mobility test #2); SMT #3 (Shoulder Mobility test #3). $*p = 0.00003$; $**p = 0.0002$. **b** Angular differences between control (ctrl, *white bar*) and treated (*black bar*) groups of the 5th class in the three tests. $^\wedge p = 0.00001$; $^{\wedge\wedge} p = 0.0055$

generated an increase in the joint mobility of the shoulder regardless their BMI class. On the contrary, the program was not effective on the elasticity of the muscular chain.

The literature about the muscular chain characterization and the relative tests and exercises for children is still poor. Interestingly, several authors [8, 11] previously demonstrated that specific exercise programs can improve children motor abilities. The concept of kinetic chain in human movement was first proposed by von Baeyer in 1933 at the International Orthopedic Conference, then the concept was elaborated and diffused by in 1955 [12] when the kinetic chains were also classified in open and close depending on the loading of the terminal part.

While open kinetic chain exercises reinforce selected muscle groups, in closed kinetic chain exercise it is stimulated the activity of agonist and antagonist muscle groups. Kinetic chain exercises have many clinical applications, e.g., functional recovery in anterior cruciate ligament reconstruction [13], patellofemoral pain syndrome [14], shoulder pain [15] and spinal cord injury [16].

Recently, it has been proposed the importance of vertebral muscle kinetic chain to limit anomalous positions during sleep of children affected by obstructive sleep apnea syndrome [17], thus sustaining the importance of kinetic chain also in children to avoid wrong positions during sleep.

In conclusion, we here demonstrate that an even minimally demanding/easy-to-perform, but specifically designed and professionally guided, physical exercise program involving muscle kinetic chain can further improve the performance of children as compared to a merely active lifestyle. Notably, our study shows also that the program is effective independent of subjects' gender (data not shown) and BMI classes. Moreover, we propose tests that allow distinguishing the effect of the program on the muscular chain elasticity respect to joint mobility, generalizing this method of analysis. Notably, further studies will be necessary to identify a program that satisfies the requirement of posterior chain elasticity amelioration.

Last but not least, it is clear that the use of anthropometry should be increased in the design of physical activity programs (single or collective), since the theoretical "ideal" program must always be tailored on the group of subjects, and the physical activity is—in the end—always "adaptive".

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures met the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Data, reported in this manuscript, were anonymously generated. Subjects were exempt from possible physical, psychological and social injury. Therefore, in accordance with the Regulations of University of Parma and of the local Ethical Committee, no ethical permission was necessary for this study as it did not present the requirements for Ethical Committee evaluation.

Informed consent Informed consent was obtained from the parents of all the participants included in the study.

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