

A cross-sectional study of Cooper test in children according to allometric scaling

Identify the most appropriate body size and shape characteristics associated with the Cooper's 12 minute run test in 11 to 13 year old children

1. Introduction

The evaluation of the physical fitness in children and adolescent in the last decades has become crucial to defining the health status of the population [1] due to the strong association between high level of physical performance and the healthy condition of the person [2]. Indeed, it has been confirmed that the regular physical activity lead to improvements in physiological and psychological health with important outcomes for disease prevention [3-5]

Even if, the definition of physical fitness involves competencies in four key areas (aerobic fitness, muscular strength, endurance, flexibility [6]) the endurance tests are the most applied to define the physical fitness level [7-8]. Indeed, the aerobic efficiency is considered an indirect expression of the cardio-respiratory-system functions which in turn is the most important condition for long-term health status [9]. In light of this, several field tests were validated to guarantee simple, cheap and context-adaptable procedures [10-13] whereas several of those allowed the estimation of the $VO_2\text{max}$ applying specific formulas and avoiding invasive or laboratory assessment [10, 14-16].

Although, the definition of $VO_2\text{max}$ before and after a specific training protocol or considering a different life condition (i.e. intellectual disability, food habits, urban or rural origin) is relatively simple; the baseline trend of $VO_2\text{max}$ are scant: in particular, during the growth path. Indeed, the physical fitness outcomes are naturally affected by large variations during growth [17] whereas the height and weight are the most evident [18-19]. Thus, a research question could focus on the modification of the $VO_2\text{max}$ according only on the healthy growth path. In particular, the natural trend (read as a reference value in healthy sedentary people; [20-21]) of the $VO_2\text{max}$ in sedentary children who are not affected by specific sport or physical activity could be assumed as an important baseline for comparison between samples belonging to different categories.

Moreover, considering the fluctuations across different BMI categories during childhood [22-24] and the exponential trend of human growth [25] a robust normalization becomes essential. In light of this, the allometric analysis could be used since it is actually the best method of scaling when physical outcomes are assessed during growth [26-30].

Thus, the aim of this cross-sectional study was the definition of the trend in Cooper endurance test along the growth. In particular, the use of an appropriate method of scaling (allometric) could be useful to introduce the effects of body mass in sedentary healthy children since the linear regression

model carries some inaccuracies due to the absence of a weight/body-mass term in the normalizing models [31-32]

Moreover, the choice of the endurance Cooper test (and in particular the raw data in meter) followed the criteria of simplicity and rapidity of administration, the benefit related to the full compliance of the children during a field test and the wide use of this test to predict, with specific formula, the VO_2max [33]

2. Methods

2.1 Participants

A total of 556 of European sedentary children aged 11-13 yrs (282 boys; 274 girls) were enrolled, at the begin of the school year 2017-18, in the study whereas the main criteria of inclusion were defined as: i) no history of illness considered likely to affect growth, ii) no neurological/orthopaedic or cardiovascular diseases, iii) active participation in Physical Education (PE) classes and iv) self-declared “sedentary”.

Children found in good general health and not under medication at the time of the study were deemed eligible. Table 1 shows the anthropometric characteristics of the study samples stratified for age.

2.2 Design and Procedures

During a common appointment in the first week of October 2017 all children, supervised by their own PE teacher, participated in the stages of the study. In particular, the first operation regarded the anthropometric measures while the second was focused on the performance assessment. In particular, the height was measured with a fixed stadiometer to the nearest 0.5 cm and weight was measured with a beam balance to the nearest 0.1 kg with the subject wearing minimal clothing.

The endurance performance was evaluated through the Endurance Cooper test (known also as 12 min run test) since is safe, easy, short and administrable with the minimal and cheap amount of equipment [34]. In particular, this test is largely used in field session of training for middle/long distance race [35-36], during valid and reliable estimation of cardio-vascular fitness [37] and aerobic power (VO_2max) [35] and often adopted as competition during inter-school challenges [38-39].

The parents (or legal guardians) and all children gave written informed consent after having received a detailed explanation of the study procedure and possible risks. The study protocol was conducted in accordance with the current national and international laws and regulations governing the use of human subjects (Declaration of Helsinki II). In particular, all procedures were not invasive and did not involve risks different from those undertaken during common PE classes. The Ethics Committee of the Provincial School Office approved the study (prtl. 1718/09/EF241) verifying that all students had the possibility to interrupt the procedure at any time.

2.3 Statistical analysis

To identify the most appropriate body size and shape characteristics as well as any categorical differences (sex, age) associated with the measure of Cooper test, a multiplicative model with allometric body-size components was applied [40]:

$$Y = a \cdot \text{mass}^{k_1} \cdot \text{height}^{k_2} \cdot \epsilon \quad (1)$$

This model enhances the proportional body-size components whereas the multiplicative error ratio assumes the error ϵ and increases in proportion to the physical performance Y (see Fig. 1).

The model (Eq. 1), then was linearized with a log transformation and a linear regression analysis on a $\log(Y)$ was applied to estimate the unknown parameters of the log-transformed model:

$$\log(Y) = \log(a) + k_1 \cdot \log(\text{height}) + k_2 \cdot \log(\text{mass}) + \log(\epsilon) \quad (2)$$

Further, group differences within the population (sex, age) were entered as discrete categories and explored varying, for each group, the constant intercept parameter ($\log(a)$ in Eq. 2) as fixed factors within an ANCOVA. The significance level was set at $p < 0.05$.

3. Results

The multiplicative model relating to the Cooper test and to the body-size components was:

$$\text{Cooper test} = a \cdot \text{mass}^{-0.325} \cdot \text{height}^{0.878} \quad (3)$$

with the mass and height exponents being $k_1 = -0.325$ (SEE=0.40) and $k_2 = 0.878$ (SEE=0.141), respectively. The adjusted coefficient of determination ($\text{adj } R^2$) was 32.3%, with a log-transformed error ratio of 0.136 or 14.5% having taken antilogs. Significant differences in the constant 'a' parameters were identified by sex ($p < 0.001$) and age ($p < 0.001$) while the interaction of sex per age was not significant ($p = 0.761$). These age and sex main effects and the non-significant interaction (log transformed) are shown in Figure 2.

4. Discussion

This study focused on comparing the potential differences in endurance test (as a predictor of VO_2max) levels within a sample of healthy sedentary children (11-13 years old) through normalization of body size by allometric scaling (Eq. 1). In particular, a proportional allometric model was applied to identify the most appropriate body size, structure and shape characteristics for the run trials that is often used to indirectly determine the VO_2max [33]. Indeed, the authors believe that a field test better meets the compliance of young students/athletes, and it is easy to apply in several outdoor contexts and require cheap instruments and short time for the procedures.

In this study, the scaling method identified the optimal height-to-body mass ratios associated with Cooper endurance test to be $(\text{height} \cdot \text{mass}^{-0.37})^{0.878}$ (note that the 95% CI of the scaled mass exponent -0.370 was -0.459 to -0.281, that encompasses -0.333): corresponding to ectomorph [40]. The model of performances (aerobic endurance), identified as height-to-weight ratios in this study, is similar to the Reciprocal Ponderal Index ($\text{height}^3/\text{weight}$ or $\text{height}/\text{weight}^{0.333}$) found by Tanaka & Matsuura [41] and Nevill et al. [40] in young Japanese athletes and Greek school-children, respectively.

Moreover, also Bustamante et al. [42] confirmed that boys whose had lower levels of adiposity and greater height (ectomorph) performed better aerobic outcomes than girls with more adiposity and minor height, suggesting that the RPI is a significant predictor of endurance efficiency [40, 43-44]. In light of this, also, Loftin et al. [45] reported that the allometric model adjusting for height and mass applied for scaling the VO_2 peak values is a good approach because it reduces of 10% the absolute value of VO_2 : the 10% difference, however, is much less than the 50% noted for only body weight [45].

In particular, our results suggest that the optimal body shape for endurance performance is an ectomorph body shape [40-41]. The results are in line with Chaouachi et al. [46] that revealed as mesomorph and the mesomorph-ectomorph north African subjects obtained greater improvements in aerobic capacity after specific training.

Other similar findings were exposed by Bustamante et al. [42] and by Nevill et al. [40] that, even more, suggested the linear physique as the best condition to gain better results in an endurance test. In these studies, boys, on average, outperformed girls also when compared by body size and shape ($p < 0.001$) and our results are, also, in line with this gender difference (Figure 2).

This could be explained with the conclusion of Armstrong & Welsman [43] that suggested that the endurance performance in the range 11-13 years (both male and female) showed a direct relation with the changes in body surface area: boys increased their own body surface more than girls and then the VO_2peak significantly increased. The multiplicative model relating the distance to the

body-size components suggested that distance covered by running decreases with the increase of weight, explaining that the body mass affects negatively the endurance performance (exponent - 0.325 in the Equation 3) while the height affects it in a positive way (exponent 0.878 in Equation 3). In particular, our trends of boys and girls showed similar qualitative trends considering the stage 11-12 and 12-13 year-old: between 12 and 13 years-old a plateau is observable (Figure 2) because the reciprocal increment between weight and height was disadvantaged for the height.

5. Conclusions

Trainer, PE teacher, parents and clinicians, following our results, have to take into account the magnitude of growth (peak of height) to control the physical efficiency because it often depend on the height/weight variations (negative effect of BMI increment) that are very tumultuous during childhood. Moreover, the attention to growth fluctuations become important to avoid alarming judgment in case children will be poorly evaluated: the cause could be due to the natural growth path and not for lacks of physical activity. Conversely, the stage 11-12 years-old represent an important cut-off to intercept children with good athletic perspective.

Finally, our results were in line with the findings of Japanese [41], North African [46], Greek [40] and even with Peruvian children [42] suggesting that an allometric model is a good approach to scaling performance outcomes: even in the case where a field test is used.

6. References

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