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ORIGINAL ARTICLE

Predictive ability of anthropometry and maturation parameters on rowing ergometer performance in inexperienced adolescents

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Abstract We aimed to establish which anthropometric and maturity offset parameters correlate with rowing ergometer performance in a sample of 114 adolescent, rowing-inexperienced boys and girls. Results showed high correlations between body mass and performance, but these reduced when body mass was scaled to account for increased on-water drag resistance. Height, leg length and arm span remained moderately correlated after size-adjustment in boys, but not in girls. Anthropometric maturity offset showed a high correlation with performance, but decreased with size-adjustment. Final height estimation revealed that few of these adolescents would reach the height of elite open-weight competitors.

PALABRAS CLAVE
Remo;
Cineantropometría;
Maduración;
Detección de talento;
Alometría;
Deporte juvenil

Capacidad predictiva de la antropometría y la maduración sobre el rendimiento en remo-ergómetro en adolescentes novatos

Resumen Nuestro objetivo fue establecer qué parámetros antropométricos y de maduración se correlacionan con el rendimiento en remo-ergómetro en una muestra de 114 adolescentes de ambos sexos sin experiencia previa en remo. Los resultados demuestran una gran correlación entre masa corporal y rendimiento, aunque esta asociación disminuyó cuando la masa corporal se ajustó por un coeficiente para compensar la mayor resistencia en el agua generada por el arrastre. La estatura, la longitud de piernas, y la envergadura de brazos se correlacionaron moderadamente luego de del ajuste de la masa corporal en varones, pero no en niñas. El ajuste de maduración por antropometría mostró una gran correlación con el rendimiento, pero

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disminuyó luego de aplicar la corrección por tamaño. La predicción de la estatura adulta reveló que pocos de estos adolescentes crecerían hasta la estatura de los competidores de remo de elite de categoría abierta.

Introduction

At the elite level, rowing biomechanics imposes selection pressures on individuals such that athletes with long limbs and stature, above average muscle mass and low adipose mass make up the competition field at Olympic Games.[1] Scientific talent identification programs in rowing aim for early adolescents possessing these distinctive anthropometric characteristics.[2] In addition, in rowing, these programs generally carry out a rowing ergometer test, consisting of a maximal performance in 500, 1000, 2000 and/or 6000-m trials.[4] Rowing ergometer performance not only has been found to have a low correlation with on-water performance,[6] but also happens to be one of the exercise tests that have the lowest test–retest coefficients of variation.[7] The caveat with this test is that it does not take into account the increased water resistance generated by heavier individuals unless a correction factor is calculated.[6,8] A large muscle and body mass will probably aid the ergometer but hamper the on-water rowing performance by increasing the drag forces stemming from the enlarged in-water boat hull surface area.[5] Two other important issues in rowing talent identification protocols are prior rowing experience and maturation timing. Claessens et al.[9] determined no effect of rowing training on age at menarche at a World Junior Championship, but no published youth rowing-ergometer test work that we know of has measured maturation status as an influencing factor on performance. Early adolescence maturation status can affect performance[10] in a way that may lead to spurious inferences on adult performance. While the standard assessment of maturation involves wrist X-rays or visual characterization of genitalia, a new anthropometric stratagem has been developed and validated for this purpose.[11] This approach also allows the estimation of adult height,[12] important for rowing.

Our specific aim is to assess the correlation of anthropometric variables and maturation status on absolute and weight-corrected performance time of an 800-m rowing ergometer test in adolescents without prior rowing experience. We further wish to determine the proportion of participating adolescents that can reach the height of Olympic rowers, based on estimated adult height calculations.

Methods

Sample

Fifty-eight adolescent girls and 56 boys without prior rowing experience attending public and private schools in the city of Zárate, Argentina, were evaluated during a rowing ergometer competition staged by a local rowing club. The Club Náutico Zárate holds this competition annually inviting all neighboring school children without rowing experience as a means to raise interest in rowing. All participants and their parents or guardians were informed of the purpose and measurements of the study and those who agreed to take part signed a consent form. A prior pre-requisite to compete in this event was medical certification of good health. Approval for the study was obtained from the Ethics Committee of the Medical Department at Club Atlético River Plate. Growth and nutritional status of the study participating sample were assessed with the National Center for Health Statistics-World health Organization (NCHS-WHO) height-for-age (HAZ) and weight-for-age (WAZ) anthropometric indices,[13] and with age-matched muscle and fat arm cross-sectional areas according to Frisancho.[14]

Collection of data

A group of trained, International Society for the Advancement of Kinanthropometry (ISAK) Levels 2 and 3 anthropometrists landmarked and took single measurements of six anthropometric variables, following the ISAK protocol.[15] Body mass was recorded with an A&D portable electronic scale (A&D, Japan); height, sitting height and arm span with wall-mounted millimeter stadiometer paper and a 50 cm sturdy wooden box (for sitting height); relaxed arm girth with Lufkin WP606 inextensible metallic measuring tapes (Rosscraft, Canada); and triceps skinfold with Harpenden skinfold calipers (Batty, United Kingdom). Leg length was calculated as standing height minus sitting height; sitting height and arm-span indexes as sitting height and arm-span by height, expressed as percentages; maturity offset (measured as distance in years from peak height velocity (PHV)) and age at peak height velocity with the Mirwald et al. equations[16]; and estimated adult height with the Sherar et al. method.[12] Overlap zones (OZ) were calculated with the method suggested by olds[16] for estimated final height of the adolescents as compared to the mean and standard deviation of heights of male and female Olympic light and open weight rowers with data from the Sydney 2000 Olympic Games.[1] Overlap zone, expressed as a percentage, indicates what proportion of a sample normal population falls within the Gaussian distribution of a sample of elite competitors for a particular variable, in this case height. Following the anthropometric measurements, subjects took part in a maximal-effort 800-m rowing ergometer test on Concept II model C rowing ergometers (Concept, USA). Rowing coaches provided a brief explanation of the test and workings of the ergometer, and a short 1-min trial ensued to assure adequate technique. The ergometers were set with a

Table 1 Descriptive characteristics of subjects and correlation coefficients of variables with time and corrected time.

Variable	Girls ($n=58$)			Boys ($n=56$)		
	Mean ± SD	Time (s) *R*	C. time (s) *r*	Mean ± SD	Time (s) *r*	C. time (s) *r*
Time (s)	228.7 ± 18.1	1		193.5 ± 14.1	1	
Corrected time (s)	191.1 ± 12.6	0.913[a]		166.2 ± 9.8	0.865[a]	
Age (years)	14.0 ± 1.1	−0.219	−0.060	14.8 ± 1.2	−0.303[a]	−0.257
Weight (kg)	55.6 ± 9.8	−0.555[a]	−0.076	62.7 ± 10.2	−0.591[a]	−0.119
Height (cm)	158.7 ± 6.5	−0.590[a]	−0.304[a]	167.5 ± 7.3	−0.647[a]	−0.467[a]
Sitting height (cm)	84.1 ± 4.1	−0.615[a]	−0.274[a]	88.3 ± 4.5	−0.582[a]	−0.356[a]
Leg length (cm)	74.5 ± 3.7	−0.351[a]	−0.228	79.2 ± 4.8	−0.436[a]	−0.374[a]
Arm span (cm)	161.4 ± 6.9	−0.516[a]	−0.262[a]	171.7 ± 7.9	−0.640[a]	−0.488[a]
Arm girth (cm)	25.9 ± 2.8	−0.541[a]	−0.112	27.2 ± 3.0	−0.423[a]	0.033
Triceps skinfold (mm)	16.2 ± 4.6	−0.269[a]	0.110	10.4 ± 4.7	0.001	0.330[a]
Log triceps skf. (mm)	2.74 ± 0.28	−0.264[a]	0.122	2.25 ± 0.40	−0.036	0.295[a]
Sit. height/height (%)	53.0 ± 1.4	−0.231	−0.038	52.7 ± 1.7	−0.058	0.059
Arm span/height (%)	101.7 ± 1.9	0.125	0.069	102.5 ± 2.0	−0.052	−0.102
Arm muscle ar. (cm^2)	34.6 ± 5.9	−0.636[a]	−0.263[a]	46.2 ± 9.4	−0.505[a]	−0.155
Height-age *Z*-score	−0.1 ± 0.9			0.0 ± 1.0		
Weight-age *Z*-score	0.4 ± 0.8			0.6 ± 1.0		
Maturity (years-PHV[b])	1.6 ± 0.9	−0.501[a]	−0.185	1.0 ± 1.1	−0.548[a]	−0.343[a]
Age at PHV[b] (years)	12.4 ± 0.6			13.8 ± 0.7		
Adult height est. cm)	163.9 ± 4.9			177.0 ± 6.1		

[a] Correlation is significant at the 0.05 level (2-tailed).
[b] PHV: peak height velocity.

beginner's drag factor of 95–105. The choice of the distance was decided upon to accommodate junior newcomers to the rowing experience, whereby the trial is not too long to elicit fatigue, nor too short to stress the anaerobic metabolism almost exclusively. Each trial was timed with Casio stopwatch chronometers (Casio, Japan) to the nearest second by rowing coaches who also provided encouragement and supervision during the test. Trials occurred simultaneously on 20 Concept II rowing ergometers inside a large indoor facility at the club's premises. Performance time in seconds was corrected for weight with the algorithm suggested by the manufacturer[8]:

$$\text{Corrected weight} \quad (\text{Wf}) = \left(\frac{\text{weight in kg} \times 2.21}{270}\right)^{0.222}$$

$$\text{Corrected time} \quad (\text{s}) = \text{corrected weight} \quad (\text{Wf}) \times \text{actual time} \quad (\text{s})$$

Data analysis

Data were analyzed for extreme values, normalcy and homogeneity of variance with visual inspection of box-plots and Q–Q plots, and with the Shapiro–Wilk and Levene tests using SPSS version 17.0 software (Chicago, IL). Five cases were removed from the original sample because of missing information and/or having improbable values, and triceps skinfolds were normalized by log-transformation. Descriptive statistics (mean, standard deviation) were calculated, differences between genders were analyzed with the independent-samples *t*-test, and correlation and linear regression analysis (using the ''enter'' method) between performance times (dependent variables) and anthropometry and maturity status (independent variables) were done. Statistical significance was set at $p < 0.05$, and correlation coefficients were classified as trivial (<0.1), small (<0.3), moderate (0.3–0.5), large (0.5–0.7), very large (0.7–0.9) and nearly perfect (>0.9) according to Hopkins.[17]

Results

This sample of adolescents had nutritional and growth anthropometric indices that position them as normal when compared with a healthy international reference (NCHS-WHO 1977 sample)[13] (Table 1). Only one girl (2%) and four boys (7%) had arm muscle areas below the fifth percentile cutoff established by Frisancho,[14] and 49 girls (86%) and 37 boys (67%) were classified as normal, placing between percentiles 15 and 85. Three girls (5%) and four boys (7%) had arm fat area above the 90th age-reference percentile.

The girls were on average younger in chronological age than the boys, but they were more mature ($p < 0.05$) (Table 1). Average estimated age at PHV for girls and boys coincides with normal expectations.[13] In the boys, nine (16%) were classified as early, 44 (79%) as average, and three (5%) as late maturers. No girls were classified as early, 52 (90%) were average, and six (10%) late maturers.

The adult height estimation yielded average heights slightly above those of an Argentine reference adult sample, Argoref (http://www.nutrinfo.com/pagina/info/argoref.pdf), of 161.1 ± 6.7 and 175.4 ± 7.3 cm for women

Table 2 Height of Olympic rowers and final height estimation of Zárate sample.

Group	Females		Males	
	n	Mean ± SD	*n*	Mean ± SD
Elite lightweight rowers	14	169.7 ± 5.3	56	182.4 ± 3.6
Elite openweight rowers	73	180.6 ± 4.6	153	192.8 ± 5.5
Estimated final height Zárate sample	58	163.9 ± 4.9	56	177.0 ± 6.1

and men respectively, but below those of elite lightweight and heavyweight rowers at an Olympiad[1] (Table 2). The overlap zones for height were similar in boys and girls when contrasted against lightweight elite rowers, but smaller in girls when contrasted against open weight elite rowers (Fig. 1A and B).

In girls, uncorrected performance time showed a large negative correlation with weight, height, sitting height, arm span, arm girth, arm muscle area and maturity offset; a moderate negative correlation with leg length; and a small negative correlation with log-triceps skinfold (Table 1). After adjusting performance time for body mass, the strength of most correlations dropped, leaving a moderate negative correlation with height, small negative correlations with sitting height, arm span and arm muscle area, and trivial associations with the other variables.

In boys, uncorrected performance time showed large negative correlations with weight, height, sitting height, arm span, arm muscle area, and maturity offset; moderate negative correlations with age, leg length and arm girth, and trivial correlations with triceps skinfold, sitting height/height and arm span/height indexes (Table 1). After adjusting performance time for body mass, again correlations dropped in strength, leaving moderate negative correlations for height, sitting height, leg length, maturity offset, and a positive moderate correlation with triceps skinfold; small negative correlations were found with age, weight, arm span/height index, and arm muscle area; and trivial correlations with arm girth and sitting height/height index.

Because of the weak correlations in girls, no regression model was attempted, and in boys the following model was derived:

$$\text{Corrected performance time}\quad (\text{s}) = 270.3 - 0.606 \times \text{arm span}\quad (\text{cm})$$

$r = 0.488$, $p < 0.001$; $R^2 = 0.224$; $\text{SEE} = 8.6$

Discussion

Many articles discussing talent identification performance-related tests generally report pre-selected subjects constituting the elite in their youth sport.[3,6,18,19] It is to be expected at face value that elite samples are in proper or superior growth and nutritional status. In the case of non-elite, previously unselected samples, as in our case, it is important to report their nutritional and growth status since these factors might influence the results. These adolescents were normal in height and weight when compared to an international reference population,[13] and also in arm muscle and fat areas,[14] showing no evidence of an important obesity or under-nutrition prevalence. We may, consequently, infer that the results were not influenced by improper nutritional or growth status.

The maturation status of this sample, as assessed with the anthropometric method designed by Mirwald and colleagues,[11] is also normal and within expectations. While it is logical to expect ethnic differences to affect this maturity calculation, until a validation study with a local population sample is carried out, the current equations will be used. The prevalence of early, normal and late maturing boys in this sample is normal, but it is interesting to find that there were no early maturing girls. This could be circumstantial, because of the small sample size, or because of ethnic differences that may affect the anthropometric maturity index. Unfortunately menarchical status of the girls was not surveyed, as this information would have been helpful in pinpointing maturity.

The final height estimation method of Sherar and colleagues[12] is a recent development which takes into account the maturity offset of the subjects. This procedure helps to reduce estimation error due to differing maturational timing in adolescents. Results

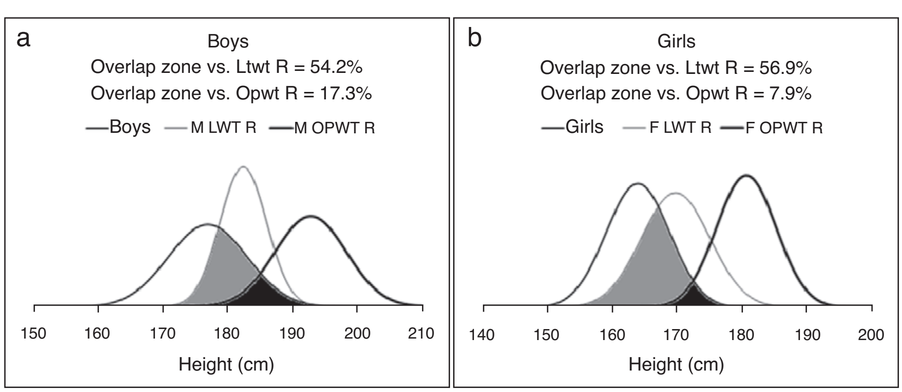

Fig. 1 (A and B) Overlap zones (%) between Zárate boys and girls's estimated final height and that of Olympic lightweight (ltwt R) and open weight (opwt R) rowers.[1]

coincide with expectations: estimated final heights for girls and boys are only slightly taller than a 20–30-year-old men and women normal healthy sample (http://www.nutrinfo.com/pagina/info/argoref.pdf). However, above-average height is a definite requirement for elite lightweight rowing and a sine-qua-non condition for the elite open weight category[1,22] (Table 2). The small coefficient of variation in the height of Olympic rowers is also eloquent of the selection pressures that impose structural homogeneity demands on its elite sportsmen.[1] Therefore as far as talent identification for rowing is concerned, accurate final height estimation might be a more important variable than actual rowing ergometer performance.

Straightforward correlations of rowing ergometer performance time with weight are large for both girls and boys, as other researchers have found; Mikulic and Ruzic[18] found a correlation of −0.79 between 1000-m rowing ergometer trial and body mass in 48 male 12.0–13.9-year-olds from rowing clubs in Zagreb with six months of training; Nevill and colleagues[6] arrived at −0.68 in 49 elite junior athletes in Great Britain, age 16.7 ± 0.5 years; Russell and colleagues in Australia (3), using a longer 2000-m ergometer test on 19 elite schoolboy rowers, found a correlation of −0.41; Yoshiga and Higuchi in Japan,[19] measuring 71 females and 120 males ages 18–24 years with a 2000-m ergometer test, found the correlation to be −0.85. Differences in the results of these authors may be due to differences in sample size, gender, age, ethnicity, size, and rowing experience; however, all correlations reported are moderate to very large for performance time in relation to body mass. A larger body mass is very likely associated with more muscle mass in athletes, and/or taller height which will translate into more power on the ergometer test, particularly at shorter distances.[5] Yoshiga and Higuchi reported an even higher correlation of −0.91 with fat-free mass,[19] and Cosgrove and colleagues[20] in Scotland found a better correlation with lean body mass when testing young adult male club rowers. Unfortunately most youth studies have not measured or do not report body composition data, nor were we able to do so in our study. If we use arm muscle area as a proxy for lean body mass, understanding that it may not reflect whole-body muscle mass, the correlation improves from −0.555 to −0.636 in girls, but not in boys (Table 1). Since girls tend to carry more body fat, as in this sample ($p < 0.05$), it is within reason to expect a better correlation value with performance time when lean mass is assessed. Correlations were also large in both sexes for corrected performance time and height and segment lengths, but this might also be because larger individuals were more mature. Maturity offset did have a large correlation with performance time in girls (Table 1), meaning that size variables during adolescent growth that affect performance time on a rowing ergometer are most likely influenced by maturation status. This is an important factor to consider in talent identification programs with adolescent athletes, because it may lead to a spurious analysis of future potential elite athletes.[10]

Actual rowing competition at the Olympic Games takes place in water, where the boat hull's surface area, which increases as heavier individuals sit in, acts as a drag force to forward propulsion.[6] As Nevill and colleagues report,[6] open weight rowers outperform their lightweight counterparts by 7.4% on the 2000-m rowing ergometer test, but are only 2.5% better rowing the same distance in the water. Raising body mass to the power of 0.222 has been suggested by the Concept II rowing ergometer manufacturers to compensate this effect,[8] and Nevill and colleagues have also devised a comparable allometric-scaling algorithm of 0.230.[6] When we applied the manufacturer's body mass correction factor, all correlations weakened (Table 1): weight no longer carried a significant bearing on performance in girls and boys, and height and body segment lengths showed small correlations in both sexes. Interestingly, maturity offset ceased to be an important factor after this weight correction in girls, and lost strength as a performance predictor in boys (Table 1). This means that now only 11.8% of the variance in performance in boys is explained by maturation, much less than the 30.0% before the body mass correction. A possible explanation for this is that body mass is an important factor in the calculation of maturity offset,[11] since the process of physical maturation is accompanied by an increase in body size and mass. A regression equation was generated for boys using arm span as the only predictor variable. This equation explains 22.4% of the variance in corrected performance time in boys, which is not much. Furthermore, arm span is highly related to height, so the two variables could be used interchangeably in these subjects. No equation was generated for girls, because the correlations of anthropometric variables with corrected performance time were small or trivial. Moreover, it is also interesting to mention that neither of the proportionality indexes, sitting height/stature nor arm span/stature correlated well with performance. Supposedly, having relatively longer legs and arms with respect to height is an advantage in rowing,[21] but this was not an important factor in this sample of novice adolescent rowers.

In conclusion, in this sample of rowing-inexperienced adolescents, rowing ergometer performance was positively related to size, but these associations were abated when adjusted for size, highlighting the important practical application of size-normalization strategies, especially in rowing where body mass is supported by the boat's hull. Although height is an important factor in talent identification for rowing, other important factors, such as performance enhancing genetic polymorphisms[22,23] play an essential role and must be accounted for when circumstances allow. This study also showed that the anthropometric evaluation of maturity status can be of help in assessing performance and estimating adult height in adolescents.

Conflict of interests

The authors have no conflicts of interest to declare.

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