Birthweight, body composition, and motor performance in 7- to 10-year-old children

MARCOS ANDRÉ MOURA-DOS-SANTOS[1] | MARCELUS BRITO DE ALMEIDA[2] | RAUL MANHÃES-DE-CASTRO[1] | PETER T KATZMARZYK[3] | JOSÉ ANTÓNIO RIBEIRO MAIA[4] | CAROL GÓIS LEANDRO[1,2]

1 Department of Nutrition, Federal University of Pernambuco, Recife; **2** Department of Physical Education and Sports Science, CAV, Federal University of Pernambuco, Vitoria de Santo Antao, Brazil. **3** Pennington Biomedical Research Center, Baton Rouge, LA, USA. **4** CIFI2D, Faculty of Sport, University of Porto, Porto, Portugal.

Correspondence to Carol Góis Leandro at Núcleo de Educação Física e Ciências do Esporte, Centro Acadêmico de Vitória – CAV, Universidade Federal de Pernambuco, Rua Alto do Reservatório, s/n CEP: 50670-901 Vitória de Santo Antão, PE, Brazil. E-mail: carolleandro22@gmail.com

PUBLICATION DATA
Accepted for publication 30th October 2014.
Published online

ABBREVIATIONS

FFM	Fat-free mass
KTK	Körper Koordination Test für Kinder
VO_{2max}	Maximal oxygen consumption

AIM The aim of this study was to analyse the influence of birthweight on motor performance and body composition in children. Further, we investigated whether associations between birthweight and motor performance changed after adjustment for current height, body mass index (BMI), fat-free mass (FFM), and % body fat.

METHOD A total of 483 children (251 males and 232 females) aged 7 to 10 years (mean 8.78, SD 1.0y) born in Vitória Santo Antão (northeast Brazil) were sampled. Motor performance was operationalized using different physical fitness components and gross motor coordination. Physical fitness was measured by handgrip strength, muscle endurance, explosive power, flexibility, agility, running speed, and maximal oxygen consumption (VO_{2max}). Gross motor coordination was evaluated by means of the *Körper Koordination Test für Kinder* (KTK).

RESULTS Positive correlations between birthweight and height, BMI, and FFM were found. Birthweight was positively correlated with handgrip strength and negatively correlated with 20-meter sprint time, even after controlling for age, height, BMI, FFM, and % body fat. Birthweight was negatively associated with relative VO_{2max} (mL/kg/min); however, the association was no longer significant after inclusion of BMI or FFM in the model.

INTERPRETATION Birthweight significantly predicted height, BMI, FFM, and performance in strength and velocity tests, but did not influence gross motor coordination.

Physical activity and fitness have a protective effect on metabolic risk factors during childhood,[1] as well as on premature morbidity and mortality in adulthood.[2,3] Poor motor performance could lead to reduced participation in physical activity and sports, which could potentially increase the health risks associated with physical inactivity. Thus, a better understanding of the determinants of poor motor performance may lead to the development of better intervention strategies with the long-term potential of improving physical activity and health.

Previous studies have indicated that low birthweight is associated with faster infant growth, abdominal fat accumulation, high blood pressure during adolescence, and the risk of metabolic diseases in adulthood.[4] A recent meta-analysis conducted by Yu et al.[5] showed that low birthweight was associated with decreased odds of obesity (OR 0.61; 95% CI 0.46–0.80), while high birthweight (>4000g) was associated with increased odds of obesity (OR 2.07; 95% CI 1.91–2.24). Similarly, low birthweight was also associated with a decreased odds of overweight (OR 0.67; 95% CI 0.59–0.76), while high birthweight (>4000g) was associated with increased odds of overweight (OR 1.66; 95% CI 1.55–1.77).[6] Using a twin sample (aged 8.9y old), a previous study reported that birthweight accounted for up to 11% of the total variance of neuromotor performance.[7] Our previous study showed that low birthweight alone cannot be considered as a biological determinant of physical growth and body composition but induces persistent deficits in muscle strength and running speed performance in children.[8]

Motor performance involves the integration of the central nervous system and the skeletal-muscle system to arrange the action of muscles, joints, and limbs to develop adequate strength, speed, and resistance for an intended motor task.[9] Motor performance encompasses several physical fitness components (cardiorespiratory, muscle strength, muscle endurance, body composition, agility, and flexibility) and motor coordination (fine and gross coordination).[10] Motor performance and gross motor coordination seem to be directly associated with regular physical activity and body composition in children and adolescents.[11] Infancy and childhood can be considered critical windows

 DOI: 10.1111/dmcn.12664

for the acquisition of physiological patterns that integrate posture with movement, and neuromotor control mechanisms.[10]

Recently, motor performance and gross motor coordination have also been associated with birthweight.[12,13] Our previous study has shown that early malnourished (as indicated by current height/age ratio) children (9y [SD 6mo]) presented lower ability to develop strength under voluntary or induced conditions.[9] Lower birthweight was linked to reduced motor performance including muscle strength, muscle endurance, and cardiorespiratory endurance in children and adolescents.[14,15] Extremely low birthweight (<1500g) is considered a risk factor of motor impairment.[12,16] Indeed, the likelihood of developmental motor coordination disorders increases for children born very preterm and/or 1500g or less, with OR of 6.29 (95% CI 4.37–9.05, p<0.0001) and 8.66 (95% CI 3.40–22.07, p<0.0001) for <5th, or 5th to 15th centile scores respectively.[13] However, the associations between birthweight and gross motor coordination are mostly limited to extremely low birthweight and little is known about the relationship of the different birthweight classes (extremely, very low, normal, and high birthweight) with gross motor coordination in children. Furthermore, few studies have explored the detailed contribution of current body composition to motor performance.

In our previous study we described the effects of low birthweight on the body composition and physical fitness variables in 7– to 10-year-old children.[8] We showed that low birthweight alone can be not considered as a biological determinant of the performance in physical fitness tests, except for muscle strength and running speed.[8] In the present study, we used birthweight as a continuous variable and we analysed children in terms of motor performance that included physical fitness and gross motor coordination. Thus, the purpose of this paper is to analyse the influence of birthweight on motor performance, and body size and composition (height, fat-free mass [FFM], body mass index [BMI], and % body fat) in children. Further, we investigated the interactions between composition and motor performance, and whether associations between birthweight and motor performance changed after adjustment for current height, BMI, FFM, and % body fat.

METHOD

Participants

This study was conducted in the city of Vitória de Santo Antão, located in a traditional and economically poor rural zone in the Pernambuco state, in northeast Brazil. A total of 483 children (251 males and 232 females) aged 7 to 10 years (mean 8.78, SD 1.0y) all born in Vitória of Santo Antão was sampled, with birthweight ranging from 2000 to 4500g. All measurements were carried out during a 6-month period from March to November 2009, according to the school calendar. No seasonality is to be expected in motor performance (physical fitness and gross motor coordination) measures given that the temperature and weather conditions are fairly stable during this period. Information on gestational age and mothers' health conditions during pregnancy was not available, and the sample included both children who were born preterm and term.

What this paper adds

- Birthweight is a predictor of body composition in 7- to 10-year-old children.
- Birthweight is positively associated with handgrip strength.
- Body composition is associated with neuromotor performance in 7- to 10-year-old children.
- Birthweight does not influence gross motor coordination in 7- to 10-year-old children.

Anthropometry and body composition

The body weight of lightly dressed and barefooted children was measured to the nearest 0.1kg with a digital scale (Filizola, São Paulo, Brazil), and the stature was measured to the nearest 0.5cm using a portable stadiometer (Sanny, São Paulo, Brazil) with each child's shoes off, feet together, and head in the Frankfurt horizontal plane.[17] BMI was calculated using the standard formula (weight [kg]/height^2 [m]). Triceps and subscapular skinfolds (mm) were measured with a Lange calliper (Lange, Santa Cruz, CA, USA) using a standard protocol.[17] The percent body fat, fat mass (kg) and FFM (kg) were estimated using Lohman and Going's formulas.[17]

Motor performance

Motor performance tests were selected from FITNESSGRAM,[18] Brazilian Sport Project,[19] and EUROFIT[20] standardized test batteries. For the present report the chosen tests were: (1) handgrip strength (measured independently in each hand) using a handgrip dynamometer (Saehan, Flintville, TN, USA); (2) standing long jump (a measure of the explosive strength of the lower limbs); (3) curl-ups (as an indicator of dynamic muscle endurance of abdominal muscles); (4) sit-and-reach as a measure of flexibility; (5) aerobic fitness (1-mile run/walk test) to estimate relative maximal oxygen consumption, where time to run the distance was transformed to VO_{2max} (mL/kg/min) using the regression equations from a previous study;[21] (6) square test as a measure of agility (complete a weaving running course [4×4m square] in the shortest possible time); and (7) 20-meter sprint time (to evaluate running speed in the shortest possible time).

Gross motor coordination

Gross motor coordination was evaluated with a standardized test battery for children which was developed in Germany (Körper Koordination Test für Kinder [KTK]),[22] and has been widely used in Brazil. The KTK includes the assessment of the following items: (1) balance – child walks backward on a balance beam 3m in length, but of decreasing widths: 6cm, 4.5cm, 3cm; (2) jumping laterally – child makes consecutive jumps from side to side over a small beam (60cm×4cm×2cm) as fast as possible for 15 seconds; (3) hopping on one leg over an obstacle – the child is instructed to hop on one foot at a time over a stack of foam squares. After a successful hop with each foot, the height is increased by adding a square (50cm×20cm×5cm); and (4) shifting platforms – the child begins by standing with both feet on one platform (25cm×25cm×2cm supported on four legs 3.7cm high), places the second platform alongside the first and steps on to it. The first platform is then placed alongside the second and the child steps on to it; the sequence continues for 20 seconds. For each task, performance was scored in a point system as suggested by the protocol, then summed and converted in the overall motor quotient sex and age specific. The overall motor quotient qualifies gross motor development in the following categories: 'not possible' (motor quotient <56), 'severe motor disorder' (motor quotient 56–70), 'moderate motor disorder' (motor quotient 71–85), 'normal' (motor quotient 86–115), 'good' (motor quotient 116–130), and 'high' (motor quotient 131–145).

Reliability

Data quality control was assessed by means of retesting 10% of the total sample 4 weeks apart. Technical errors of measurement (TEM) and ANOVA-based intraclass correlation coefficients (*R*) were used to estimate intraobserver reliability. TEM for anthropometric measurements were 0.41kg for weight, 0.43cm for stature, 0.52mm and 0.58mm for triceps and subscapular skinfolds respectively. For motor performance, *R* values ranged from 0.88 (1-mile run/walk) to 0.99 (standing long jump); and in gross motor coordination *R* ranged also from 0.85 (sideways movements) to 0.93 (balancing backwards).

Statistical analysis

Exploratory data analysis was used to identify potentially inaccurate information and outliers. Variables with skewed distributions were log transformed to obtain a more symmetrical distribution. Descriptive statistics are presented as means and standard deviations, minimum and maximum values. Potential interaction factors (i.e. sex-by-birthweight and age-by-birthweight) were evaluated using ANOVA models. As no statistically significant interactions were found, all sex and age groups were analysed together.

After inspection of correlation results (Spearman correlations) among the main studied variables, the effects of birthweight on motor performance were analysed by linear regression in an extended-model approach. Thus, a series of linear regression models were consecutively tested: Model I included only the main predictor (birthweight) and motor performance as the dependent variable; for model II, current decimal age+age^2 were entered to account for possible linear and non-linear effects of age; for model III, height was entered into the model (age+age^2+height); for model IV, BMI was entered into the model instead of height (age+age^2+BMI); for model V, FFM was entered into the model instead of BMI (age+age^2+FFM); for model VI, % body fat was entered into the model instead of previous indices (age+age^2+% body fat). Separate models were used for each body composition variable to determine how each one influenced the association between birthweight and motor performance variables. SPSS software version 18.0 (SPSS Inc, Chicago, IL, USA) was used for all analysis, and the significant level was set at 5%.

Ethics statement

This study was approved by the ethics committee of the Centre of Health Science, Federal University of Pernambuco (protocol number 0175.0.172.000–09) in accordance with the ethical standards of the 1964 Helsinki Declaration. Written informed consent from parents or legal guardians was a criterion for the inclusion of each child in the study. Birthweights were obtained from health booklets in which this information was recorded by nurses and/or paediatricians.

RESULTS

Basic descriptive information concerning physical growth, body composition, motor performance, and gross motor coordination is shown in Table I.

Table II shows the Spearman correlation (*r* and *p* values) among birthweight, motor performance, gross motor coordination, current body size (height and BMI), and body composition (FFM, % body fat). Birthweight was positively correlated with height, BMI, FFM, handgrip strength, and absolute VO_{2max}. Birthweight was negatively correlated with 20-meter sprint time, (L/min), and relative VO_{2max} (mL/kg/min). No statistically significant correlations were

Table I: Sample descriptive characteristics (mean with SD, minimum and maximum) of physical growth, body composition, motor performance, and gross motor coordination variables

	Mean (SD) (n=483)	Min	Max
Birthweight, g	3120 (415.5)	2000	4500
Age, decimal age	8.78 (1.0)	6.9	10.4
Growth and body composition			
Weight, kg[a]	30.2 (7.6)	16.9	57.1
Height, cm[a]	132.3 (8.4)	110.6	158.0
BMI, kg/m^{2}[a]	17.0 (2.9)	11.1	28.4
Body fat, %[a]	21.2 (8.5)	6.6	47.0
Fat mass, kg[a]	6.8 (4.4)	1.2	23.2
Fat-free mass, kg[a]	23.4 (4.4)	13.4	48.7
Physical fitness			
Handgrip strength, kg/f[b]	13.2 (3.5)	4.0	24.5
Standing long jump, cm[a]	108.4 (21.2)	38.0	168.0
Sit and reach, cm[a]	25.5 (5.7)	9.0	46.5
Curl-ups, *n*/min[a]	16.2 (8.0)	0.0	39.0
20-meter sprint time, s	4.6 (0.5)	3.6	6.6
Square test, s	7.6 (0.6)	5.3	11.2
VO_2 max, mL/kg/min	45.7 (4.0)	32.9	57.3
VO_2 max, L/min	1.3 (0.2)	0.78	2.4
Gross motor coordination			
Balancing backwards[a]	38.6 (13.1)	5	69
One-legged obstacle jumping[a]	38.9 (12.1)	8	84
Jumping from side to side[a]	44.6 (13.1)	14	104
Sideway movements[a]	36.1 (5.8)	21	56
Motor quotient	109.0 (11.1)	71	142

[a]Log-transformed variables were used in the latter analysis. [b]The average of left and right hand scores is shown. BMI, body mass index; VO_{2max}, maximal oxygen consumption.

Table II: Bivariate correlations (Spearman correlation coefficients, *r* [*p* values]) among birthweight, body size, body composition, motor performance, and gross motor coordination

Variables	Birthweight, g	Height, cm	BMI, kg/m^{-2}	% body fat	FFM, kg
Birthweight, g	(–)	0.111 (0.016)	0.123 (0.008)	0.001 (0.975)	0.198 (<0.001)
Motor performance					
Handgrip strength, kg/f[a]	0.214 (<0.001)	0.633 (<0.001)	0.372 (<0.001)	0.193 (<0.001)	0.673 (<0.001)
Standing long jump, cm	0.030 (0.520)	0.196 (<0.001)	−0.167 (<0.001)	−0.345 (<0.001)	0.166 (<0.029)
Sit and reach, cm	0.066 (0.156)	−0.180 (<0.001)	0.017 (0.710)	−0.048 (0.299)	−0.075 (0.101)
Curl-ups, *n*/min	0.034 (0.465)	0.035 (0.450)	−0.184 (<0.001)	−0.292 (<0.001)	0.043 (0.350)
20-meter sprint time, s	−0.170 (<0.001)	−0.222 (<0.001)	0.089 (0.057)	0.267 (<0.001)	−0.221 (<0.001)
Square test, s	−0.050 (0.282)	−0.222 (<0.001)	0.081 (0.082)	0.249 (<0.001)	−0.221 (<0.001)
VO_{2max}, mL/kg/min	−0.114 (0.014)	−0.075 (0.107)	−0.689 (<0.001)	−0.639 (<0.001)	−0.281 (<0.001)
VO_{2max}, L/min	0.109 (0.019)	0.855 (<0.001)	0.675 (<0.001)	0.557 (<0.001)	0.906 (<0.001)
Gross motor coordination					
Balancing backwards	0.006 (0.892)	−0.300 (<0.001)	−0.293 (<0.001)	−0.333 (<0.001)	−0.300 (<0.001)
One-legged obstacle jumping	−0.061 (0.189)	−0.176 (<0.001)	−0.295 (<0.001)	−0.430 (<0.001)	0.173 (<0.001)
Jumping from side to side	0.018 (0.694)	−0.179 (<0.001)	−0.153 (<0.001)	−0.285 (<0.001)	0.133 (<0.001)
Sideway movements	−0.005 (0.912)	−0.184 (<0.001)	−0.136 (0.003)	−0.221 (<0.001)	0.139 (0.003)

[a]The average of left and right hand scores is shown. BMI, body mass index; FFM, fat-free mass; VO_{2max}, maximal oxygen consumption.

found between birthweight and % body fat, standing long jump, sit and reach, curl-ups, the square test, and tests of gross motor coordination (p>0.05). There were significant associations between height, BMI, % body fat, and FFM, and some motor performance variables and most gross motor coordination tests (Table II).

Results for the multiple linear regression models are presented in Table III, showing the estimated changes in the selected motor performance variables per 1g increase in birthweight. Birthweight positively and significantly predicted handgrip strength, even after adjusting for age and age^2, as well as the additional covariates (height, BMI, FFM, and % body fat). There was a significant negative association between birthweight and 20-meter sprint time, and this association remained significant after adjusting for age, age^2, and any of height, BMI, FFM, and % body fat. Estimated relative VO_{2max} (mL/kg/min) was also negatively associated with birthweight; however, the relationship was no longer significant when BMI or FFM entered the model. Birthweight positively and significantly predicted absolute estimated VO_{2max} (L/min); however, the relationship changed direction when age, age^2, and FFM entered the model.

Table III: Linear regression coefficients (beta estimates±standard errors, 95% CI, and *p* values) showing estimated change in mean handgrip strength, running speed, and cardiorespiratory endurance (estimated VO_{2max} expressed in mL/kg/min) per 1g increase in birthweight among 483 children aged 7 to 10 years

Birthweight (kg)	β (SE)	95% CI	*p*
Handgrip strength, kg/f[a]			
No covariates	1.337 (0.306)	0.73 to 1.939	<0.001
Age+Age^2	1.040 (0.256)	0.537 to 1.543	<0.001
Age+Age^2+Height[b]	0.875 (0.229)	0.425 to 1.335	<0.001
Age+Age^2+BMI[b]	0.901 (0.244)	0.421 to 1.381	<0.001
Age+Age^2+FFM[b]	0.525 (0.222)	0.089 to 0.962	0.018
Age+Age^2+% body fat[b]	1.043 (0.254)	0.544 to 1.542	<0.001
20-m sprint time, s			
No covariates	−0.156 (0.045)	−0.245 to −0.067	0.001
Age+Age^2	−0.131 (0.043)	−0.216 to −0.046	0.003
Age+Age^2+Height[b]	−0.131 (0.043)	−0.217 to −0.046	0.003
Age+Age^2+BMI[b]	−0.155 (0.042)	−0.238 to −0.072	<0.001
Age+Age^2+FFM[b]	−0.118 (0.044)	−0.204 to −0.033	0.007
Age+Age^2+% body fat[b]	−0.130 (0.041)	−0.211 to −0.048	0.002
VO_{2max}, mL/kg/min			
No covariates	−0.860 (0.354)	−1.556 to −0.163	0.016
Age+Age^2	−0.951 (0.352)	−1.642 to −0.261	0.007
Age+Age^2+Height[b]	−0.844 (0.344)	−1.521 to −0.168	0.015
Age+Age^2+BMI[b]	−0.365 (0.217)	−0.791 to 0.061	0.093
Age+Age^2+FFM[b]	−0.349 (0.310)	−0.958 to 0.259	0.260
Age+Age^2+% body fat[b]	−0.970 (0.267)	−1.495 to −0.444	<0.001
VO_{2max}, L/min			
No covariates	0.054 (0.025)	0.005 to 0.104	0.031
Age+Age^2	0.031 (0.021)	0.011 to 0.073	0.145
Age+Age^2+Height[b]	0.008 (0.014)	−0.019 to 0.035	0.563
Age+Age^2+BMI[b]	−0.005 (0.014)	−0.032 to 0.021	0.690
Age+Age^2+FFM[b]	−0.033 (0.011)	−0.053 to −0.012	0.002
Age+Age^2+% body fat[b]	0.032 (0.017)	−0.001 to 0.066	0.061

[a]The average of left and right hand scores is shown. [b]Log-transformed variables were used in the analysis. BMI, body mass index; FFM, fat-free mass; VO_{2max}, maximal oxygen consumption.

DISCUSSION

In the present study, some important findings arise from the analysis of the association between birthweight, motor performance, and gross motor coordination in 7- to 10-year-old children. We found that birthweight was positively associated with current height, BMI, and FFM, which corroborates previous studies.[6,23] Accordingly, for every 100g increase in birthweight, the odds of overweight at 7 years of age are increased by 1.05 (95% CI 1.03–1.08).[24] Birthweight affects later physical growth, and high-birthweight infants have greater weight gains and increased risk of overweight/obesity than low- and normal-birthweight infants.[5] Postnatal catch-up growth and high fat accumulation during infancy/childhood have been associated with significantly increased risk of cardiovascular disorders in adulthood and reduced lifespan.[4,25–28]

In terms of motor performance, birthweight was positively associated with handgrip strength and negatively associated with 20-meter sprint time. To adjust for confounding factors, we used different multiple linear regression models, and it was shown that birthweight predicted handgrip and 20-meter sprint time across all models (age, age^2, height, BMI, FFM, and % body fat). Aligned with the present study, a previous investigation reported that low birthweight induced persistent deficits in the strength and running speed in children aged 7 to 10 years even when adjusted for covariates (height, FFM, and % body fat).[8] The associations between birthweight and performance in the strength and sprint time tests can potentially be explained by physiological mechanisms that include neuroendocrine and musculoskeletal systems. A previous study in rats demonstrated that a perinatal low-protein diet (8% protein) altered the brain growth spurt and the ontogeny of reflexes[29] and mechanical properties (contractility and elasticity) of skeletal muscle[30] of low-birthweight offspring. Although increasing evidence indicates that the neural and muscular systems maintain some degree of plasticity throughout life, it has been shown that early environmental factors influence neural development.[31]

There was no direct association between birthweight and motor coordination, but the positive association between birthweight and height and FFM seems to be the bridge that links early events and long-term consequences. It is well recognized that the performance in some motor performance tests is negatively affected by larger body size.[10,32,33] By analysing the magnitude of relationships, height and FFM was strongly associated with handgrip strength (0.664 and 0.650 respectively) and absolute VO_{2max} (0.842 and 0.900 respectively). On the other hand, height and FFM showed a weak association with standing long jump (0.195 and 0.101 respectively), 20-meter sprint time, square test, and gross motor coordination tests (see Table II). One study showed that after adjusting for height and lean mass, the difference in the performance of some motor tests was no longer found,[8] a finding that we reproduced in the present study. In addition, we found that BMI was negatively associated with standing long jump, curl-ups, and relative VO_{2max}. As expected, % body fat was negatively associated with standing long jump, curl-ups, relative VO_{2max}, and all tests of gross motor coordination. The present study reinforces the great deal of importance that has been focused on the influence of BMI and fat mass on motor performance tests.[10,26,34] These results can be confounded by other variables such as physical activity levels, for example.

To study the associations among birthweight, body composition, and motor performance without overestimating the influence of birthweight and unduly selective emphasis on particular results, the present study used multiple linear regression models of increasing complexity. It was shown that the expectations of mean changes in the handgrip strength and 20-meter sprint time per 1g increase in birthweight in children are independent of current height, BMI, FFM, and % body fat. On the other hand, the relationship between birthweight and relative VO_{2max} was weakened by the inclusion of BMI or FFM in the regression model. The combined effects of birthweight and motor performance during childhood have been investigated in some previous studies that support the present findings.[14,16,35,36] Reduced birthweight can be related to early impaired development of muscle fibres.[37] Skeletal muscle is a highly plastic tissue, adapting to environmental challenges by regulating the composition of slow- and fast-twitch myofibres.[38] Low birthweight induced by maternal undernutrition also caused changes in the skeletal muscle phenotype (reduced type I fibre and increased type IIb fibres)[39] and reduced maximum twitch and tetanic tension of the skeletal muscle in rats.[30] In humans, low birthweight was associated with increased proportion of type IIx fibres and reduced type IIa fibres of the vastus lateralis muscle of young males (19y).[40] However, this effect is not deterministic and interventions including endurance exercise can induce the trans-differentiation of myofibres.[38] Indeed, physical exercise is a well-known inducer of positive organic adaptations that can recover the short- and long-term effects of birthweight.

The limitations of the present work are the lack of information about the period of gestational age and lactation that could also influence the body composition and motor performance outcomes. Physical activity is also an important variable that could be analysed to better understand the current effects of the environment. In addition, although the sample size of the present study is fairly similar to previous research, there is a potential problem with reported p values given the number of computed correlations. This is an issue that was never addressed in previous papers, but it is a real one. One solution to this problem would be a Bonferroni p value adjustment, but this would imply a too stringent p value (0.05 divided by the number of all possible calculated correlations). Unless the sample size is very big, the chance of finding significant correlations would be very low with the new p values. Yet, we feel that our results are within the expected margin for this type of research. Still, we suggest that future studies use bootstrap techniques to compute 95% confidence intervals for all correlations so that investigators may be more confident with their results.

In conclusion, birthweight was associated with the components of body composition (height, FFM, and BMI) of children. There was no direct association between birthweight and gross motor coordination. Current height, % body fat, and FFM were strongly associated with muscular strength, velocity, flexibility, cardiorespiratory endurance, agility, and the four components of the KTK. But further investigation is needed to evaluate the mechanisms underlying these effects. From a public health perspective, given the associations between fitness and risk factors/chronic disease, our findings suggest that there might need to be a greater emphasis on physical training in schoolchildren in populations with higher prevalence of lower birthweight.

ACKNOWLEDGEMENTS

This study was supported by the National Council for Scientific and Technological Development (CNPq), Coordination for the Improvement of Higher Level (or Education) Personnel (CAPES), and State of Pernambuco Science and Technology Support Foundation (FACEPE). We thank all children and their families for participating in this study. The authors have stated that they had no interests that might be perceived as posing a conflict or bias.

REFERENCES

1. Strong WB, Malina RM, Blimkie CJ, et al. Evidence based physical activity for school-age youth. *J Pediatr* 2005; **146**: 732–7.
2. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT, Lancet Physical Activity Series Working Group. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet* 2012; **380**: 219–29.
3. Blair SN, Kampert JB, Kohl HW 3rd, et al. Influences of cardiorespiratory fitness and other precursors on cardiovascular disease and all-cause mortality in men and women. *JAMA* 1996; **276**: 205–10.
4. Barker DJ, Osmond C, Forsen TJ, Kajantie E, Eriksson JG. Trajectories of growth among children who have coronary events as adults. *N Engl J Med* 2005; **353**: 1802–9.
5. Yu ZB, Han SP, Zhu GZ, et al. Birth weight and subsequent risk of obesity: a systematic review and meta-analysis. *Obes Rev* 2011; **12**: 525–42.
6. Schellong K, Schulz S, Harder T, Plagemann A. Birth weight and long-term overweight risk: systematic review and a meta-analysis including 643,902 persons from 66 studies and 26 countries globally. *PLoS ONE* 2012; **7**: e47776.
7. Lopes AA, Tani G, Katzmarzyk PT, Thomis MA, Maia JA. Association between birth weight and neuromotor performance: a twin study. *Scand J Med Sci Sports* 2014; **24**: e140–7.
8. Moura-Dos-Santos M, Wellington-Barros J, Brito-Almeida M, Manhaes-de-Castro R, Maia J, Gois Leandro C. Permanent deficits in handgrip strength and running speed performance in low birth weight children. *Am J Hum Biol* 2013; **25**: 58–62.
9. Paiva M, Souza TO, Canon F, et al. Stunting delays maturation of triceps surae mechanical properties and motor performance in prepubertal children. *Eur J Appl Physiol* 2012; **112**: 4053–61.
10. Lopes VP, Rodrigues LP, Maia JA, Malina RM. Motor coordination as predictor of physical activity in childhood. *Scand J Med Sci Sports* 2011; **21**: 663–9.
11. Malina RM. Physical growth and biological maturation of young athletes. *Exerc Sport Sci Rev* 1994; **22**: 389–433.
12. Dewey D, Creighton DE, Heath JA, et al. Assessment of developmental coordination disorder in children born with extremely low birth weights. *Dev Neuropsychol* 2011; **36**: 42–56.
13. Edwards J, Berube M, Erlandson K, et al. Developmental coordination disorder in school-aged children born very preterm and/or at very low birth weight: a systematic review. *J Dev Behav Pediatr* 2011; **32**: 678–87.
14. Ridgway CL, Brage S, Anderssen SA, Sardinha LB, Andersen LB, Ekelund U. Do physical activity and aerobic fitness moderate the association between birth weight and metabolic risk in youth?: the European Youth Heart Study. *Diabetes Care* 2011; **34**: 187–92.
15. Natalucci G, Seitz J, von Siebenthal K, et al. The role of birthweight discordance in the intellectual and motor outcome for triplets at early school age. *Dev Med Child Neurol* 2011; **53**: 822–8.
16. Schmidhauser J, Caflisch J, Rousson V, Bucher HU, Largo RH, Latal B. Impaired motor performance and movement quality in very-low-birthweight children at 6 years of age. *Dev Med Child Neurol* 2006; **48**: 718–22.
17. Lohman TG, Going SB. Body composition assessment for development of an international growth standard for preadolescent and adolescent children. *Food Nutr Bull* 2006; **27**: S314–25.
18. Research TCIfA. FITNESSGRAM Test Administration Manual. 2nd edn. Champaign, IL: Human Kinetics, 1999.
19. Brazil MS. Project Brazilian Sport: Manual. Available from: http://www.proesp.ufrgs.br, 2012.
20. EUROFIT. Handbook for the EUROFIT Tests of Physical Fitness. Rome: Council of Europe Committee for the Development of Sport, 1988.
21. Cureton KJ, Sloniger MA, O'Bannon JP, Black DM, McCormack WP. A generalized equation for prediction of VO2peak from 1-mile run/walk performance. *Med Sci Sports Exerc* 1995; **27**: 445–51.
22. Kiphard EJ, Schilling F. Korper-Koordinations-Test fur Kinder. Ktk.Manual. Weiheim: Beltz Test GmbH, 1974.
23. Chomtho S, Wells JC, Williams JE, Lucas A, Fewtrell MS. Associations between birth weight and later body composition: evidence from the 4-component model. *Am J Clin Nutr* 2008; **88**: 1040–8.
24. Reilly JJ, Armstrong J, Dorosty AR, et al. Early life risk factors for obesity in childhood: cohort study. *BMJ* 2005; **330**: 1357.
25. Baker JL, Olsen LW, Sorensen TI. Childhood body-mass index and the risk of coronary heart disease in adulthood. *N Engl J Med* 2007; **357**: 2329–37.
26. Rooney BL, Mathiason MA, Schauberger CW. Predictors of obesity in childhood, adolescence, and adulthood in a birth cohort. *Matern Child Health J* 2011; **15**: 1166–75.
27. Ozanne SE, Hales CN. Lifespan: catch-up growth and obesity in male mice. *Nature* 2004; **427**: 411–2.
28. de Brito Alves JL, Nogueira VO, de Oliveira GB, et al. Short- and long-term effects of a maternal low-protein diet on ventilation, O_2/CO_2 chemoreception and arterial blood pressure in male rat offspring. *Br J Nutr* 2013; **111**: 606–15.
29. Falcao-Tebas F, Bento-Santos A, Fidalgo MA, et al. Maternal low-protein diet-induced delayed reflex ontogeny is attenuated by moderate physical training during gestation in rats. *Br J Nutr* 2012; **107**: 372–7.
30. Toscano AE, Manhaes-de-Castro R, Canon F. Effect of a low-protein diet during pregnancy on skeletal muscle mechanical properties of offspring rats. *Nutrition* 2008; **24**: 270–8.
31. Young JB. Developmental origins of obesity: a sympathoadrenal perspective. *Int J Obes (Lond)* 2006; **30**(Suppl 4): S41–9.
32. Martins D, Maia J, Seabra A, et al. Correlates of changes in BMI of children from the Azores islands. *Int J Obes (Lond)* 2010; **34**: 1487–93.
33. Mota J, Guerra S, Leandro C, Pinto A, Ribeiro JC, Duarte JA. Association of maturation, sex, and body fat in cardiorespiratory fitness. *Am J Hum Biol* 2002; **14**: 707–12.
34. Freitas D, Beunen G, Maia J, et al. Tracking of fatness during childhood, adolescence and young adulthood: a 7-year follow-up study in Madeira Island, Portugal. *Ann Hum Biol* 2012; **39**: 59–67.
35. Ortega FB, Labayen I, Ruiz JR, et al. Are muscular and cardiovascular fitness partially programmed at birth? Role of body composition. *J Pediatr* 2009; **154**: 61–6.e1
36. Salonen MK, Kajantie E, Osmond C, et al. Developmental origins of physical fitness: the Helsinki Birth Cohort Study. *PLoS ONE* 2011; **6**: e22302.
37. Brameld JM. The influence of undernutrition on skeletal muscle development. *Br J Nutr* 2004; **91**: 327–8.
38. Rockl KS, Hirshman MF, Brandauer J, Fujii N, Witters LA, Goodyear LJ. Skeletal muscle adaptation to exercise training: AMP-activated protein kinase mediates muscle fiber type shift. *Diabetes* 2007; **56**: 2062–9.
39. Leandro CG, da Silva Ribeiro W, Dos Santos JA, et al. Moderate physical training attenuates muscle-specific effects on fibre type composition in adult rats submitted to a perinatal maternal low-protein diet. *Eur J Nutr* 2012; **51**: 807–15.
40. Jensen CB, Storgaard H, Madsbad S, Richter EA, Vaag AA. Altered skeletal muscle fiber composition and size precede whole-body insulin resistance in young men with low birth weight. *J Clin Endocrinol Metab* 2007; **92**: 1530–4.