European Journal of Sport Science
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tejs20

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Published online: 28 Oct 2011.

To cite this article: Vítor P Lopes, José A. R. Maia, Luis P Rodrigues & Robert Malina (2012) Motor coordination, physical activity and fitness as predictors of longitudinal change in adiposity during childhood, European Journal of Sport Science, 12:4, 384-391, DOI: 10.1080/17461391.2011.566368

To link to this article: http://dx.doi.org/10.1080/17461391.2011.566368

European Journal of Sport Science, July 2012; 12(4): 384–391

Routledge
Taylor & Francis Group

ORIGINAL ARTICLE

Motor coordination, physical activity and fitness as predictors of longitudinal change in adiposity during childhood

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Abstract

The purpose of this study was to examine the influence of motor coordination (MC), physical fitness (PF) and physical activity (PA) on the development of subcutaneous adiposity in a sample of children followed longitudinally from 6 to 10 years of age. Participants were 142 girls and 143 boys. Height, weight, and the triceps and subscapular skinfolds were measured annually between the ages of 6 and 10 years. PA was estimated with the Godin–Shephard questionnaire. MC was evaluated with the Körperkoordination Test für Kinder (KTK) test battery, and PF was assessed with four Fitnessgram tests: curl-ups (CU), push-ups (PU), trunk-lifts (TL) and one mile run/walk (MRW). Hierarchical linear modelling with MC, PF items and PA as predictors of the sum of two skinfolds (SKF) was used. The results showed that boys and girls differed significantly in SKF at baseline (girls: 19.7 mm; boys: 16.6 mm). Three PF items (CU, PU and MRW) and MC had a positive influence on SKF. For each unit improvement in CU, PU, MRW and MC, SKF was reduced by 0.06, 0.04, 0.06 and 0.12 mm, respectively. In conclusion, motor coordination, muscular strength and endurance, and aerobic endurance attenuated the accumulation of subcutaneous adipose tissue during childhood.

Keywords: *Children, strength, endurance, skinfolds, movement skill, motor development*

Introduction

Many westernised countries and countries undergoing economic transition have experienced an increase in the prevalence of childhood obesity (Lobstein, Baur, & Uauy, 2004). Risk factors for childhood obesity include parental fatness, high birth weight, diet (including early infant feeding practices), rate of maturation (especially among girls), physical inactivity, low levels of physical activity, low socioeconomic status, and several behavioural and psychological factors (Dietz, 1996). Although the relative importance of specific risk factors are not ordinarily specified at the level of the individual and population, a sedentary lifestyle and excessive energy intake are often considered as primary mechanisms contributing to potentially unhealthy weight gain and in turn to becoming overweight and obesity. A primary component of excessive weight gain in children is subcutaneous adipose tissue (Bouchard & Katzmarzyk, 2010; Bray & Gray, 1988).

Subcutaneous adiposity tends to decline, on average, from infancy to about 6 or 7 years of age and then to increase through childhood (Malina, Bouchard, & Bar-Or, 2004). The increase in subcutaneous adiposity occurs at approximately the same time as the "adiposity rebound" defined by an increase in the body mass index (BMI) at these ages (Rolland-Cachera et al., 1984). Although it may be a coincidence, proficiency in the majority of basic movement patterns is also reasonably well established by 6–7 years of age (Malina et al., 2004). Movement is the substrate of physical activity and basic movement patterns are the basis for physical fitness testing which often begins at these ages. It is possible that

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ISSN 1746-1391 print/ISSN 1536-7290 online
http://dx.doi.org/10.1080/17461391.2011.566368

proficiency in movement skills, habitual physical activity and physical fitness interact at these young ages to influence the subsequent accumulation of subcutaneous adipose tissue during childhood.

Excessive adiposity has a negative influence on fitness tests requiring movement and projection of the body through space as in runs and jumps, and in lifting and supporting the body off the ground as in pull-ups and flexed arm hang in children (Malina, 1994; Malina et al., 1995). Obese children show lower levels of motor coordination and endurance (Graf et al., 2004), and are more likely to have lower levels of fundamental movement skills (Okely, Booth, & Chey, 2004) than non-obese children. Although the literature is generally equivocal on the physical activity or inactivity status of obese children (Malina et al., 2004), children with higher levels of activity tend to be more proficient in movement skills (Fisher et al., 2005; Williams et al., 2008; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006) and more physically fit (Dencker, Bugge, Hermansen, & Andersen, 2009; Pate, Dowda, & Ross, 1990; Sallis, McKenzie, & Alcaraz, 1993a).

Low levels of physical activity and physical fitness, and limited motor coordination, either together or independently, may thus be relevant to the development of obesity in childhood. The purpose of this study was to examine the influence of motor coordination (MC), physical fitness (PF) and physical activity (PA) on the development of subcutaneous adipose tissue in children followed longitudinally from 6 to 10 years of age. MC, PF and PA were specifically evaluated as predictors of subcutaneous adiposity between 6 and 10 years of age. It was hypothesised that PA, PF and MC, either individually or in combination, would be significant predictors of subcutaneous adiposity in the children at these ages.

Materials and methods

Four cohorts of Azorean children (Azores Islands, Portugal) were followed longitudinally from 2002 to 2007. Participants in each cohort were, respectively, 6, 10, 13 and 16 years of age at first observation. Children in the first age cohort (6 years) who were followed from 6 to 10 years of age are the focus of this study.

Participants

Participants were 285 elementary school children, 142 girls and 143 boys, followed annually from 6 to 10 years of age. The schools did not have regular physical education or sport programmes. Organised physical activities were held only periodically. Written informed consent was obtained from the parents of each child and the study was approved by the ethical committee of the local health authority.

Body dimensions

Body weight and height were measured with a digital scale (SECA, Hamburg, Germany) and Siber Hegner anthropometer, respectively. The body mass index (BMI, weight/height^2) was calculated. Triceps and subscapular skinfolds were measured on the right side of the body to the nearest 0.1 mm following the protocol described by Harrison et al. (1988). The two skinfolds are perhaps the most commonly used in studies of children and provide an estimate of subcutaneous fatness on the upper extremity and upper trunk (Malina et al., 2004). A Holtain skinfold caliper (GPM-caliper, Zurich, Switzerland) was used. The skinfolds were measured in duplicate by the same trained technician. Technical errors of measurement varied between 0.02 and 0.84 mm during the course of the study. The averages of the two measurements of each skinfold was retained for analysis and were summed (SKF) as an indicator of subcutaneous adiposity.

Physical activity

Physical activity was assessed with the Godin–Shephard questionnaire (Godin & Shephard, 1985) which was administered in an interviewer-assisted format. Children were asked to report the number of times they spent more than 15 min in activities classified as mild (3 METs – metabolic equivalents), moderate (5 METs), or strenuous (9 METs) in a typical week. A total score was derived by multiplying the frequency of each category by the MET value and summing the products. Although objective instruments (e.g. accelerometers) are preferred for the assessment of PA in children, it was not feasible in the present study. The Godin–Shephard questionnaire has been widely used with children, although its reported validity is only moderate, $r = 0.32$ to 0.42 (Sallis, Michael, Roby, Micale, & Nelson, 1993b; Scerpella, Tuladhar, & Kanaley, 2002).

Motor coordination

Motor coordination was evaluated during the first four years of the study (6–9 years of age) with the Kiphard–Schilling body coordination test which was developed on a sample of German children (Körperkoordination Test für Kinder [KTK], Kiphard & Schilling, 1974). The test battery has four items:

1. Balance – the child walked backwards on a balance beam 3 m in length but of decreasing widths: 6 cm, 4.5 cm, 3 cm; the number of successful steps was recorded.
2. Jumping laterally – the child made consecutive jumps from side to side over a small beam (60 cm × 4 cm × 2 cm) as fast as possible for 15 s. The child was instructed to keep his/her feet together; the number of correct jumps was recorded.
3. Hopping on one leg over an obstacle – the child was instructed to hop on one foot over a stack of foam squares. After a successful hop with each foot (cleared the square without touching it and continued to hop on the same foot at least two times), the height was increased by adding a square (50 cm × 20 cm × 5 cm). The child had three attempts at each height and with each foot; the height of the final successful jump was recorded.
4. Shifting platforms – the child began by standing with both feet on one platform (25 cm × 25 cm × 2 cm supported on four legs 3.7 cm high) and holding a second identical platform in his/her hands. The child was instructed to place the second platform alongside the first and to step on to it. The first box was then lifted and placed alongside the second and the child stepped on to it. The sequence continued for 20 s. Each successful transfer from one platform to the other was given two points (one for shifting the platform, the other for transferring the body). The number of points in 20 s was recorded. If the child fell off a platform in the process of transferring, he/she simply got back on to the platform and continued the test.

Each performance item was scored relative to gender- and age-specific reference values for the population upon which the KTK was established (Kiphard & Schilling, 1974). The sum of the standardised scores for the four items provides an overall motor quotient which was used as the indicator of MC.

The psychometric characteristics of the KTK have been documented (Kiphard & Schilling, 1974). The test–retest reliability coefficient for the raw score on the total test battery was 0.97, while corresponding coefficients for individual tests ranged from 0.80 to 0.96. Factor analysis of the four individual tests resulted in a single factor labelled gross MC. The percentage of total variance in MC explained by the four tests varied from 81% at 6 years to 98% at 9 years (Kiphard & Schilling, 1974). Intercorrelations among the four tests varied from 0.60 to 0.81 for the reference sample of 1228 children. Both the factor analysis and intercorrelations thus indicated acceptable construct validity. Validity was further determined through differentiation of normal from disabled children. The KTK test differentiated 91% of children with brain damage from normal children.

Physical fitness

Physical fitness was assessed with four items from the Fitnessgram test battery (Welk & Meredith, 2008): one mile run/walk (MRW), trunk lift (TL), push-ups (PU), and curl-ups (CU). Tests were administered at the schools in the following order with sufficient rest between items: TL, PU, CU and MRW. Although the Fitnessgram is a criterion referenced battery that emphasises scores within or outside of a "healthy fitness zone", the raw scores for each item were used in the present study. Validity of the Fitnessgram is extensively discussed in the reference guide (Welk & Meredith, 2008).

Data quality control

All measurements and tests were taken during a two month period in September and October of each year, thus reducing potential seasonal variation. Reliability of measurements and tests was estimated with intraclass correlations using the test–retest protocol. Estimated reliability was high for body dimensions (weight, height and skinfolds), 0.98 to 0.99; moderately high to high for individual fitness (0.72 to 0.99) and motor coordination (0.75 to 0.91) test items; and moderately high for estimated level of physical activity, 0.75.

Statistical analysis

Repeated measures ANOVA was used to compare boys and girls in body size, subcutaneous adiposity, PA, MC and individual PF items over time. Since repeated measures were nested within subjects, the longitudinal data set was treated as hierarchical.

Table I. Summary of models tested

Step	Model
1	Inclusion of quadratic and cubic effects of time: to test for non-linear changes over time.
2	Inclusion of sex as a level 2 predictor: to test for significant differences between boys and girls at the baseline.
3	Inclusion of MC, PF test items and PA as level 1 predictors: to test if these variables are significant predictors of SKF over time.
4	Inclusion of cross-level interactions between sex and time: to test if the rate of change was different between boys and girls.
5	Inclusion of the random effect of time: to test whether there are inter-individual differences in changes in SKF over time among subjects.

Two-level hierarchical linear models were tested with SKF as the dependent variable (Table I). In the first model, non-linear changes of SKF over time were tested. MC, PA and PF variables were tested as predictors of SKF in subsequent models. Both level 1 and level 2 predictors were retained in the models only if they had a significant effect. Maximum likelihood estimation was used with the HML5 statistical software (Raudenbush, Bryk, Cheong, & Congdon, 2001). A robust standard errors estimation analysis was used to control for the non-normality of several variables. The model retained was based on parsimony, using the Akaike Information Criterion (AIC) (Hox, 2002).

Results

Descriptive statistics for body height, body weight, SKF, MC, PA and PF at each observation are summarised in Table II. Boys are taller and heavier than girls, but girls have, on average, thicker SKF at each age. Boys show, on average, consistently higher levels of MC and PA and better performances on three of the four PF items compared to girls at each observation; the exception is TL in which girls perform better than boys. Scores on individual fitness tests and SKF increase, on average, with age, i.e. across observations in boys and girls. PA declines with age in both sexes, especially from observation 1 through 3. MC is, on average, similar across the four annual assessments in boys, and has non-significant increases from observations 1 through 3 but declines at observation 4 in girls.

The first hierarchical model (Table III) shows no significant linear effect of time on SKF between 6 and 10 years of age, but the quadratic and cubic effects are significant. By inference, SKF changes non-linearly over time. The curves have a cubic shape with a small initial acceleration followed by a dramatic increase and then a decrease in the rate of change (Figure 1). Boys and girls differ significantly in mean SKF at baseline (girls 19.7 mm, boys 16.6 mm). The interactions gender * time squared ($time^2$) and gender * time cubed ($time^3$) suggest that the rate of change in SKF is different between girls and boys. Girls show a greater increment in rate of subcutaneous adipose tissue accumulation (mm/year) until 8 years of age and then a decrease in rate to 10 years of age. On the other hand, boys have a slow but continuous increase in rate of subcutaneous adipose tissue accumulation to 9 years of age and then a decline in rate between 9 and 10 years of age (Figure 1).

Model 2 (Table III) highlights the significant sex difference in SKF; boys have, on average, thinner SKF than girls across the age range. Model 3 (Table

Table II. Means and standard deviations for age, body dimensions, sum of skinfolds, tests of physical fitness, physical activity and motor coordination at each observation

Observations		0 – baseline	1	2	3	4
Age (years)	Girls	5.9(0.3)	6.9(0.4)	7.9(0.4)	8.9(0.5)	9.8(1.0)
	Boys	5.9(0.3)	6.9(0.4)	7.9(0.4)	8.9(0.6)	9.7(1.5)
Height (cm)*†	Girls	117.5(5.4)	122.5(5.8)	128.1(6.2)	133.2(6.5)	139.4(7.2)
	Boys	119.0(5.1)	123.9(5.6)	129.6(5.9)	134.8(6.4)	139.8(6.6)
Weight (kg)*†	Girls	23.9(4.6)	26.1(5.6)	29.6(6.5)	33.4(7.8)	37.3(9.0)
	Boys	24.6(5.1)	26.8(6.1)	30.3(7.6)	34.4(9.0)	37.7(9.8)
BMI ($kg \cdot m^{-2}$)	Girls	17.2(2.4)	17.3(2.7)	17.9(2.9)	18.7(3.3)	19.1(3.5)
	Boys	17.3(2.5)	17.3(2.8)	17.9(3.2)	18.7(3.6)	19.1(3.7)
SKF (mm)*†	Girls	19.3(8.3)	20.4(9.6)	22.8(9.8)	24.8(11.4)	26.6(11.4)
	Boys	16.0(8.6)	16.4(8.1)	18.5(10.3)	20.7(11.6)	22.5(12.1)
MRW (min)*†	Girls	14.1(2.6)	14.6(3.4)	14.2(3.0)	13.8(2.4)	13.2(2.6)
	Boys	13.0(2.7)	13.8(4.0)	13.4(3.7)	12.4(2.9)	11.4(3.0)
CU (number)*†	Girls	11.7(14.9)	10.8(13.7)	18.9(20.8)	20.4(21.3)	16.9(17.5)
	Boys	13.1(18.8)	13.0(16.5)	24.7(32.5)	27.8(26.3)	18.7(14.7)
TL (cm)*†	Girls	26.8(6.7)	27.9(6.2)	31.2(5.6)	33.5(7.7)	33.4(7.7)
	Boys	26.6(8.2)	26.7(5.8)	29.4(5.5)	31.9(7.3)	32.3(6.9)
PU (number)*†	Girls	6.6(7.0)	8.6(7.3)	13.0(11.9)	10.1(8.8)	8.8(7.9)
	Boys	8.9(8.7)	10.5(8.7)	15.4(10.7)	15.9(13.0)	15.7(11.3)
PA ($METS \cdot week^{-1}$)*†	Girls	41.4(32.0)	36.0(22.2)	26.0(21.4)	33.4(20.1)	26.3(16.7)
	Boys	51.5(31.1)	44.2(25.1)	36.4(22.7)	48.3(23.8)	41.7(20.2)
MC (points)†	Girls	70.3(12.6)	75.0(13.4)	77.7(14.4)	71.3(16.8)	…‡
	Boys	82.1(12.2)	82.2(14.1)	80.6(14.5)	79.8(17.1)	…‡

BMI: body mass index; SKF: sum of skinfolds; MRW: one mile run/walk; CU: curl-up; TL: trunk lift; PU: push-up; PA: physical activity; MC: motor coordination.
*Significant changes over time.
†Significant gender difference at each observation.
‡Motor coordination was not tested at observation 4.

Table III. Summary of models 1, 2 and 3: Parameter specification, associated standard errors (SE) and confidence intervals for fixed effects

Parameter	Estimate(SE)	95% Confidence Interval
Model 1		
Intercept	17.64(0.60)	16.45 – 18.84
Time	0.002(0.58)	−1.15 – 1.15
Time^2	0.96(0.37)	0.22 – 1.70
Time^3	−0.13(0.06)	−0.25 – −0.01
Model 2		
Intercept	19.74(0.80)	18.15 – 21.33
Time^2	0.96(0.11)	0.74 – 1.18
Time^3	−0.13(0.02)	−0.18 – −0.07
Gender	−4.17(1.12)	−6.37 – −1.97
Model 3		
Intercept	18.70(0.74)	17.23 – 20.17
Time^2	1.59(0.22)	1.15 – 2.02
Time^3	−0.31(0.07)	−0.45 – −0.17
Gender	−3.21(1.02)	−5.23 – −1.19
MC	−0.05(0.01)	−0.08 – −0.02
MRW	0.13(0.05)	0.02 – 0.23
CU	−0.04(0.01)	−0.04 – −0.02
PU	−0.06(0.02)	−0.09 – −0.02
TL	0.03(0.02)	−0.02 – 0.07
PA	0.004(0.005)	−0.006 – 0.014

MRW: one mile run/walk; CU: curl-up; TL: trunk lift; PU: push-up; PA: physical activity; MC: motor coordination; time^2: time squared; time^3: time cubed.

III) includes MC, the four PF items and PA as predictors of SKF. Three fitness items, MRW, PU and CU, are significant predictors of SKF, while PA and TL are not. Model 4 indicates a significant effect for the gender * time interactions (cubic and quadratic). The interactions suggest a gender dependent rate of change in subcutaneous adiposity. Model 5 shows no significant random effect of time. Hence, model 4 was retained and is summarised in Table IV. Three physical fitness items: CU, PU and

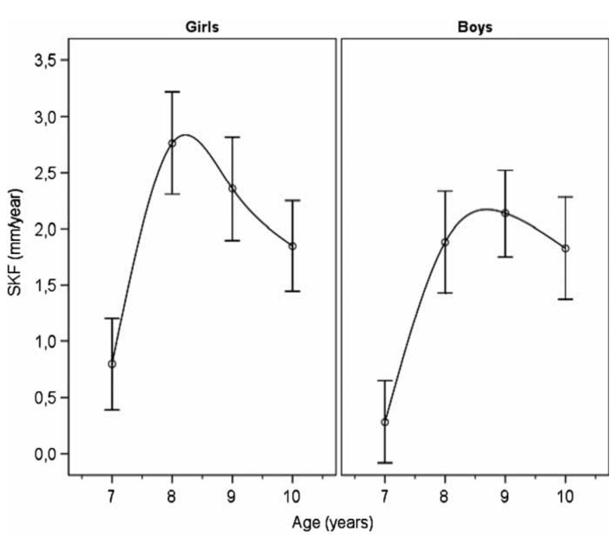

Figure 1. Changes in SKF (means and standard errors) with age in boys and girls.

Table IV. Parameter specification for the final model, associated standard errors (SE) and confidence intervals

Parameter	Estimate(SE)	95% Confidence Interval
Fixed effect		
Intercept	19.72(0.51)	18.72 – 20.72
Gender	−3.11(1.03)	−5.13 – −1.09
Time squared	1.58(0.17)	1.25 – 1.91
Time cubed	−0.30(0.05)	−0.39 – −0.20
MC	−0.06(0.02)	−0.09 – −0.02
CU	−0.04(0.01)	−0.06 – −0.02
PU	−0.06(0.02)	−0.09 – −0.02
MRW	0.12(0.05)	0.02 – 0.22
Time^2*Gender	−1.20(0.32)	−1.83 – −0.57
Time^3*Gender	0.38(0.09)	0.20 – 0.56
Random effects	**variance**	
SKF (Baseline)	70.09†	
Level 1 error	11.43	

MRW: one mile run/walk; CU: curl-up; PU: push up; MC: motor coordination; time^2: time squared; time^3: time cubed.
†Significant at $P < 0.001$.

MRW and MC have a positive and significant influence on SKF. For each unit change (improvement) over time in CU, PU, MRW and MC, SKF declines by 0.04, 0.06, 0.12 and 0.06 mm, respectively (Table III).

Discussion

Motor coordination (MC), four tests of physical fitness (PF) and physical activity (PA) were evaluated as predictors of change in subcutaneous adiposity (sum of two skinfolds) with hierarchical linear modelling in a sample of Portuguese children followed longitudinally from 6 to 10 years of age. The retained model showed higher adiposity in girls than boys at the baseline (6 years of age) and at all observations between 6 and 10 years of age.

MC and three components of PF (PU and CU-muscular strength and endurance, and MRW-aerobic endurance) were significant predictors of changes of subcutaneous adiposity between 6 and 10 years of age. The increase in subcutaneous adiposity between 6 and 10 years of age was less in children who were more physically fit and had better MC. The results thus suggested a role for physical fitness and motor skill as modulators of changes in subcutaneous fatness at the time of the adiposity rebound.

The rate of change in SKF increased rather markedly among the Azorean children between 6 and 7 years of age and continued to increase through 9 years of age; subsequently, the rate of change decreased to 10 years of age. The estimated rate of change was significantly higher in girls compared to boys, which was generally consistent with the literature on changes in subcutaneous fatness during childhood (Malina et al., 2004) and with the concept of adiposity rebound (Rolland-Cachera et al., 1984; Taylor, Goulding, Lewis-Barned, & Williams, 2004; Williams, 2005). The BMI declines in early childhood and begins to increase at about 6 years of age; the increase in the BMI at this time was labelled as the adiposity rebound (Rolland-Cachera et al., 1984). It has been postulated that the increase in BMI during the adiposity rebound is associated with an increase in subcutaneous and total body fat mass. The increase in the BMI and SKF in Azorean children between 6 and 8 years of age were thus consistent with the adiposity rebound.

Although it is generally assumed that PA has a significant role in energy expenditure and in turn adiposity among children, results of the hierarchical linear modelling suggested that MC and PF together were better predictors of changes in subcutaneous adiposity in this sample of Azorean children during middle childhood than was PA. It was possible that PF and MC and their interactions with PA masked potential effects of PA per se on subcutaneous adiposity. On the other hand, it is possible that the measure of PA was not sufficiently specific and sensitive to changes in subcutaneous adiposity during childhood. Direct and objective measures of PA were, unfortunately, not available for the study. Nevertheless, similar results to the Azorean study were noted in a longitudinal study of Italian children in which questionnaire-based PA was not related to changes in the BMI between 8 and 10 years of age (Maffeis, Talamini, & Tatò, 1998).

Although the present study did not include a specific PA intervention, evidence suggests that enhanced PA programs have a minimal effect on direct and indirect indicators of adiposity in normal weight children but contribute significantly to a reduction in several measures of adiposity in obese youth (Gutin, 2010; Strong et al., 2005). It is possible that children with body weights in the "normal" range may require a greater volume and intensity of PA to bring about changes in adiposity (Strong et al., 2005). It is also possible that physical inactivity is a more significant predictor of becoming overweight and obesity in youth in contrast to PA (Gordon-Larsen, Adair, & Popkin, 2002).

Reference data for the growth and weight status of Portuguese children are lacking. Nevertheless, approximately 30% of the Azorean sample of children 6–10 years of age were overweight or obese according to the International Obesity Task Force cut-off values for the BMI (Cole, Bellizzi, Flegal, & Dietz, 2000). The percentage was consistent with that for Portuguese children 7–9 years of age, 31% (Padez, Fernandes, Mourão, Moreira, & Rosado, 2004).

The present study utilised the sum of two skinfolds as the indicator of subcutaneous adipose tissue. Although skinfold thicknesses have several limitations, they provide an estimate of subcutaneous adiposity that is correlated with other more direct estimates of adipose tissue mass (Malina et al., 2004). Relationships between skinfold thicknesses and body fatness vary during growth, but this should be tempered with variation among estimates of body fatness, e.g., densitometry, total body water, bioelectrical impedance, dual-energy X-ray absorptiometry (DXA), etc. (Malina, 2005; Malina et al., 2004; Malina & Geithner, 2011). Nevertheless, skinfolds have traditionally been used and continue to be used as an indicator of subcutaneous adiposity in children. Some evidence suggests that skinfold thicknesses during childhood are a better predictor of elevated fatness during adulthood than other proxy measures including the BMI (Nooyens et al., 2007). The use of skinfolds has disadvantages, including intra- and inter-observer measurement variation. In the present study, a single individual made the measurements at each observation point and reliabilities of measurements were high. In addition, data for adults suggest that skinfolds tend to overestimate adipose tissue mass in lean and underestimate adipose tissue mass in obese individuals (Fogelholm, Sievänen, van Marken Lichtenbelt, & Westerterp, 1997; Peterson, Czerwinski, & Siervogel, 2003).

Allowing for limitations, results of the present study suggest a potentially important role for proficiency in motor skills (MC) and components of PF (muscular strength and endurance, and aerobic endurance), in contrast to PA, in mediating the increase in subcutaneous adipose tissue in boys and girls during middle childhood. The results also highlight a potentially important role for preschool and early elementary school physical education programmes in the development and improvement of MC and PF in children, which in turn may influence subcutaneous adiposity.

Physical activity is a complex behaviour that is influenced by a variety of factors (Horst, Paw, Twisk, & Mechelen, 2007; Sallis, Prochaska, & Taylor, 2000). Unfortunately, indicators of PF and MC have not been systematically included in studies that consider correlates of PA. MC is related to PA in several recent studies of children, but relationships tend to be moderate (Fisher et al., 2005; Lopes, Rodrigues, Maia, & Malina, 2010; Okely, Booth, & Patterson, 2001; Williams et al., 2008; Wrotniak et al., 2006). It is possible that PA may be an outcome of MC and PF in children, whereby adequate levels of MC and PF contribute directly to enjoyable and successful participation in PA, and in turn promote further engagement and persistence in physical activities. Limited PF and MC, on the other hand, may serve as constraints to PA.

Acknowledgements

The data of the present study are part of a larger study funded by the Department of Physical Educational and Sports and the Department of Science and Technology of Autonomic Government of Azores Region (*Direcção Regional de Educação Física e Desporto e Direcção Regional da Ciência e Tecnologia da Região Autónoma dos Açores*), Portugal.

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