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Temporal trends in muscular fitness of English 10-year-olds 1998-2014 an allometric approach

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Objectives: To identify temporal trends in muscular fitness of English children using allometric scaling for height and weight to adjust for the influence of body size.

Design: Repeated cross-sectional study.

Methods: We measured; height, weight, standing broad-jump, handgrip, sit-ups and bent-arm hang in 10-year-old boys and girls from Chelmsford, England in: 2014 (n=306), 2008 (n=304) and 1998 (n=310). Physical activity was (PAQ-C) was assessed in 2008 and 2014. Muscular fitness was allometrically scaled for height and weight. We assessed temporal trends using General Linear Models (fixed factors: wave and sex) and reported effect sizes using partial eta squared (η_P^2). We compared percentage change per year 1998-2008 with 2008-2014.

Results: Ten-year-olds in 2014 were taller and heavier than in 2008 and 1998 but there were no differences in BMI. Compared with 2008, physical activity was lower in boys (ηP2=0.012) and girls (η_P^2=0.27) assessed in 2014. There were significant main effects of wave for handgrip (ηP2=0.060), sit-ups (η_P^2=0.120) and bent-arm hang (η_P^2=0.204). Pairwise comparisons showed muscular fitness of both sexes was significantly lower in 2014 than in 1998. From 2008 to 2014 percent change per year in handgrip (1.6%) and sit-ups (3.9%) were greater than for the preceding decade (handgrip 0.6%, sit-ups 2.6%).

Conclusions: Downward temporal trends in muscular fitness appear independent of secular changes in body size. We found a decrease in self-reported physical activity concurrent with the accelerated declines in fitness from 2008 to 2014. These findings suggest the declines in children are not engaging in physical activities which support development of muscular fitness.

KEYWORDS: Epidemiology; Physical Fitness; Muscular Strength; Anthropometry

Introduction

In youth, muscular fitness is assessed by measuring performance in tests of muscular strength, power and strength-endurance. In children and adolescents, muscular strength is associated with cardiometabolic health independent of weight status[1-4] and aerobic capacity[3]. As lower muscular fitness in childhood is associated with increased risk of developing several non-communicable diseases in adulthood[1, 5] it has been proposed that monitoring temporal trends in muscular fitness could can support the development of health-promotion strategies[6].

Given the association of poor muscular fitness with negative health outcomes, the recent temporal declines in muscular fitness of Lithuanian[7], Spanish[8], Portuguese[9], Canadian[10] and English[11] youth are of concern. In contrast, the muscular fitness of Belgian[6] Dutch[12] and Finnish[13] youth appears more stable. Temporal studies of muscular fitness have not, however, accounted for secular increases in height and weight also reported in these countries[13]. As height and weight are known to influence performance on physical fitness tests[14] it is important to normalize measures of fitness for body size to avoid potentially confounding effects[15, 16] and better understand temporal trends.

Muscular fitness is assessed by physical test performance which can be adjusted for body size allometrically using a multiplicative model with derived allometric exponents for weight and height[14-18]. Allometric scaling partitions out the influence of body size on of physical performance measures and has been used to compare fitness between groups that differ in body size[16, 19, 20] but has not been used widely in the monitoring of temporal fitness trends[10].

Our first aim was to provide an update on temporal trends in muscular fitness of English children over the six years from 2008 to 2014[11]. Our second aim was to determine whether temporal trends in muscular fitness (1998 to 2014) were independent of changes in body size using allometric scaling for height and weight. We also examined whether trends varied between boys and girls and compared rates of muscular fitness changes from 2008-2014 with those of the preceding decade (1998-2008).

Methods and Materials

The study used data from previous waves (1998 and 2008) of the Chelmsford Children's Fitness and Activity Survey both of which were approved by the ethical review committee at the University of Essex. Ethical approval for the 2014 wave was provided by ethical review board of Writtle College, Chelmsford. Descriptions of recruitment and sample characteristics published previously show the population of Chelmsford is predominantly white British (93%) and the area is within the lowest quintile for deprivation nationally. For the 2014 wave, we purposefully recruited schools in the borough of Chelmsford, Essex to obtain a sample of *n*=309 10-year-olds which was comparable with the populations tested in previous waves[21].

All protocols were explained in letters to parents who were required to provide proxy consent for child's participation. Measurements were then made during scheduled PE classes at the school. The response rates in 1998, 2008 and 2014 were 96%, 95% and 93% respectively.

We made duplicate measures of mass (Seca Scales Model 708, Seca Ltd., Hamburg, Germany) and stature (Seca Portable Stadiometer, Model 778, Seca Ltd., Hamburg, Germany) to the nearest 0.1 kg and 0.1 cm, respectively. Germany). Participants wore sports clothing (shorts and T-shirt) but no shoes. We calculated BMI (kg/m^2) as an index of adiposity and body surface area as an index of overall body size using the formula BSA (m^2) = $height[cm]^{0.5}$ x weight[kg]/3600.

All muscular fitness tests were performed in accordance with standardized protocols in a random order by small groups of children with a 5:1 participant to researcher ratio. At each station, trained researchers demonstrated the test protocol to the group, individuals then practiced the movements before completing the pre-determined number of trials on each test.

Muscular strength was measured as maximum isometric handgrip (Takei 5001 Analogue Dynamometer, Takei Corp Ltd., Tokyo, Japan). Handgrip strength is a reliable measure providing a useful index of upper body strength and an independent predictor of metabolic risk[11 1-4]. After adjustment for participant hand size participants completed three attempts using the dominant hand and the highest value was recorded.

Standing Broad Jump (SBJ) is a reliable[22] indicator of lower body explosive power associated with metabolic risk-score in childhood and adolescence[3]. Participants stood with toes behind the jump-line and were instructed to jump as far as possible using a two footed take-off and landing. SBJ was recorded as the greatest distance jumped from three trials using the correct technique.

Measures of strength-endurance are associated with metabolic risk in adults[23] and children as a component of composite fitness scores[3]. Upper body strength-endurance was assessed using the bent-arm hang test which requires children to support their own body weight using their arms by hanging from gymnasium wall with arms bent to 90^0 holding their chin above the bar. Performance was measured as duration (s) of hang-time from a single trial.[22, 24] Strength-endurance of the trunk and hip-flexor muscles was assess as the number of Sit-Ups performed in 30 s. Participants laid supine with arms across the chest and knees bent to 90^0 with feet anchored. The correct technique was demonstrated and practiced prior to assessment. Performance was expressed as the number of complete sit-ups corrected in 30 s from one trial.

Physical activity was assessed using and Anglicized version of the Physical Activity Questionnaire for Older Children (PAQ-C)[25]. This 7-day recall instrument provides an estimate of overall physical activity during the past week as a score from 1 (lowest) through 5 (highest)[25]. Participant's home postcode was used to assess area level deprivation using the English Index of Deprivation (EID). The EID combines 37 separately-weighted indicators of deprivation to create a single numerical indicator of deprivation.

Allometric scaling was performed using the approach described by Neville *et al.*[15] using a multiplicative model including allometric exponents for derived from the data set by taking the natural logarithms of height, weight and all muscular fitness measures. To account zero-values in the bent-arm hang test, 1 was added to all values prior to transformation.

The allometric equation Y = a · weight^{k1}· height^{k2} (where Y is muscular fitness) was linearized to Ln(Y) = a · [Ln(weight) · k^1] + [Ln(height) · k^2]. The unknown scaling exponents (k^1 and k^2) were calculated by for each outcome measure by calculating the parameter estimates for Ln(weight) and Ln(height) using general linear model. Each model included muscular fitness as the dependent variable (Ln([Y]), round and sex as fixed factors with Ln(height) and Ln(weight) included as covariates. The height and weight exponents and standard error (se) for each outcome are shown in Equations 1·5 where '*a*' is allowed to vary by round and sex to provide an estimate for each fixed effect in the general linear model.

To examine differences between waves by sex we reported the main effect for wave and the wave-by-sex interaction effect and partial eta squared (η_P^2) to denote small (η_P^2>0.01), medium (η_P^2>0.06) and large (η_P^2>0.14) effect sizes.[26] To compare six- and ten-year temporal trends we calculated the percentage change per year in each measure overall and in boys and girls separately (Figure 1).

Results

Boys and girls assessed in 2014 were taller and heavier than in 2008 and 1998 (Table 1). Between-wave analysis of BSA showed a small main effect in boys (η_P^2=0.051) and a medium effect in girls (η_P^2=0.071). Main effects for BMI were trivial and there were no meaningful pairwise differences in in BMI or RPI. There were small main effects of wave (2008-2014) for PAQ-C scores in girls (η_P^2=0.012) and boys (η_P^2=0.027).

Equation 1. $SBJ\ (cm)\ a \cdot weight^{-0.31(0.03)} \cdot height^{0.91(0.05)}$

Equation 2. $Handgrip\ (kg)\ a \cdot weight^{0.30(0.05)} \cdot height^{1.12(0.22)}$

The multiplicative model for SBJ is shown in equation 1. The main effect for wave was statistically significant but of a small magnitude small (η_P^2=.020) and no significant (wave-by-sex) interaction effect. Pairwise comparisons showed 2014 children had lower SBJ values than in 1998.

Equation 2 shows the multiplicative model for handgrip. There were significant main effect of wave of medium magnitude (η_P^2=.060) and a small wave-by-sex interaction effect (η_P^2=0.020). Pairwise comparisons showed significant differences in boys' handgrip between all waves and lower handgrip in 2014 girls compared with 2008 and 1998.

Equation 3. $$Sit-ups\ in\ 30\ s\ \ (n) = \text{weight}^{-0.35\ (0.08)} \cdot \text{height}^{0.77\ (0.34)}$$

Equation 4. $$Bent-arm\ hang\ (s) = \text{weight}^{-2.06\ (0.19)} \cdot \text{height}^{1.27\ (0.85)}$$

Equations 3 and 4 show the multiplicative models associated with sit-ups and bent-arm hang. There was a large main effect of wave for sit-ups (η_P^2=0.120) and a small sex –by-wave interaction effect ($\eta_P^2=0$.023). Pairwise comparisons showed significant differences in sit-ups performance between all three waves in boys and girls. We also found a large main effect of wave (η_P^2=.204) but no significant interaction effect. Pairwise comparisons showed bent-arm hang scores of boys and girls were significantly different between all three waves.

Figure 1 shows temporal trends in muscular fitness expressed as percentage change per year. In boys, handgrip decreased more quickly after 2008 whereas decreases in bent-arm hang were less steep. There was an increased rate of decline in sit-ups performance in both sexes as well as a steepening in the downward trend in girls' bent-arm hang.

Discussion

This aims of this study were to provide an update on the temporal trends in muscular fitness of English children. We also aimed to determine if these trends and those reported since 1998 were independent of changes in children's height and weight.

These data show secular increases in the height and weight of ten-year-olds from this area of England. The magnitudes of these secular increases were broadly comparable in magnitude to those reported in other European children over the past two decades[7, 9]. The combination of increases in both measures provide evidence for an overall increase in body size for children of this age which is evident from the greater body surface area of boys and girls assessed in 2014. Trends in BMI from 2008-2014, as those reported for the preceding decade (1998-2008) suggest little change in adiposity within cohorts of 10-year-olds from this affluent area[11]. In contrast, temporal trends indicate that aerobic fitness has continued to decline over the six-year period [21]

We found a modest downward trend in SBJ, which is in agreement with findings reported for Spanish[8] and Lithuanian[7] but contrary to studies a number of studies showing no change[6 13] or temporal increases[9 27] in jump performance. The discrepancy in findings may be explained by varying approaches used to account for the secular increases in body size, particularly increases in height, often reported.[9 27]

The positive exponent for height in the multiplicative model for SBJ illustrates the positive influence of height on SBJ performance. Opposing signs for height and weight exponents in this ratio means our model approximates the Reciprocal Ponderal index (RPI = height · weight$^{-0.333}$) as commonly reported for SBJ[15 19 29].

Opposing signs for weight and height exponents in multiplicative models associated with sit-ups and bent-arm hang have been reported previously. Like SBJ, the models for sit-ups and bent-arm hang predict that taller, leaner children (lower weight:height ratio) should perform better on all of these tests of muscular fitness. The similarity in BMI and RPI values across all waves suggest changes in test performance are unlikely caused by differences in height and weight. Declines in bent-arm hang have been attributed to secular increases in body weight[12] but the present trends remained significant when adjusting for body-size. These findings suggest the influence of alternative factors, such as muscle mass, metabolic capacity or neural drive. Declines in sit-ups test performance have been reported previously[7, 8, 11] as have downward temporal trends in bent-arm hang[8 12]. Contrary trends in sit-ups performance have been reported in Greek[28] and Portuguese[9] children but, to our knowledge, no studies have reported improvements in bent-arm hang.

The positive height and weight exponents identified for handgrip agree with previous findings[14, 16 18] illustrating the positive association between overall body size and handgrip strength[14]. Comparable declines in handgrip of Canadian children[10] and Spanish adolescents[29] despite increases in body mass. Such trends are of concern as low handgrip strength relative to weight is associated with higher metabolic risk scores in children[3, 30]

The percentage change each year for all measures (Figure 1) show temporal declines are greater in measures of strength-endurance (sit-ups, bent-arm hang) than in other measures, similar to findings reported in Dutch children.[12] The cause of these accentuated declines in strength-endurance is not clear, although we have previously suggested that a reduced willingness to tolerate the discomfort associated with these performance of these tests may be a contributory factor. Greater strength-endurance than maximum strength (handgrip) declines would suggest reduced local muscular fatigue resistance related to local metabolic capacity, in addition to neuromuscular or muscle mass related trends – the determinants of maximum strength. Nonetheless, given the association of both aspects of muscular fitness with markers of metabolic health these trends in muscular strength and endurance are of concern from a public health perspective, particularly as declines in performance on the majority of tests appear to be accelerating with larger decreases between 2008 and 2014 than in the preceding decade in three out of four measures (Figure 1). While accelerated downward trends in fitness were reported for Lithuanian youth, these are the first evidence of such trends in English children.

Given that the trends in muscular fitness reported here were shown to be independent of changes body size it seems likely that they are due to changes in children's physical activity habits. The difference in overall physical activity between 2008 and 2014 was of a small, but meaningful magnitude, despite the limited sensitivity of self-reported measures. Adjusting muscular fitness for PAQ-score may have indicated whether differences in muscular fitness are attributable to changes in physical activity but data were not available for 1998. However, trends in the exposure to specific types of PA which stimulate the development of muscular fitness may differ from that of overall PA. Self-report tools to quantify these type of activities should be considered, as secular trends in aerobic and muscular fitness in youth have been shown to diverge[17].

Like all serial cross-sectional comparison study designs, we cannot account for potential between-cohort variation, so cannot discount the possibility that the differences observed may be due to such variation. We assessed clustering by school but there was some variation which schools participated in each wave of data collection. This may have created additional variation in between waves. Height and weight are two indices of body size but additional information regarding adiposity and fat free mass could improve scaling. Similarly, we did not adjust for pubertal status which is also known to influence children's muscular fitness.

Conclusion

Our goal was to provide an update on the temporal trends in muscular fitness and use allometric scaling to adjust for body size as a potential confounder. These data provide further evidence of declining muscular fitness in 10-year-olds of both sexes which are independent of body size and which appear to be accelerating in the last decade. A concurrent fall in self-reported physical activity suggests that these trends in muscular fitness may be related to declining levels of overall habitual physical activity in this age group.

Practical Applications

- Routine measurement of components of muscular fitness could be valuable addition to health surveillance in children
- Measures used to monitor temporal trends in children's muscular fitness should account for secular differences in body size

- Allometric scaling is a useful method by which to adjust muscular fitness for body size
- Children's muscular fitness has continued to decline from 2008 to 2014 independent of secular changes in height and weight
- Poorer muscular fitness is likely to be related lower physical activity levels in 2014 relative to children 16 years ago

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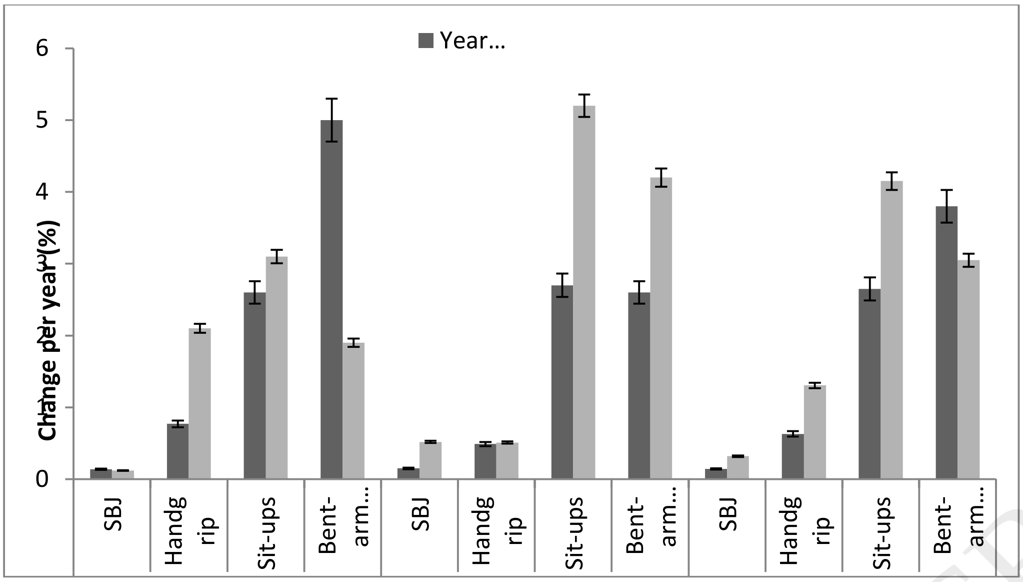

Figure 1 Percent change per year in four indices of muscular fitness in ten-year old boys and girls living in Chelmsford, England: 1998-2008 versus 2008-2014.

Table 1. characteristics and anthropometric measures for English schoolchildren in 1998, 2008 and 2014

	Boys 1998	Boys 2008	Boys 2014	ANOVA Main Effect	Girls 1998	Girls 2008	Girls 2014	ANOVA Main Effect
Schools	n=6	n=5	n=5		n=6	n=5	n=5	
Participants	n=16	n=15	n=157		n=146	n=150	n=149	
Age (years)	10.4	10.4	10.6		10.4	10.4	10.6	
	(0.39)	(0.38)	(0.43)		(0.38)	(0.38)	(0.42)	
EID	*-NA-*	9.8	9.1		*-NA-*	8.1	7.9	
		(6.4)	(8.9)			(6.2)	(6.6)	
Height (cm)	142.1	142.6	146.1[a]	*F*=13.9 *p*<0.001 η_P^2=0.055	142.4	142.9	146.2	*F*=15.4 *p*<0.001 η_P^2=0.063
	(8.1)	(7.8)	(7.3)		(8.7)	(7.0)	(6.8)	
Weight (kg)	35.7	36.8[a]	38.9[a,b]	*F*=8.1, *p*<0.001 η_P^2=0.033	36.7	37.6	39.1	*F*=11.6, *p*<0.001 η_P^2=0.049
	(7.6)	(8.9)	(7.8)		(8.4)	(7.0)	7.1)	
BMI (kg·m²)	17.8	18.2	17.9	*F*=1.4, *p*=0.778 η_P^2=0.006	18.5	18.2	18.6	*F*=0.3, *p*=0.379 η_P^2=0.004
	(3.6)	(3.5)	(3.1)		(3.0)	2.9)	(3.1)	
BSA	1.42	1.46	1.58	*F*=12.9 *p*<0.001 η_P^2=0.051	1.45	1.49	1.58	*F*=17.6, *p*<0.001 η_P^2=0.071
	(0.21)	(0.21)	0.23)		(0.22)	(0.21)	(0.24)	
RPI (cm· kg$^{-.333}$)	43.4	43.1	43.3	*F*=1.9 *p*<0.312 η_P^2=0.007	42.6	42.9	42.7	*F*=0.5, *p*=0.919 η_P^2=0.001
	(6.9)	(7.0)	(8.2)		(6.4)	(6.1)	(7.9)	
Physical Activity PAQ-C (1-5)	*-NA-*	3.12	2.77[b]	*F*=3.9 *p*=0.002 η_P^2=0.012	*-NA-*	3.02	2.65 [b]	*F*=4.8 *p*=0.001 η_P^2=0.027
		(0.77)	(0.72)			(0.77	(0.67)	

Legend: All values are shown as unadjusted means and standard deviations (SD). EID – English indices of deprivation obtained from postcode data of UK Office for National Statistics (2007). PAQ-C Physical Activity Questionnaire for Children (Anglicized version). BMI – body mass index, BSA – body surface area calculated at $(cm·kg/3600)^{0.5}$
RPI – Reciprocal Ponderal Index calculated as height(cm) · weight (kg)$^{-.333}$
***-NA-* Not Applicable: English Indices of Deprivation not available before 2007; *-NA-* PAQ-C data not collected in Wave 1 (1998).**

Table 2.Estimated marginal means (95%CI) of muscular fitness for English 10-year-olds assessed in: 1998, 2008 and 2014.

		Wave 1 (1998)	Wave 2 (2008)	Wave 3 (2014)	Mean Difference (95%CI)	Mean Difference (95%CI)	Main Effect (Wave)	Interaction (Wave-by Sex)
Standing broad-jump (cm)	***Boys***	137 (136,138)	135 (134,140)	134 [a] (132,135)	2.1 (-0.3,3.2)	0.8 (-1.1,0.9)	F=8.9, p<0.001 η_P^2=0.021	F=0.1, p=0.881 η_P^2=0.00
	Girls	130 (129,132)	128 (126,130)	124 [a] (122,128)	1.9 (-0.7,3.2)	3.8 (3.1,4.6)		
Handgrip (kg)	***Boys***	18.5 (17.9,19.1)	17.2 [a] (17.9,19.7)	13.3 [a,b] (12.9,13.5)	1.3 (0.9,2.0)	2.2 (1.9,2.4)	F=23.4, p<0.001 η_P^2=0.060	F=4.8, p=0.001 η_P^2=0.020
	Girls	16.8 (16.5,17.2)	15.9 (15.4,16.2)	15.1 [a,b] (14.8,15.3)	0.9 (0.2,1.5)	0.8 (0.1,1.4)		
Sit-ups (n)*	***Boys***	26.3 (25.9,26.8)	19.2 [a] (18.9,19.5)	15.4 [a,b] (15.0,16.1)	7.1 (5.3,9.2)	3.8 (3.5,4.2)	F=33.7 p<0.001 η_P^2=0.120	F=10.1, p<0.001 η_P^2=0.022
	Girls	23.9 (23.2,24.3)	17.6 [a] (17.1,17.9)	10.7 [a,b] (10.5,10.9)	6.3 (5.1,9.0)	7.1 (6.5,7.8)		
Ben-arm hang (s)	***Boys***	21.8 (20.9,22.3)	10.2 [a] (9.6,11.0)	8.3 [a,b] (7.6,9.0)	10.6 (8.7,13.5)	1.9 (0.3,3.1)	F=38.1, p<0.001 η_P^2=0.204	F=0.9, p=0.988 η_P^2=0.000
	Girls	17.8 (17.1,19.0)	13.2 [a] (12.5,13.7)	9.8 [a,b] (9.5,10.2)	5.6 (2.1, 8.4)	3.4 (2.6,4.0)		

Legend: Values shown are anti-logs of estimated marginal means (95%CI) from ANCOVA adjusted for ln(weight) and ln(height)

[a] Significantly different to 1998 values; [b] significantly different to 2008 (Bonferroni pairwise comparison) *Values are estimated marginal means from a mixed linear including school as a random factor to adjust for clustering.