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BRIEF REPORTS

Tracking of Cardiorespiratory Fitness from Childhood to Mid-adulthood

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High cardiorespiratory fitness (CRF) in adulthood is important for survival from major chronic diseases and preserving good health. We examined how childhood CRF tracks, or persists, into adulthood. Among a cohort of 748 school children followed over 34 years, we found child CRF correlated with young- (r = 0.30) and mid-adulthood (r = 0.16) CRF. *(J Pediatr 2024;264:113778).*

Cardiorespiratory fitness (CRF) is a physical fitness component representing the body's ability to supply oxygen to skeletal muscle for physical work.[1] Higher CRF levels are associated with broad health benefits in adulthood, including increased survival and reduced chronic disease risk.[2,3] Indeed, CRF is an important risk factor for cardiovascular disease that remains an independent and additive marker of risk over traditional risk factors.[2] As such, physical activity and exercise training interventions are targeted to adults to help raise or maintain adequate CRF levels.[4] Because CRF clusters within families,[5] early life might provide an important window in the development of CRF,[3] such that prevention and intervention programs aimed at raising CRF levels in childhood might have the benefit of persistently high CRF (or tracking) and improving associated health outcomes[6] across the life course. However, studies of CRF tracking from childhood to adulthood have been limited by small sample sizes,[7] short follow-up durations,[8-10] different measurement methods at baseline and follow-up,[7,8,10,11] and the availability of measurements from only two time-points.[7,11] We aimed to address these gaps by determining the tracking of CRF from childhood to young- and mid-adulthood using data collected from a prospective cohort over 34 years.

Methods

Participants

In 1985, 8498 children and adolescents aged 7-15 years participated in the Australian Schools Health and Fitness Survey (ASHFS). The ASHFS used a two-stage probability sampling frame (school, then individual) achieving a nationally representative sample of primary and secondary school children across Australia.[12] Due to time and economic constraints, all participants that were aged 9, 12, or 15 years had additional technical measurements, including a submaximal graded exercise test. Students of these ages were selected to approximate prepubertal, pubertal, and postpubertal growth stages and formed a subset of n = 2626. Although not originally intended as a cohort study, participants in ASHFS were traced and enrolled into the Childhood Determinants of Adult Health Study and subsequently invited to attend clinics held across Australia when they were adults (young adulthood–data collection from 2004 to 2006 when aged 27-36 years; and mid-adulthood–data collection from 2014 to 2019 when aged 37-49 years). Participants in the adult follow-ups undertook a similar suite of measures that were collected from them as children, including a submaximal graded exercise test. The sample of participants included in this analysis (n = 748) were those aged 9, 12, or 15 years who had their CRF levels estimated from the submaximal graded exercise tests performed in ASHFS and at least 1 adult time-point, 32.5% (n = 243) of participants had their CRF estimated at all three time-points. **Figure 1**, Online; available at www.jpeds.com) provides a flowchart of participation. The ASHFS was approved by the State Directors General of Education with participant consent obtained from a parent and assent obtained from the child. The Southern Tasmania Health and Medical Human Research Ethics Committee and the Tasmania Health and Medical Human Research Ethics Committee approved the adult follow-up studies, when participants gave written informed consent.

ASHFS	Australian Schools Health and Fitness Survey
CI	Confidence intervals
CRF	Cardiorespiratory fitness
PWC170	Physical working capacity at a heart rate of 170 beats per minute

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CRF and Anthropometric Measures

CRF in childhood, young, and mid-adulthood was estimated using a submaximal graded exercise test–physical working capacity at a heart rate of 170 beats per minute (PWC170). The PWC170 test is a widely used method of estimating CRF with reasonable criterion validity and test-retest reliability.[13-16] The test was performed using Monark bicycle ergometers (Monark Exercise AB) in childhood (model 818E), young adulthood (model 828E), and mid-adulthood (model 928G3r). At each time-point, participants pedaled at a cadence of 60 revolutions per minute. The test included successive workloads that increased resistance stepwise. Three 3-minute workloads were used in childhood and three 4-minute workloads were used at each adult follow-up. In the final minute of each workload, a research technician recorded the workload setting and the participant's heart rate. In childhood, heart rate was measured using a stethoscope and a stopwatch. Polar heart rate monitors (Polar Electro Oy) were used in young adulthood (model A5) and mid-adulthood (model RS300X). For each participant, heart rate was regressed on workload and extrapolated (or interpolated if final heart rate was >170 beats per minute) to estimate workload in watts at heart rate of 170 beats per minute (PWC170). As the absolute workload achieved in the PWC170 test is a function of muscle mass, measures of PWC170 not attributable to lean body mass were created by regressing PWC170 on lean body mass (methods outlined below) and using the residuals added to the grand mean.[17]

Body mass was measured using regularly calibrated bathroom scales to the closest 0.5 kg in childhood and with Heine scales (Heine) to the closest 0.1 kg in adulthood. Height was measured to the closest 0.1 cm employing a KaWe height tape (KaWe Krichner & Wilhelm, Aspeg, Germany) in childhood and a Leicester height measure (Invicta, Leicester, UK) in adulthood. Body mass index was computed as body mass (kg)/[height (m)]^2. Skinfolds at four sites (biceps, triceps, subscapular, and supra-iliac) were assessed in childhood to the nearest 0.2 mm with Holtain skinfold callipers (Holtain), and in adulthood to the nearest 1 mm with Slim Guide callipers. Body density was calculated from the log of the sum of four skinfolds using age-specific regression equations.[18-20] Body fat was determined from body density[21] and lean body mass was approximated as the difference between total body mass and fat mass.

Statistical Analysis

Statistical analyses were made using Stata 17.0 (StataCorp). Participant characteristics are presented as mean and SD stratified by sex. CRF in this study was represented by age- and sex-standardised PWC170 adjusted for lean body mass.

Two different statistical approaches were used to quantify the tracking of CRF from childhood to adulthood. Firstly, rank correlations were quantified between CRF measured in childhood and young or mid-adulthood–a common technique used to assess tracking between two time-points. Secondly, generalized estimating equations were used to estimate tracking as *stability coefficients*, described previously by Twisk and colleagues.[22] This approach allows childhood CRF to be regressed on the change of CRF from the first adult follow-up to the last, with the coefficients at different time points tested simultaneously. The stability coefficients are comparable to the average value of rank correlations between child CRF and each adulthood CRF.[23] Strengths of this approach are that all measurements are considered in the tracking estimate and it is robust to unequal time between follow-ups, as is the case for participants in this study. The stability coefficient ranges between 0 and 1 if the correlations between the measurements is positive (as is assumed in tracking analyses),[22] with a coefficient closer to 1 representing stronger stability.[22] Each model (rank correlation or stability coefficient) was adjusted for duration of follow-up as the young-adult follow-up occurred across a 2-year period, and the mid-adulthood follow-up occurred across a 5-year period; and stratified by sex and baseline age (9, 12, and 15 years old). We also tested for interaction by age, sex, and duration of follow-up. To account for missing data at follow-up, we adapted an approach by Seaman et al.[24] Missing values of baseline variables that explain loss to follow-up (smoking status, socioeconomic status, school status, gender, and baseline age) were imputed and then inverse probability weighting was used with weights based on the probability of participating in follow-up using these baseline variables.

Results

Participant characteristics are shown in **Table I**. Mean (SD) duration of follow-up from childhood to young adulthood was 19.9 (0.6) years (range 18.7-21.0 years), and from childhood to mid-adulthood was 32.5 (1.2) years (range 29.2-33.8 years).

Table II shows rank correlations for tracking of CRF from childhood to young and mid-adulthood. When analyzing the entire cohort, we found that CRF tracked more strongly from childhood to young adulthood (r = 0.30) than from childhood to mid-adulthood (r = 0.16). We observed a correlation of 0.41 between CRF in young and mid-adulthood, when duration of follow-up was 12.5 years (**Table IV**). This pattern of stronger correlations over shorter periods of follow-up was largely consistent across different sex and age strata. Though we observed some differences in correlations between sexes and by baseline age, confidence intervals (CI) were wide and overlapped.

The stability coefficients and CIs for the tracking of CRF from childhood to adulthood are presented in **Table III**, with a stability coefficient of 0.24 observed for the whole cohort. We observed no strong evidence of interaction by sex or baseline age, but longer duration of follow-up tended to associate with a smaller stability coefficient (**Table IV**, Online; available at www.jpeds.com).

Table I. Participant characteristics at childhood, young-, and mid-adulthood

	Childhood n = 748		Young adulthood n = 651		Mid-adulthood n = 340	
	Males	Females	Males	Females	Males	Females
Characteristic	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Age, years	12.0 (2.4)	11.9 (2.4)	31.9 (2.5)	31.8 (2.5)	44.5 (2.8)	44.4 (2.6)
Weight, kg	44.4 (13.9)	42.4 (12.0)	85.6 (13.9)	68.7 (15.3)	89.5 (16.9)	74.1 (17.7)
Height, cm	153.2 (15.6)	149.5 (12.9)	180.1 (6.3)	166.2 (6.1)	179.4 (6.3)	165.9 (6.0)
Sum of skinfolds, cm	30.3 (15.6)	40.9 (18.2)	65.5 (25.0)	79.6 (33.2)	73.1 (27.6)	85.1 (32.4)
Body mass index, kg/m^2	18.4 (2.7)	18.6 (2.9)	26.4 (3.9)	24.9 (5.4)	27.8 (4.6)	26.9 (6.2)
Lean body mass, kg	35.5 (10.1)	31.9 (7.3)	64.5 (7.7)	45.0 (6.6)	65.3 (8.7)	47.3 (7.9)
PWC170, W	109.9 (43.8)	79.5 (27.8)	197.7 (43.2)	132.4 (32.6)	183.7 (69.8)	107.0 (37.9)
Std.PWC170.Adj	0.08 (0.94)	0.02 (1.04)	−0.06 (0.96)	−0.01 (1.04)	−0.01 (1.02)	−0.05 (0.97)

PWC170, physical work capacity at a heart rate of 170 beats per minute; SD, standard deviation; Std.PWC170.Adj, age and sex standardized physical work capacity at a heart rate of 170 beats per minute adjusted for lean body mass.

Discussion

Previous research has shown that CRF tends to track from childhood to adulthood, although comparison across studies is difficult due to variation in the methods used to calculate tracking.[22] Our study adds to this body of evidence, drawing on the largest database to date with one of the longest follow-up periods. While direct comparisons with other studies are difficult, a recent meta-analysis of correlations from 18 studies found that CRF tracks from childhood and adolescence to adulthood (r = 0.38, 95% CI: 0.29-0.48) over a mean duration of follow-up of 20.8 years.[25] Our study's childhood to young adulthood correlation (r = 0.30) is comparable, as it falls within the 95% CI estimated from the meta-analysis, and our mean duration of follow-up (19.9 years) is similar. However, the meta-analysis did not find duration of follow-up to significantly moderate tracking in metaregression, while our study did find evidence of weaker tracking as duration of follow-up increased. Notably, the two studies included in the meta-analysis with a longer duration of follow-up than ours had smaller sample sizes, but our 32.5-year correlation was within both studies' 95% CI. This suggests that the meta-analysis may not have been well represented by studies with longer duration of follow-up, as estimates of publication bias indicated a major positive bias, suggesting that the pooled effect may have been overstated. Our findings extend previous works by including a third data point, allowing for generalized estimating equation estimates of tracking, which were comparable with the point estimates of the rank coefficients.[23] Additionally, our study had a larger sample size and duration of follow-up than most prior individual studies, and our findings provide further insight into the potential moderating effect of duration of follow-up on CRF tracking.

Understanding the extent to which factors track from childhood to adulthood can help determine the value of screening for such factors in childhood (those that track well) or identify factors that might be more responsive to lifestyle changes (those that track less well). Our cohort has shown stronger tracking from childhood to adulthood for low-density lipoprotein cholesterol (males r = 0.58, females r = 0.60),[26] body mass index (males r = 0.37-0.56, females r = 0.41-0.59),[27] and muscular strength (r = 0.47)[28,29] than we observed for CRF. However, CRF tracks similarly to systolic blood pressure (r = 0.31)[30] and more strongly than physical activity (males: r = 0.07, females: r = 0.04).[31] The reason for CRF tracking less well than other factors is unclear but could be related to greater measurement error or a weaker genetic contribution. If CRF is indeed relatively transitory,[32] as our and other data suggest,[22] interventions aimed at raising CRF in children and maintaining CRF into adulthood may be particularly important. School-based physical activity interventions have been shown to increase CRF, indicating a potential strategy to improve CRF levels in childhood and adolescence.[33] Furthermore, important life stage transitions occur from childhood to mid-adulthood that could impact physical activity during these periods and, in-turn, influence CRF levels[32,34] and tracking, as recent data

Table II. Rank correlation coefficients for tracking of cardiorespiratory fitness from childhood to young and mid-adulthood

	Childhood to young adulthood			Childhood to mid-adulthood		
Baseline age (years)	N	Correlation coefficient	95% Confidence intervals	n	Correlation coefficient	95% Confidence intervals
9						
Male	114	0.31	0.13, 0.49	56	0.27	0.003, 0.53
Female	111	0.40	0.22, 0.57	59	0.10	−0.17, 0.36
All	225	0.36	0.24, 0.49	115	0.22	0.04, 0.40
12						
Male	114	0.22	0.03, 0.40	47	0.10	−0.20, 0.40
Female	105	0.27	0.07, 0.45	67	0.10	−0.15, 0.35
All	219	0.27	0.14, 0.40	114	0.10	−0.09, 0.29
15						
Male	108	0.16	−0.03, 0.35	55	0.09	−0.19, 0.37
Female	99	0.26	0.07, 0.46	56	0.44	0.20, 0.69
All	207	0.24	0.10, 0.37	111	0.23	0.04, 0.41
All participants						
Male	336	0.27	0.17, 0.37	158	0.16	−0.0001, 0.31
Female	315	0.31	0.20, 0.41	182	0.16	0.01, 0.30
All	651	0.30	0.23, 0.38	340	0.16	0.06, 0.27

Table III. Generalized estimating equation stability coefficients for cardiorespiratory fitness tracking from childhood to adulthood

Baseline age (years)	n	GEE stability coefficients	95% confidence intervals
9			
Male	125	0.22	0.04, 0.40
Female	131	0.24	0.05, 0.43
All	256	0.23	0.10, 0.36
12			
Male	124	0.34	0.06, 0.61
Female	129	0.21	0.06, 0.35
All	253	0.25	0.12, 0.38
15			
Male	120	0.13	−0.05, 0.32
Female	119	0.36	0.20, 0.53
All	239	0.23	0.09, 0.37
All participants			
Male	369	0.23	0.10, 0.36
Female	379	0.24	0.13, 0.35
All	748	0.24	0.15, 0.32

All stability coefficients adjusted for length to follow-up.
GEE, generalized estimating equation.

have shown.[35] While maintaining lower levels of adiposity[36] and achieving higher education levels[31] may also play a role in CRF tracking and development from childhood to adulthood, further investigation into other factors is needed.

Limitations of this study include the potential for bias if loss to follow-up was nonignorable. Inverse probability weighting with multiple imputation of some baseline variables were applied on the assumption that drop-out was ignorable (related to observed variables). If some loss to follow-up was nonignorable, it is reassuring that any residual bias would be slight and toward the null. Our estimates may be a little conservative, but they are not exaggerated. It would have been ideal to examine tracking as the likelihood of maintaining stable CRF levels over time, but this is not recommended when consensus cut-offs are lacking, as is the case for childhood CRF.[36] Pubertal status was not collected, which might have influenced tracking, particularly the 12- and 15-year olds at baseline. Study strengths were the long follow-up period spanning childhood to mid-adulthood, a large national sample, and measurement of CRF using a consistent protocol at all three time-points.

In conclusion, while CRF is an important health marker in childhood and a clinical indicator of cardiometabolic health in adulthood, our tracking data suggest limitations in using CRF levels as a predictor of lifelong levels. This underscores the importance of promoting modifiable factors throughout life to increase or maintain CRF levels. ■

Declaration of Competing Interest

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