

Added predictive value of childhood physical fitness to traditional risk factors for adult cardiovascular disease

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Aims

Childhood physical fitness is a predictor of cardiovascular (CV) health but is underutilized in health surveillance. This study determined the predictive utility of child physical fitness levels on obesity, hypertension, dyslipidaemia, and the metabolic syndrome (MetS) in adulthood over traditional CV risk factors in childhood.

Methods and results

This is a longitudinal cohort study of Childhood Determinants of Adult Health Study participants who had their fitness [cardiorespiratory fitness (CRF): 1.6 km run/walk, physical work capacity at 170 b.p.m.; muscular fitness: dominant handgrip strength and standing long jump] measured as children and their CV health assessed as children and adults (mean follow-up = 27 years). Participants had their body mass index (BMI), waist circumference, blood pressure, fasting blood sample (lipids, glucose), and smoking status assessed as children in 1985 and in early adulthood (2004–06, 26–36 years) and/or middle adulthood (2014–19, 36–49 years) where obesity, hypertension, dyslipidaemia, and MetS were defined. Logistic regression was used to model associations (n range = 578–5049). Additionally considering childhood CRF or muscular fitness improved the ability to discriminate and fit models to predict adult obesity, low HDL cholesterol (HDL-C), and MetS when added to demographics (age and sex) and the corresponding measure in childhood (BMI, HDL-C, and CV risk score), as reflected by increments in area under the curve (Δ range = 0.003–0.022), net reclassification index (range = 0.026–0.149), integrated discrimination index (range = 0.003–0.027), reductions in deviance and Brier scores, and statistically significant likelihood ratio tests.

Conclusion

Cardiorespiratory fitness and muscular fitness are independent health indicators that could complement other risk factors in childhood to identify individuals at increased long-term CV risk.

Lay summary

Using data collected over 30 years from the Childhood Determinants of Adult Health Study, we examined if adding childhood physical fitness to traditional cardiovascular (CV) risk factors in childhood improves their prediction of hypertension, obesity, dyslipidaemia, and the metabolic syndrome measured in adulthood.

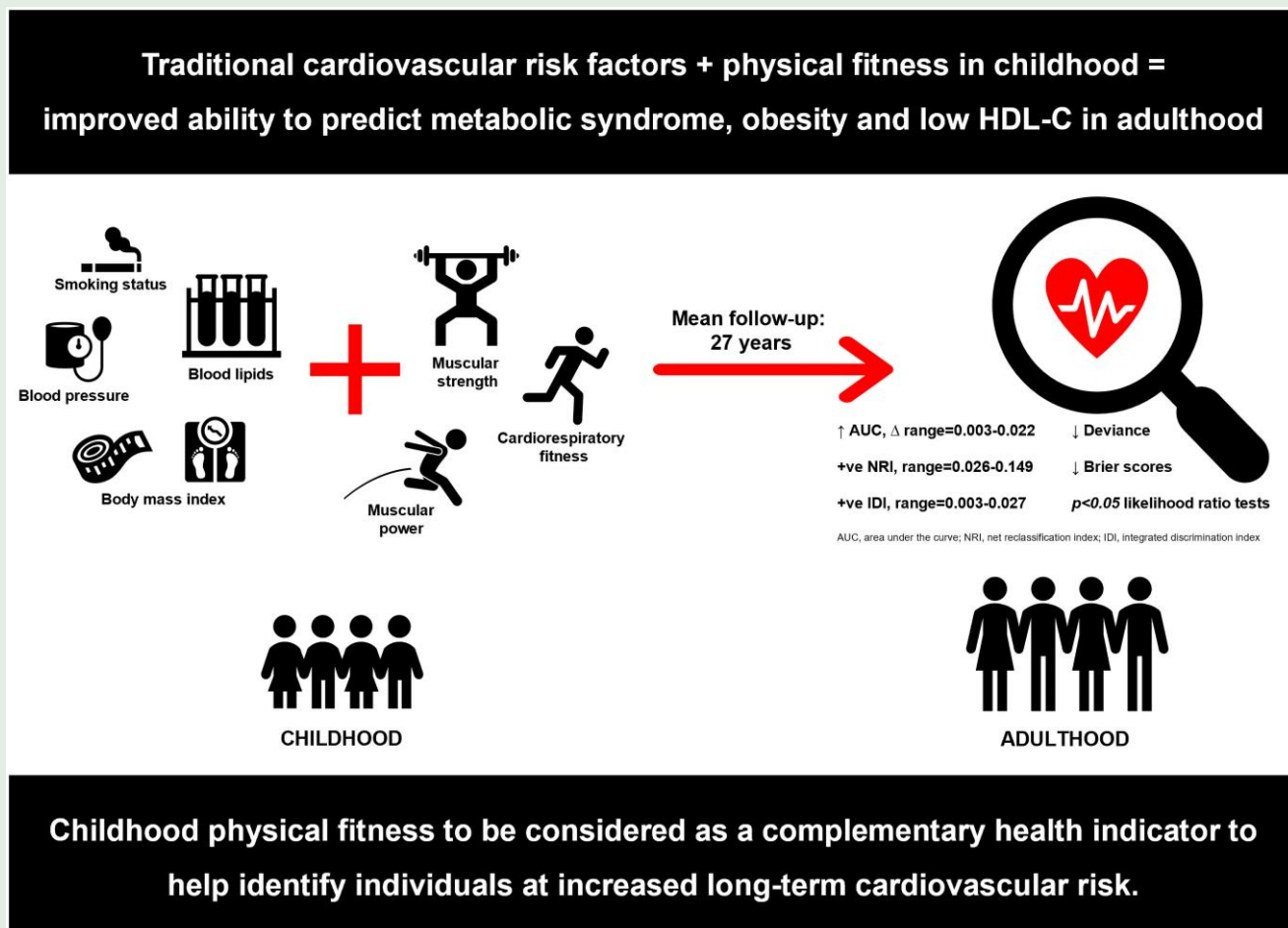
- Adding a measure of childhood physical fitness to traditional CV risk factors improved the ability to discriminate and fit models with adult metabolic syndrome, obesity, and low HDL-C.
- Cardiorespiratory fitness and muscular fitness are reliable, scalable, non-invasive, and relatively cost-effective indicators of population health that could complement other measures as part of a health surveillance system or be considered in CV disease risk prediction.

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Graphical Abstract



Keywords

Cardiovascular diseases • Longitudinal studies • Hypertension • Physical fitness • Risk factors • Dyslipidaemias

Introduction

The American Heart Association has advocated for physical fitness as a clinical vital sign,^{1,2} describing childhood physical fitness as an important marker of health.³ However, in Australia, child physical fitness levels [cardiorespiratory fitness (CRF) and muscular fitness] are not routinely measured and are not used in health surveillance. Population health surveillance indicators for children have historically been self-reported physical activity levels and body mass index (BMI), with physical fitness less often included despite efforts to advocate its benefits.⁴⁻⁶

Cardiorespiratory fitness and muscular fitness are consistently strong indicators of health.⁷⁻⁹ In adults, muscular fitness has been shown to be a stronger predictor of all-cause and cardiovascular (CV) mortality than systolic blood pressure,¹⁰ with the American Heart Association highlighting the ability of CRF to outperform more traditional risk factors (e.g. smoking status and high cholesterol).^{1,2} Recommendations exist for the routine measurement of blood pressure, lipids, and adiposity to identify those at increased CV disease risk,¹¹ but no such recommendations exist for physical fitness measurement. Physical fitness in childhood is a feasible, practical, and scalable target that could improve child health and help prevent the development of CV disease and its risk factors in later life. Our research group

has previously shown how childhood physical fitness is significantly associated with CV risk factors in adulthood.¹²⁻¹⁴ However, it is unknown how the predictive utility of CRF and muscular fitness compares with other risk factors in children. If the ability to predict CV health improves by adding child physical fitness to more traditional risk factors, childhood physical fitness could be promoted as a population health indicator that could complement other measures as part of national health surveillance and screening systems. This is of particular interest given recent commentary promoting childhood as a critical point of engagement for improving CV health,¹⁵ emphasizing the need for earlier prevention of CV diseases.¹⁶

This study determined the predictive utility of child physical fitness levels on obesity, hypertension, dyslipidaemia, and the metabolic syndrome (MetS) in adulthood over traditional CV risk factors in childhood.

Methods

Participants

In 1985, a nationally representative sample of 8498 Australian children (7-15 years) had their health and fitness (field-based test of CRF and

muscular power) assessed as part of the Australian Health and Fitness Survey, with a subset of children aged 9, 12, and 15 years receiving additional testing (including blood pressure, lipids, muscular strength, and CRF estimated via a sub-maximal graded exercise test). As part of the Childhood Determinants of Adult Health (CDAH) Study, participants were followed up and had their CV health assessed in early adulthood (in 2004–06, age 26–36 years) and middle adulthood (in 2014–19, age 36–49 years). Included in this study were participants who provided at least one measure of fitness in childhood and had CV risk factors assessed in childhood and again at least once as an adult (up to $n = 901$ for blood pressure, $n = 5049$ for BMI, $n = 605$ for LDL-C, $n = 608$ for triglycerides, $n = 605$ for HDL-C, and $n = 578$ for CV risk score). The varying Ns for analysis were due to subsampling of key measures in childhood owing to time and economic constraints and participants not consenting or attending for the blood sampling. A flowchart of participation is presented in [Supplementary material online, Figure S1](#). The baseline study was approved by the State Directors General of Education, and the follow-up studies were approved by the Tasmania Health and Medical Human Research Ethics Committee. Consent was obtained from parents and assent obtained from children at baseline, with participants providing written informed consent at both time points in adulthood.

Physical fitness in childhood

Measures of CRF and muscular strength and power were examined in childhood. A field-based test (1.6 km run/walk) and a sub-maximal graded exercise test (physical work capacity at 170 b.p.m., PWC170) were used to assess CRF in childhood. The time it took children (aged 7–15 years) to complete a 1.6 km run/walk was recorded, with longer run/walk times reflecting lower CRF levels. Cardiorespiratory fitness was estimated as PWC170 for children aged 9, 12, and 15 years using a Monark 818E bicycle ergometer (Monark Exercise AB, Vansbro, Sweden). This sub-maximal test included three progressive 3-minute work rates. Heart rate (beats per minute) and work rate (watts) were recorded in the final minute of each workload and were then plotted and extrapolated to estimate PWC170. Muscular strength was assessed in 9-, 12- and 15-year-olds as right and left handgrip strength (to the nearest 0.5 kg), measured via maximum voluntary contraction using an isometric dynamometer (Smedley's Dynamometer, TTM, Tokyo, Japan). Participants gripped the dynamometer with maximum force with one hand, as the dynamometer rested on the opposite shoulder. In childhood, participants had one attempt at right and left grip strength, whereas at each adult time point, the maximum of two attempts on each side was recorded. Participants reported whether their dominant hand was right or left, with handgrip strength of the dominant hand used in analyses. Muscular power was assessed as the longer distance (centimetre) of two attempts at a standing long jump test. This test required a two footed take-off and landing and was completed by children aged 7–15 years.

Cardiovascular risk factors in childhood

Body mass was measured to the nearest 0.5 kg using regularly calibrated scales and height was measured using a KaVVe height tape (KaVVe Kirchner & Wilhelm, Asperg, Germany) to the closest 0.1 cm. Body mass index was calculated as body mass (kilogram) divided by height (metre) squared. Cole's international cut-points for children were used to classify participants' BMI levels as normal weight or overweight/obese. Blood pressure measurements were taken while seated, after 5 min of quiet rest. Korotkoff sound I (systolic blood pressure) and Korotkoff sound V (diastolic blood pressure) were obtained from the left brachial artery using a standard mercury sphygmomanometer. The mean of the two readings was recorded. Hypertension was defined as systolic or diastolic blood pressure ≥ 95 th age-, sex- and height-specific percentile or $\geq 130/80$ mmHg (whichever was lower) for children aged 9 and 12 years, or $\geq 130/80$ mmHg for children aged 15 years.¹⁷ Participants provided a fasting blood sample. Total cholesterol and triglycerides were determined using a Technicon Auto Analyzer II (Technicon Instrument Corp, Tarrytown, NY), and HDL cholesterol (HDL-C) was analysed following precipitation of apo-B

containing lipoproteins with heparin manganese. LDL cholesterol (LDL-C) was indirectly determined using the Friedewald formula. High LDL-C was defined as ≥ 3.36 mmol/L (≥ 130 mg/dL), high triglycerides as ≥ 1.13 mmol/L (≥ 100 mg/dL) for children aged 9 years and ≥ 1.47 mmol/L (≥ 130 mg/dL) for children aged 12 and 15 years, and low HDL-C as < 1.04 mmol/L (< 40 mg/dL).¹¹ Smoking status was defined using self-reported responses to the question 'How long have you been smoking regularly?', where non-smokers were defined as those who responded that they did not smoke regularly, with smokers defined as any participant who responded that they had either just started smoking regularly or had been smoking regularly for a period (ranging from 1–6 months to > 4 years). A combined CV risk z-score, made up of five risk factors most often evaluated in childhood, was calculated as the unweighted mean of age- and sex-standardized values of BMI, systolic blood pressure, total cholesterol levels, and the natural log of triglyceride levels, added to smoking status (0 = non-smoker and 2 = smoker).¹⁸ This CV risk score has been shown to associate with incident adult CV events.¹⁸

Cardiovascular risk factors in adulthood

In adulthood, body mass was measured to the nearest 0.5 kg using Heine scales (Heine, Dover, NH), waist circumference was measured at the narrowest point between the lower costal border and the iliac crest, and height was measured to the closest 0.1 cm using a Leicester height measure (Invicta, Leicester, UK). Body mass index was subsequently calculated. Self-reported height and mass (with a correction factor applied^{19,20}) were used to estimate BMI for those who did not attend clinics. Resting systolic and diastolic blood pressure were measured on the participant's right arm using the OMRON HEM-907 Digital Automatic Blood Pressure Monitor (Omron Healthcare Co., Ltd., Kyoto, Japan) after 5 min of quiet sitting. The mean of the three readings was used in analyses. A fasting blood sample was analysed for total cholesterol, HDL-C, triglycerides, and glucose using an Olympus AU5400 automated analyser (Olympus Optical, Tokyo, Japan) in early adulthood and a Siemens Advia 2400 Chemistry analyser (Siemens Healthcare Diagnostics Inc., Deerfield, IL, USA) in middle adulthood. At both time points, LDL-C was determined using the Friedewald formula.

The adult CV risk factors of interest in this study were hypertension, obesity, dyslipidaemia (high LDL-C, high triglycerides, and low HDL-C), and a clustering of risk factors operationalized as MetS. In both young and middle aged adults, hypertension was defined as systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 80 mmHg²¹ or current medication use to lower blood pressure; obesity as BMI ≥ 30 ; and high LDL-C as ≥ 4.14 mmol/L (≥ 160 mg/dL) or current medication use to lower blood cholesterol, high triglycerides as ≥ 2.26 mmol/L (≥ 200 mg/dL), and low HDL-C as < 1.04 mmol/L (< 40 mg/dL).²² Using the harmonized MetS definition, MetS was assigned when at least three of the following five components were present²³: waist circumference (male: ≥ 102 cm, female: ≥ 88 cm), fasting glucose [≥ 5.6 mmol/L (≥ 100 mg/dL), or doctor diagnosis of type 2 diabetes], triglycerides [≥ 1.7 mmol/L (≥ 150 mg/dL)], HDL-C [male: < 1.03 mmol/L (< 40 mg/dL), female: < 1.30 mmol/L (< 50 mg/dL)], and blood pressure ($\geq 130/85$ or treatment of previously diagnosed hypertension). Participants were categorized as having these CV risk factors if they met the relevant criteria at least once as adults.

Statistical analyses

All statistical analyses were performed using Stata (version 17.0; StataCorp, College Station, Texas). Participant characteristics are presented as mean (standard deviation) or median (interquartile range) for continuous variables and proportion (number of participants) for categorical variables.

Logistic regression models were used to estimate the utility of childhood risk factors for predicting CV risk factors in adulthood. To account for missing data at follow-up, all logistic regression models included inverse probability weighting with multiple imputation of incomplete baseline data.²⁴ Of interest in this study were a series of 'restrictive models' (models that

included a series of traditional childhood risk factors) and 'less restrictive models' (models that additionally included a measure of physical fitness). Based on the results of each logistic model, area under the curve (AUC), deviance, and Brier scores were quantified. The AUC is a global measure of improvement in model performance. However, AUC values are hard to increase, especially if the baseline model has high discrimination. Given changes in the AUC tend to be proportional to changes in measures of clinical predictive performance, small increments in AUC values could reflect important improvements in prediction. A DeLong test, which includes a Wald test of the null hypothesis that all classifier AUC values are equal, was performed to test the equality of AUC values quantified for the 'less restrictive' and 'restrictive' models. A $P \leq 0.05$ for this test suggests there is a significant difference in discrimination for the two models being compared. To provide additional information around improvement in model fit and predictive utility, we also considered additional model performance metrics. Following the approach recommended by Pepe et al.,²⁹ likelihood ratio tests were performed to compare the log likelihoods of a series of 'restrictive models' and 'less restrictive models' and test whether this difference was statistically significant. If the difference was statistically significant ($P \leq 0.05$), the less restrictive model (the one with a measure of physical fitness included) was interpreted as fitting the data significantly better than the more restrictive model. To further quantify the prediction increment and any improvements in discrimination of including a measure of physical fitness to each restrictive model, we calculated the category-free net reclassification improvement (NRI), the integrated discrimination index (IDI), and the relative IDI.

Given the strength at which CV risk factors persist, or *track*, over time,^{26–29} the baseline measures for each adult CV risk factor were considered the key predictor of each outcome and were determined *a priori* as the childhood variable included in each of the 'restrictive models' (i.e. child combined CV risk z-score included when examining adult MetS; child systolic and diastolic blood pressure and high blood pressure included when examining adult hypertension; child BMI and overweight/obesity included when examining adult obesity; child LDL-C and high LDL-C included when examining high adult LDL-C; child triglycerides and high triglycerides included when examining high adult triglycerides; and child HDL-C and low HDL-C included when examining low adult HDL-C).

Results

Demographics

Characteristics of participants are presented in [Table 1](#). The average length of follow-up between childhood and early adulthood was 19.9 (0.6) years and between childhood and middle adulthood was 32.4 (1.3) years.

Predictive utility of childhood risk factors on cardiovascular risk factors in adulthood with and without the inclusion of a measure of childhood physical fitness

Indices related to the predictive utility of childhood risk factors on MetS, hypertension, obesity, and dyslipidaemia (high LDL-C, high triglycerides, and low HDL-C) in adulthood are shown in [Tables 2–5](#). Adding a measure of childhood physical fitness to traditional child risk factors increased the AUC, NRI, and IDI/relative IDI values and decreased the deviance and Brier scores for most models with CV risk factors in adulthood. On the odd occasion where the AUC, NRI, and/or IDI/relative IDI did not increase with the inclusion of a measure of childhood physical fitness, they remained broadly unchanged.

After introducing a measure of childhood physical fitness to the model, the most notable improvements in discrimination and model fit were observed for models with MetS ([Table 2](#)), obesity ([Table 4](#)),

and low HDL-C ([Table 5](#)) in adulthood. Adding a measure of muscular fitness (standing long jump) or CRF (1.6 km run) to the combined CV risk z-score in childhood improved the ability to fit models with MetS in adulthood ([Table 2](#)). Statistically significant improvements in model fit with adult obesity were observed when adding a measure of childhood CRF or muscular fitness to age, sex, and BMI (or overweight/obesity) ([Table 4](#)), with similar results observed for those with and without overweight/obesity in childhood. Significant improvements in discrimination were also observed, most notably when standing long jump or the duration of a 1.6 km run was included in the model.

Adding a measure of child CRF (1.6 km run duration or PWC170) or muscular fitness (most notably dominant handgrip strength) to age, sex, and HDL-C (or low HDL-C levels) resulted in statistically significant improvements in model fit with low HDL-C levels in adulthood ([Table 5](#)). Including a measure of CRF to the child measures of age and sex improved discrimination and model fit with low HDL-C levels in adulthood for children with normal HDL-C levels, with the inclusion of handgrip strength improving model fit for those with low HDL-C levels in childhood. Improvements in model fit were accompanied by improvements in discrimination for some but not all models.

Sensitivity analyses

Our primary results showed that additionally considering a childhood measure of CRF or muscular strength and/or muscular power improved measures of discrimination and model fit with CV risk factors in adulthood. Therefore, a series of sensitivity analyses were performed to assess whether there was any additional predictive value in considering different components of physical fitness above a single measure of physical fitness alone. Results presented in [Supplementary material online, Table S1–S6](#) highlight the predictive utility of considering different components of physical fitness whereby adding a measure of muscular strength and/or muscular power to CRF, or CRF to muscular strength and/or muscular power, further improved the ability to discriminate and fit models with adult MetS, hypertension, obesity, and low HDL-C.

To additionally consider the predictive utility of peak oxygen uptake (VO_{2peak}), 1.6 km run times were used to estimate VO_{2peak} using the Cureton et al.³⁰ equation. The predictive utility of estimated VO_{2peak} (see [Supplementary material online, Table S7](#)) was consistent with estimates presented for the 1.6 km run duration.

Discussion

Adding a measure of childhood CRF and/or muscular fitness to traditional CV risk factors improved the ability to discriminate and fit models with adult CV risk factors, most notably MetS, obesity, and low HDL-C. These findings provide support for childhood physical fitness to be considered as a complementary health indicator to help identify individuals at increased CV risk in adulthood.

The link between childhood physical fitness and MetS, obesity, and low HDL-C in adulthood, independent of a measure of childhood adiposity, has been identified previously using CDAH data.^{12–14} Our findings extend current understanding by highlighting the predictivity utility of childhood physical fitness with MetS, obesity, and low HDL-C in adulthood, in addition to the respective child measure (e.g. combined CV risk z-score, BMI, and HDL-C levels). The added predictive value of additionally considering childhood physical fitness could reflect the inability of BMI to discriminate between fat and fat-free mass; represent the independent effects of fitness above fatness, a potential result of the

Table 1 Characteristics of the participants

| Characteristic | Males | | Females | |
|---|-------|------------------------|---------|------------------------|
| | | Statistic ^a | | Statistic ^a |
| Childhood | | | | |
| Age, years | 2388 | 11.0 (2.5) | 2662 | 10.9 (2.5) |
| Dominant handgrip strength, kg | 773 | 25.6 (10.6) | 902 | 21.3 (6.7) |
| Standing long jump distance, cm | 2384 | 152.0 (30.8) | 2650 | 137.2 (25.2) |
| 1.6 km run duration, min | 2235 | 8.3 (1.6) | 2447 | 10.0 (1.8) |
| Estimated VO ₂ peak, mL/kg/min | 2235 | 50.5 (4.2) | 2447 | 44.7 (3.8) |
| PWC170, watts | 741 | 108.7 (44.8) | 850 | 79.5 (26.6) |
| BMI, kg/m ² | 2388 | 18.1 (2.7) | 2662 | 18.3 (2.9) |
| BMI cut-points, % (n) | 2388 | | 2662 | |
| Normal weight | | 90 (2149) | | 89 (2369) |
| Overweight/obese | | 10 (239) | | 11 (293) |
| Systolic blood pressure, mmHg | 755 | 110.8 (13.7) | 885 | 108.6 (12.1) |
| Diastolic blood pressure, mmHg | 750 | 65.4 (12.4) | 880 | 67.2 (11.4) |
| Hypertension, % (n) | 750 | | 881 | |
| No | | 77 (580) | | 77 (680) |
| Yes | | 23 (170) | | 23 (201) |
| LDL-C, mmol/L | 520 | 2.60 (0.63) | 543 | 2.82 (0.68) |
| High LDL-C, % (n) | 520 | | 543 | |
| No | | 89 (464) | | 81 (439) |
| Yes | | 11 (56) | | 19 (104) |
| Triglycerides, mmol/L | 525 | 0.64 (0.49, 0.85) | 551 | 0.64 (0.51, 0.86) |
| High triglycerides, % (n) | 525 | | 551 | |
| No | | 94 (493) | | 93 (513) |
| Yes | | 6 (32) | | 7 (38) |
| HDL-C, mmol/L | 521 | 1.44 (0.30) | 546 | 1.46 (0.30) |
| Low HDL-C, % (n) | 521 | | 546 | |
| No | | 93 (485) | | 93 (509) |
| Yes | | 7 (36) | | 7 (37) |
| Total cholesterol, mmol/L | 525 | 4.36 (0.71) | 551 | 4.62 (0.72) |
| Smoking status | 1831 | | 2034 | |
| Non-smoker | | 88 (1615) | | 87 (1759) |
| Smoker | | 12 (216) | | 13 (275) |
| Combined CV risk z-score | 509 | 0.03 (-0.33, 0.52) | 525 | 0.05 (-0.34, 0.53) |
| Early adulthood | | | | |
| Age, years | 1813 | 31.4 (2.6) | 2139 | 31.2 (2.7) |
| BMI, kg/m ² | 2378 | 26.4 (4.3) | 2632 | 24.9 (5.5) |
| Waist circumference, cm | 1147 | 89.5 (10.5) | 1179 | 78.0 (11.3) |
| Systolic blood pressure, mmHg | 1149 | 125.3 (10.9) | 1252 | 111.4 (10.4) |
| Diastolic blood pressure, mmHg | 1149 | 74.9 (8.9) | 1252 | 70.0 (8.9) |
| LDL-C, mmol/L | 1142 | 3.12 (0.86) | 1249 | 2.83 (0.80) |
| Triglycerides, mmol/L | 1158 | 1.00 (0.70, 1.60) | 1255 | 0.80 (0.60, 1.20) |
| HDL-C, mmol/L | 1158 | 1.30 (0.26) | 1255 | 1.56 (0.34) |
| Glucose, mmol/L | 1157 | 5.17 (0.48) | 1254 | 4.82 (0.40) |
| Middle adulthood | | | | |
| Age, years | 927 | 43.8 (2.8) | 1159 | 43.5 (2.9) |
| BMI, kg/m ² | 920 | 27.8 (4.9) | 1136 | 27.3 (6.2) |
| Waist circumference, cm | 721 | 93.6 (12.2) | 832 | 83.0 (13.0) |
| Systolic blood pressure, mmHg | 721 | 125.3 (13.8) | 838 | 113.8 (13.2) |

Continued

Table 1 Continued

| Characteristic | Males | | Females | |
|--------------------------------|-------|------------------------|---------|------------------------|
| | | Statistic ^a | | Statistic ^a |
| Diastolic blood pressure, mmHg | 721 | 76.3 (10.9) | 838 | 71.4 (10.8) |
| LDL-C, mmol/L | 702 | 3.28 (0.87) | 817 | 2.93 (0.75) |
| Triglycerides, mmol/L | 703 | 1.10 (0.80, 1.60) | 817 | 0.90 (0.70, 1.20) |
| HDL-C, mmol/L | 703 | 1.32 (0.30) | 817 | 1.66 (0.41) |
| Glucose, mmol/L | 703 | 4.94 (0.93) | 816 | 4.66 (0.62) |
| Adulthood ^b | | | | |
| Hypertension, % (n) | 1304 | | 1462 | |
| No | | 49 (635) | | 76 (1107) |
| Yes | | 51 (669) | | 24 (355) |
| Obesity, % (n) | 2388 | | 2661 | |
| No | | 79 (1879) | | 79 (2101) |
| Yes | | 21 (509) | | 21 (560) |
| High LDL-C, % (n) | 1295 | | 1468 | |
| No | | 83 (1072) | | 93 (1366) |
| Yes | | 17 (223) | | 7 (102) |
| High triglycerides, % (n) | 1296 | | 1468 | |
| No | | 86 (1116) | | 96 (1414) |
| Yes | | 14 (180) | | 4 (54) |
| Low HDL-C, % (n) | 1296 | | 1468 | |
| No | | 79 (1028) | | 94 (1387) |
| Yes | | 21 (268) | | 6 (81) |
| Metabolic syndrome, % (n) | 1283 | | 1449 | |
| No | | 86 (1098) | | 93 (1343) |
| Yes | | 14 (185) | | 7 (106) |

^aStatistics are mean (standard deviation) or median (interquartile range) for continuous variables or proportion (number of participants) for categorical variables.

^bParticipants were categorized as having these cardiovascular risk factors in adulthood if they met the relevant criteria in young and/or middle adulthood.

BMI, body mass index; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein; PA, physical activity; PWC170, physical work capacity at 170 b.p.m.; VO₂peak, peak oxygen uptake.

Fat but Fit paradox; or highlight the beneficial relationship between exercise and lecithin-cholesterol acyl trans, the enzyme responsible for ester transfer to HDL cholesterol, and increases in lipoprotein lipase activity.³¹ The added predictive value may also reflect exercise-induced increases in insulin signalling and skeletal muscle glucose uptake,³² or could represent indirect effects of greater fitness habits through to middle adulthood given physical fitness tracks between childhood and adulthood.³³ However, it must be acknowledged that a lack of significant improvement in model fit or discrimination of hypertension and high LDL-C and triglycerides in adulthood when additionally considering childhood physical fitness does not suggest that physical fitness should be dismissed when seeking predictors of CV risk. Given childhood physical fitness is associated with traditional CV risk factors such as measures of adiposity, blood pressure, and blood lipids,^{34–36} the ‘more restrictive’ model (i.e. the model without a physical fitness measure included) may already be capturing information on physical fitness, with an indirect effect on each outcome operating via the respective baseline factor (e.g. childhood blood pressure, BMI, and blood lipids). Additionally including a measure of childhood physical fitness to these models enables the direct effect of physical fitness on the outcome not explained by the respective child measure to be captured, as seen in our models with adult MetS, obesity, and low HDL-C.

The predictive utility of physical fitness has been examined in part previously. In adulthood, CRF has been shown to improve the ability to predict CV morbidity or mortality in addition to other CV risk factors,³⁷ with handgrip strength identified as a stronger predictor of all-cause and CV mortality than systolic blood pressure.¹⁰ In 2016, the American Heart Association advocated for CRF to be used as a clinical vital sign to help improve patient risk classification when added to traditional biomarkers,¹ with more recent evidence strengthening calls to re-introduce CRF as a vital sign of CV risk.^{2,9,38} Furthermore, the American Heart Association has specifically promoted the importance of childhood CRF in predicting current and future health, describing CRF as an important marker of health.³ Our study supports these statements, while also highlighting the complementary and additive predictive utility of childhood muscular fitness, supporting recent reviews emphasizing the link between muscular fitness and CV health.^{39,40} In response to the growing evidence base highlighting both childhood CRF and muscular fitness as significant and independent predictors of future CV health,^{41–43} others have speculated how the addition of objective measures of physical fitness could contribute to building a better understanding of population health among youth,⁵ advocating for physical fitness to be used in health surveillance.⁶ However, when the diagnostic accuracy of childhood physical fitness to predict CV health was

Table 2 Indices of the predictive utility of childhood risk factors on metabolic syndrome in adulthood with and without the inclusion of a measure of childhood physical fitness

| Restrictive model | n | AUC | Deviance | Brier score | Less restrictive model | AUC | Deviance | Brier score | NRI | IDI | Relative IDI | DeLong test P-value | LR test P-value |
|------------------------------------|-----|-------|----------|-------------|--|-------|----------|-------------|--------|-------|--------------|---------------------|-----------------|
| Age, sex, combined CV risk z-score | 576 | 0.668 | 5661.9 | 0.095 | Age, sex, combined CV risk z-score, dominant handgrip strength | 0.668 | 5661.4 | 0.095 | -0.005 | 0.000 | 0.002 | 0.77 | 0.96 |
| Age, sex, combined CV risk z-score | 576 | 0.667 | 5659.9 | 0.095 | Age, sex, combined CV risk z-score, standing long jump | 0.689 | 5566.2 | 0.094 | 0.026 | 0.010 | 0.222 | 0.23 | 0.02 |
| Age, sex, combined CV risk z-score | 549 | 0.669 | 5748.3 | 0.098 | Age, sex, combined CV risk z-score, 1.6 km run | 0.691 | 5699.6 | 0.096 | 0.043 | 0.010 | 0.208 | 0.13 | 0.02 |
| Age, sex, combined CV risk z-score | 561 | 0.663 | 5704.5 | 0.100 | Age, sex, combined CV risk z-score, PWC170 | 0.667 | 5630.2 | 0.095 | 0.041 | 0.009 | 0.192 | 0.81 | 0.08 |

All P-values are italicized, with P-values less than 0.05 displayed in bold text.

AUC, area under the curve; CI, confidence intervals; CV, cardiovascular; IDI, integrated discrimination index; LR, likelihood ratio; NRI, net reclassification improvement; PWC170, physical work capacity at 170 b.p.m.

reviewed,^{44,45} most of the available literature focused on short-term CV health outcomes. Our findings provide additional support for including physical fitness in health surveillance and screening by identifying improvements in model fit and discriminatory ability to detect CV risk in adulthood when considering measures of childhood CRF and muscular fitness in combination with traditional CV risk factors.

Our findings highlight CRF and muscular fitness as indicators of population health that could complement other measures as part of a health surveillance system or be considered in CV disease risk prediction. Given physical fitness tests are reliable, scalable, non-invasive, and relatively cost effective, the benefits of including such tests as health screening tools are apparent. The American Heart Association have highlighted the benefits of regularly assessing objective measures of health, such as physical fitness, and highlight how physical fitness could identify children who would benefit from lifestyle interventions who may be overlooked using current standards of care, such as self-reported physical activity, anthropometric measures, or CV risk factor testing.³ Our findings provide longitudinal evidence in support of this, whereby the inclusion of measures of CRF and/or muscular fitness to traditional CV risk factors, including BMI, and self-reported physical activity improves the ability to predict CV risk factors in adulthood.

In 2012, the National Academy of Medicine (formerly the Institute of Medicine) stated that health-related physical fitness measures should be incorporated in national youth fitness surveys,⁴⁶ sentiments echoed more recently by European experts via the ALPHA (Assessing Levels of Physical Activity) and FitBack initiatives. However, it was recommended that in order to better characterize the importance of childhood physical fitness as a health indicator, there was a need for

studies to examine how physical fitness in childhood predicts adult health outcomes,⁴⁶ similar to a recent longitudinal study linking sedentary time and physical activity with changes in cardiac structure and function,⁴⁷ for example. International experts have recently identified the need for longitudinal research as the number one priority for physical fitness research and surveillance among children.⁴⁸ Our study addresses this knowledge gap and highlights how measuring childhood physical fitness could assist in the identification of individuals at increased CV risk in adulthood. However, to enable physical fitness to be incorporated into fitness surveys or health surveillance and screening systems, universally accepted test protocols and health-related criterion-referenced physical fitness cut-points that can be used to identify children at increased risk of poor health must be established.^{44,45}

Potential limitations of our study include loss to follow-up. To reduce the likelihood of bias and account for missingness, all analyses included inverse probability weighting. Furthermore, owing to time and resource constraints at baseline, a sub-sample of children aged 9, 12, and 15 years received additional measurements of blood pressure, blood sampling, and more detailed fitness tests (including dominant handgrip strength and PWC170), which meant the sample size of each model varied depending on the childhood risk factors and physical fitness measure of interest. We acknowledge how the intricacies of HDL-C's causal role in CV disease incidence require additional attention, specifically the effect of high HDL-C. However, low HDL-C was included as an outcome in this study given low HDL-C levels are a marker of increased risk for CV disease and all-cause mortality. A strength of our study was the use of longitudinal national data from the CDAH Study. Participants had

Table 3 Indices of the predictive utility of childhood risk factors on hypertension in adulthood with and without the inclusion of a measure of childhood physical fitness

| Restrictive model | n | AUC | Deviance | Brier score | Less restrictive model | AUC | Deviance | Brier score | NRI | IDI | Relative IDI | DeLong test P-value | LR test P-value |
|-------------------------------------|-----|-------|----------|-------------|--|-------|----------|-------------|--------|--------|--------------|---------------------|-----------------|
| Age, sex, SBP, DBP | 899 | 0.724 | 10 085.3 | 0.200 | Age, sex, SBP, DBP, dominant handgrip strength | 0.724 | 10 085.1 | 0.200 | 0.003 | -0.000 | -0.000 | 0.99 | 0.82 |
| Age, sex, SBP, DBP | 899 | 0.722 | 10 104.6 | 0.201 | Age, sex, SBP, DBP, standing long jump | 0.723 | 10 089.4 | 0.201 | 0.033 | 0.001 | 0.006 | 0.85 | 0.22 |
| Age, sex, SBP, DBP | 844 | 0.714 | 10 168.2 | 0.203 | Age, sex, SBP, DBP, 1.6 km run | 0.717 | 10 124.5 | 0.202 | -0.005 | 0.004 | 0.031 | 0.44 | 0.046 |
| Age, sex, SBP, DBP | 876 | 0.725 | 10 086.8 | 0.200 | Age, sex, SBP, DBP, PWC170 | 0.724 | 10 082.2 | 0.200 | 0.008 | 0.001 | 0.004 | 0.68 | 0.48 |
| Age, sex, hypertension | 899 | 0.701 | 10 141.2 | 0.201 | Age, sex, hypertension, dominant handgrip strength | 0.711 | 10 134.3 | 0.201 | 0.003 | 0.001 | 0.007 | 0.29 | 0.25 |
| Age, sex, hypertension | 899 | 0.700 | 10 158.5 | 0.202 | Age, sex, hypertension, standing long jump | 0.712 | 10 147.9 | 0.201 | 0.032 | 0.000 | 0.003 | 0.18 | 0.28 |
| Age, sex, hypertension | 844 | 0.696 | 10 179.5 | 0.202 | Age, sex, hypertension, 1.6 km run | 0.707 | 10 134.0 | 0.201 | -0.006 | 0.004 | 0.032 | 0.29 | 0.06 |
| Age, sex, hypertension | 876 | 0.708 | 10 092.6 | 0.200 | Age, sex, hypertension, PWC170 | 0.708 | 10 085.1 | 0.200 | -0.001 | 0.001 | 0.005 | 0.94 | 0.35 |
| Children with normal blood pressure | | | | | | | | | | | | | |
| Age, sex | 709 | 0.663 | 10 114.6 | 0.199 | Age, sex, dominant handgrip strength | 0.669 | 10 113.7 | 0.198 | 0.014 | 0.000 | 0.004 | 0.43 | 0.37 |
| Age, sex | 710 | 0.661 | 10 134.2 | 0.199 | Age, sex, standing long jump | 0.675 | 10 114.8 | 0.199 | 0.037 | 0.001 | 0.017 | 0.26 | 0.22 |
| Age, sex | 668 | 0.649 | 10 169.8 | 0.201 | Age, sex, 1.6 km run | 0.656 | 10 141.9 | 0.200 | 0.009 | 0.003 | 0.044 | 0.66 | 0.14 |
| Age, sex | 689 | 0.665 | 10 042.0 | 0.197 | Age, sex, PWC170 | 0.662 | 10 040.9 | 0.197 | 0.005 | 0.000 | 0.000 | 0.57 | 0.96 |
| Children with hypertension | | | | | | | | | | | | | |
| Age, sex | 190 | 0.677 | 10 463.0 | 0.210 | Age, sex, dominant handgrip strength | 0.687 | 10 395.4 | 0.210 | 0.001 | 0.004 | 0.028 | 0.66 | 0.44 |
| Age, sex | 189 | 0.675 | 10 475.3 | 0.210 | Age, sex, standing long jump | 0.677 | 10 473.8 | 0.211 | -0.007 | -0.000 | -0.001 | 0.93 | 0.96 |
| Age, sex | 176 | 0.707 | 10 358.5 | 0.205 | Age, sex, 1.6 km run | 0.708 | 10 158.7 | 0.204 | -0.014 | 0.013 | 0.095 | 0.96 | 0.23 |
| Age, sex | 187 | 0.672 | 10 512.9 | 0.212 | Age, sex, PWC170 | 0.712 | 10 253.7 | 0.208 | 0.010 | 0.023 | 0.191 | 0.13 | 0.04 |

All P-values are italicized, with P-values less than 0.05 displayed in bold text. AUC, area under the curve; BMI, body mass index; CI, confidence intervals; DBP, diastolic blood pressure; IDI, integrated discrimination index; LR, likelihood ratio; NRI, net reclassification improvement; PWC170, physical work capacity at 170 b.p.m.; SBP, systolic blood pressure.

Table 4 Indices of the predictive utility of childhood risk factors on obesity in adulthood with and without the inclusion of a measure of childhood physical fitness

| Restrictive model | n | AUC | Deviance | Brier score | Less restrictive model | AUC | Deviance | Brier score | NRI | IDI | Relative IDI | DeLong test P-value | LR test P-value |
|----------------------------------|------|-------|----------|-------------|--|-------|----------|-------------|--------|--------|--------------|---------------------|-------------------|
| Age, sex, BMI | 1674 | 0.750 | 7667.5 | 0.143 | Age, sex, BMI, dominant handgrip strength | 0.754 | 7614.3 | 0.142 | 0.055 | 0.007 | 0.042 | 0.27 | 0.001 |
| Age, sex, BMI | 5033 | 0.749 | 7684.3 | 0.143 | Age, sex, BMI, standing long jump | 0.752 | 7645.4 | 0.142 | 0.149 | 0.005 | 0.032 | 0.16 | <0.0001 |
| Age, sex, BMI | 4681 | 0.748 | 7658.5 | 0.142 | Age, sex, BMI, 1.6 km run | 0.752 | 7627.4 | 0.142 | 0.108 | 0.004 | 0.026 | 0.03 | <0.0001 |
| Age, sex, BMI | 1590 | 0.743 | 7728.9 | 0.144 | Age, sex, BMI, PWC170 | 0.744 | 7720.3 | 0.144 | 0.021 | 0.002 | 0.011 | 0.69 | 0.23 |
| Age, sex, overweight/obesity | 1674 | 0.638 | 8216.4 | 0.153 | Age, sex, overweight/obesity, dominant handgrip strength | 0.641 | 8216.4 | 0.153 | 0.002 | -0.000 | -0.000 | 0.17 | 0.99 |
| Age, sex, overweight/obesity | 5033 | 0.648 | 8163.6 | 0.151 | Age, sex, overweight/obesity, standing long jump | 0.664 | 8107.3 | 0.150 | 0.169 | 0.007 | 0.072 | 0.01 | <0.0001 |
| Age, sex, overweight/obesity | 4681 | 0.647 | 8126.8 | 0.151 | Age, sex, overweight/obesity, 1.6 km run | 0.678 | 8030.2 | 0.149 | 0.193 | 0.011 | 0.120 | <0.0001 | <0.0001 |
| Age, sex, overweight/obesity | 1590 | 0.626 | 8260.4 | 0.153 | Age, sex, overweight/obesity, PWC170 | 0.635 | 8252.1 | 0.153 | 0.016 | 0.001 | 0.008 | 0.17 | 0.22 |
| Children with normal weight | | | | | | | | | | | | | |
| Age, sex | 1508 | 0.535 | 7883.7 | 0.144 | Age, sex, dominant handgrip strength | 0.544 | 7875.0 | 0.144 | 0.032 | 0.001 | 0.362 | 0.26 | 0.25 |
| Age, sex | 4506 | 0.553 | 7765.8 | 0.141 | Age, sex, standing long jump | 0.577 | 7719.1 | 0.140 | 0.131 | 0.006 | 1.115 | 0.01 | <0.0001 |
| Age, sex | 4195 | 0.549 | 7729.1 | 0.140 | Age, sex, 1.6 km run | 0.596 | 7644.7 | 0.139 | 0.204 | 0.010 | 2.423 | <0.0001 | <0.0001 |
| Age, sex | 1436 | 0.527 | 7921.5 | 0.144 | Age, sex, PWC170 | 0.540 | 7891.9 | 0.144 | 0.031 | 0.004 | 2.108 | 0.49 | 0.03 |
| Children with overweight/obesity | | | | | | | | | | | | | |
| Age, sex | 166 | 0.600 | 11 298.2 | 0.233 | Age, sex, dominant handgrip strength | 0.655 | 10 952.6 | 0.224 | 0.028 | 0.039 | 1.323 | 0.17 | 0.01 |
| Age, sex | 527 | 0.573 | 11 530.6 | 0.242 | Age, sex, standing long jump | 0.606 | 11 372.8 | 0.237 | 0.050 | 0.019 | 1.314 | 0.11 | 0.001 |
| Age, sex | 486 | 0.581 | 11 472.0 | 0.240 | Age, sex, 1.6 km run | 0.615 | 11 258.3 | 0.234 | -0.005 | 0.025 | 1.358 | 0.10 | 0.0002 |
| Age, sex | 154 | 0.598 | 11 417.0 | 0.236 | Age, sex, PWC170 | 0.631 | 11 273.8 | 0.231 | 0.022 | 0.019 | 0.726 | 0.31 | 0.06 |

All P-values are italicized, with P-values less than 0.05 displayed in bold text.

AUC, area under the curve; BMI, body mass index; CI, confidence intervals; IDI, integrated discrimination index; LR, likelihood ratio; NRI, net reclassification improvement; PWC170, physical work capacity at 170 b.p.m.

Table 5 Indices of the predictive utility of childhood risk factors on dyslipidaemia in adulthood with and without the inclusion of a measure of childhood physical fitness

| Restrictive model | n | AUC | Deviance | Brier score | Less restrictive model | AUC | Deviance | Brier score | NRI | IDI | Relative IDI | DeLong test P-value | LR test P-value |
|-----------------------------------|-----|-------|----------|-------------|--|-------|----------|-------------|--------|--------|--------------|---------------------|-----------------|
| High LDL-C | | | | | | | | | | | | | |
| Age, sex, LDL-C | 602 | 0.815 | 4727.2 | 0.083 | Age, sex, LDL-C, dominant handgrip strength | 0.815 | 4715.1 | 0.083 | 0.011 | 0.001 | 0.006 | 1.00 | 0.71 |
| Age, sex, LDL-C | 603 | 0.815 | 4723.0 | 0.083 | Age, sex, LDL-C, standing long jump | 0.816 | 4710.2 | 0.082 | 0.030 | 0.003 | 0.016 | 0.80 | 0.34 |
| Age, sex, LDL-C | 573 | 0.811 | 4721.3 | 0.083 | Age, sex, LDL-C, 1.6 km run | 0.811 | 4719.3 | 0.083 | -0.011 | -0.000 | -0.000 | 0.79 | 0.66 |
| Age, sex, LDL-C | 571 | 0.802 | 4791.0 | 0.084 | Age, sex, LDL-C, PWC170 | 0.802 | 4785.1 | 0.084 | -0.002 | 0.001 | 0.005 | 0.87 | 0.67 |
| Age, sex, high LDL-C | 602 | 0.757 | 5190.3 | 0.091 | Age, sex, high LDL-C, dominant handgrip strength | 0.756 | 5184.3 | 0.091 | -0.012 | 0.000 | 0.003 | 0.76 | 0.93 |
| Age, sex, high LDL-C | 603 | 0.757 | 5186.2 | 0.091 | Age, sex, high LDL-C, standing long jump | 0.755 | 5185.9 | 0.091 | 0.015 | 0.000 | 0.002 | 0.65 | 0.99 |
| Age, sex, high LDL-C | 573 | 0.760 | 5175.1 | 0.091 | Age, sex, high LDL-C, 1.6 km run | 0.762 | 5167.2 | 0.091 | -0.008 | 0.001 | 0.006 | 0.71 | 0.45 |
| Age, sex, high LDL-C | 571 | 0.733 | 5182.4 | 0.091 | Age, sex, high LDL-C, PWC170 | 0.728 | 5182.4 | 0.091 | -0.005 | 0.000 | 0.000 | 0.29 | 0.82 |
| Children with normal LDL-C levels | | | | | | | | | | | | | |
| Age, sex | 501 | 0.725 | 4255.4 | 0.070 | Age, sex, dominant handgrip strength | 0.724 | 4254.0 | 0.070 | -0.043 | -0.000 | -0.006 | 0.93 | 0.57 |
| Age, sex | 502 | 0.724 | 4252.2 | 0.070 | Age, sex, standing long jump | 0.728 | 4250.6 | 0.070 | 0.025 | -0.000 | -0.003 | 0.66 | 0.57 |
| Age, sex | 475 | 0.727 | 4203.7 | 0.068 | Age, sex, 1.6 km run | 0.735 | 4202.4 | 0.068 | 0.002 | -0.000 | -0.007 | 0.46 | 0.61 |
| Age, sex | 476 | 0.714 | 4353.6 | 0.072 | Age, sex, PWC170 | 0.728 | 4326.2 | 0.071 | 0.033 | 0.008 | 0.173 | 0.29 | 0.12 |
| Children with high LDL-C levels | | | | | | | | | | | | | |
| Age, sex | 101 | 0.609 | 9753.1 | 0.196 | Age, sex, dominant handgrip strength | 0.610 | 9742.4 | 0.196 | 0.003 | 0.002 | 0.035 | 0.92 | 0.67 |
| Age, sex | 101 | 0.609 | 9753.1 | 0.196 | Age, sex, standing long jump | 0.614 | 9734.6 | 0.196 | 0.007 | 0.002 | 0.045 | 0.73 | 0.60 |
| Age, sex | 98 | 0.597 | 9851.7 | 0.198 | Age, sex, 1.6 km run | 0.625 | 9781.3 | 0.196 | -0.002 | 0.006 | 0.153 | 0.16 | 0.31 |
| Age, sex | 95 | 0.619 | 9229.7 | 0.186 | Age, sex, PWC170 | 0.655 | 8812.3 | 0.178 | 0.032 | 0.046 | 0.734 | 0.42 | 0.06 |
| High triglycerides | | | | | | | | | | | | | |
| Age, sex, triglycerides | 605 | 0.743 | 5082.6 | 0.083 | Age, sex, triglycerides, dominant handgrip strength | 0.747 | 5069.6 | 0.083 | 0.032 | 0.002 | 0.027 | 0.48 | 0.23 |
| Age, sex, triglycerides | 605 | 0.746 | 5126.4 | 0.084 | Age, sex, triglycerides, standing long jump | 0.748 | 5091.8 | 0.083 | -0.004 | 0.004 | 0.052 | 0.83 | 0.10 |
| Age, sex, triglycerides | 573 | 0.744 | 5043.6 | 0.082 | Age, sex, triglycerides, 1.6 km run | 0.744 | 5043.0 | 0.082 | 0.013 | 0.001 | 0.009 | 0.74 | 0.63 |
| Age, sex, triglycerides | 573 | 0.750 | 5143.8 | 0.084 | Age, sex, triglycerides, PWC170 | 0.747 | 5140.4 | 0.084 | -0.011 | 0.000 | 0.002 | 0.44 | 0.96 |
| Age, sex, high triglycerides | 605 | 0.702 | 5250.6 | 0.084 | Age, sex, high triglycerides, dominant handgrip strength | 0.716 | 5241.0 | 0.084 | 0.034 | 0.002 | 0.027 | 0.31 | 0.26 |

Continued

Table 5 Continued

| Restrictive model | n | AUC | Deviance | Brier score | Less restrictive model | AUC | Deviance | Brier score | NRI | IDI | Relative IDI | DeLong test P-value | LR test P-value |
|--|-----|-------|----------|-------------|--|-------|----------|-------------|--------|--------|--------------|---------------------|-----------------|
| Age, sex, high triglycerides | 605 | 0.706 | 5299.2 | 0.085 | Age, sex, high triglycerides, standing long jump | 0.719 | 5262.6 | 0.085 | -0.010 | 0.004 | 0.058 | 0.39 | 0.12 |
| Age, sex, high triglycerides | 573 | 0.693 | 5234.6 | 0.084 | Age, sex, high triglycerides, 1.6 km run | 0.695 | 5224.6 | 0.084 | 0.018 | 0.003 | 0.063 | 0.94 | 0.37 |
| Age, sex, high triglycerides | 573 | 0.702 | 5307.5 | 0.085 | Age, sex, high triglycerides, PWC170 | 0.703 | 5301.6 | 0.085 | -0.001 | 0.000 | 0.002 | 0.97 | 0.92 |
| Children with normal triglyceride levels | | | | | | | | | | | | | |
| Age, sex | 568 | 0.672 | 5102.7 | 0.080 | Age, sex, dominant handgrip strength | 0.690 | 5089.1 | 0.080 | 0.028 | 0.002 | 0.076 | 0.29 | 0.24 |
| Age, sex | 569 | 0.677 | 5151.5 | 0.081 | Age, sex, standing long jump | 0.695 | 5106.8 | 0.081 | 0.016 | 0.006 | 0.183 | 0.30 | 0.11 |
| Age, sex | 540 | 0.661 | 5104.0 | 0.080 | Age, sex, 1.6 km run | 0.658 | 5103.6 | 0.080 | 0.013 | -0.000 | -0.007 | 0.72 | 0.86 |
| Age, sex | 539 | 0.677 | 5158.7 | 0.081 | Age, sex, PWC170 | 0.677 | 5154.4 | 0.081 | 0.019 | 0.000 | 0.002 | 0.98 | 0.90 |
| Children with high triglyceride levels | | | | | | | | | | | | | |
| Age, sex | 37 | 0.825 | 6547.7 | 0.136 | Age, sex, dominant handgrip strength | 0.851 | 6542.6 | 0.137 | -0.004 | -0.001 | -0.003 | 0.16 | 0.76 |
| Age, sex | 36 | 0.819 | 6562.9 | 0.140 | Age, sex, standing long jump | 0.811 | 6561.2 | 0.140 | -0.000 | 0.000 | 0.000 | 0.64 | 0.61 |
| Age, sex | 33 | 0.790 | 6685.5 | 0.144 | Age, sex, 1.6 km run | 0.870 | 5439.2 | 0.111 | 0.024 | 0.189 | 0.901 | 0.31 | 0.06 |
| Age, sex | 34 | 0.818 | 6543.9 | 0.141 | Age, sex, PWC170 | 0.827 | 6542.4 | 0.141 | -0.013 | 0.000 | 0.000 | 0.61 | 0.85 |
| Low HDL-C | | | | | | | | | | | | | |
| Age, sex, HDL-C | 602 | 0.813 | 5813.3 | 0.103 | Age, sex, HDL-C, dominant handgrip strength | 0.820 | 5670.9 | 0.100 | 0.100 | 0.020 | 0.102 | 0.34 | 0.002 |
| Age, sex, HDL-C | 603 | 0.820 | 5742.8 | 0.101 | Age, sex, HDL-C, standing long jump | 0.825 | 5699.4 | 0.101 | 0.060 | 0.003 | 0.015 | 0.23 | 0.048 |
| Age, sex, HDL-C | 572 | 0.822 | 5718.5 | 0.101 | Age, sex, HDL-C, 1.6 km run | 0.831 | 5633.4 | 0.099 | 0.059 | 0.012 | 0.062 | 0.07 | 0.01 |
| Age, sex, HDL-C | 571 | 0.818 | 5705.2 | 0.100 | Age, sex, HDL-C, PWC170 | 0.830 | 5553.5 | 0.096 | 0.062 | 0.027 | 0.138 | 0.13 | 0.001 |
| Age, sex, low HDL-C | 602 | 0.716 | 6371.6 | 0.113 | Age, sex, low HDL-C, dominant handgrip strength | 0.742 | 6300.6 | 0.112 | 0.067 | 0.010 | 0.089 | 0.22 | 0.04 |
| Age, sex, low HDL-C | 603 | 0.723 | 6311.3 | 0.111 | Age, sex, low HDL-C, standing long jump | 0.752 | 6282.8 | 0.111 | 0.049 | 0.002 | 0.021 | 0.13 | 0.13 |
| Age, sex, low HDL-C | 572 | 0.731 | 6260.4 | 0.111 | Age, sex, low HDL-C, 1.6 km run | 0.776 | 6137.0 | 0.109 | 0.069 | 0.016 | 0.127 | 0.02 | 0.001 |
| Age, sex, low HDL-C | 571 | 0.720 | 6292.6 | 0.110 | Age, sex, low HDL-C, PWC170 | 0.754 | 6219.9 | 0.109 | 0.059 | 0.012 | 0.103 | 0.11 | 0.02 |
| Children with normal HDL-C levels | | | | | | | | | | | | | |
| Age, sex | 573 | 0.702 | 6198.5 | 0.108 | Age, sex, dominant handgrip strength | 0.730 | 6150.7 | 0.107 | 0.045 | 0.006 | 0.069 | 0.15 | 0.13 |

Continued

Table 5 Continued

| Restrictive model | n | AUC | Deviance | Brier score | Less restrictive model | AUC | Deviance | Brier score | NRI | IDI | Relative IDI | DeLong test P-value | LR test P-value |
|--------------------------------|-----|-------|----------|-------------|--------------------------------------|-------|----------|-------------|--------|--------|--------------|---------------------|-----------------|
| Age, sex | 574 | 0.705 | 6133.9 | 0.106 | Age, sex, standing long jump | 0.734 | 6110.0 | 0.106 | 0.045 | 0.002 | 0.020 | 0.15 | 0.17 |
| Age, sex | 545 | 0.711 | 6103.3 | 0.106 | Age, sex, 1.6 km run | 0.761 | 5979.2 | 0.103 | 0.076 | 0.020 | 0.237 | 0.02 | 0.001 |
| Age, sex | 542 | 0.705 | 6103.5 | 0.105 | Age, sex, PWC170 | 0.735 | 6044.3 | 0.104 | 0.047 | 0.009 | 0.114 | 0.13 | 0.047 |
| Children with low HDL-C levels | | | | | | | | | | | | | |
| Age, sex | 29 | 0.740 | 7989.1 | 0.196 | Age, sex, dominant handgrip strength | 0.750 | 6747.0 | 0.188 | 0.017 | 0.107 | 0.398 | 0.79 | 0.046 |
| Age, sex | 29 | 0.740 | 7989.1 | 0.196 | Age, sex, standing long jump | 0.721 | 7771.2 | 0.193 | -0.005 | 0.013 | 0.047 | 0.41 | 0.46 |
| Age, sex | 27 | 0.733 | 7053.7 | 0.218 | Age, sex, 1.6 km run | 0.717 | 7053.0 | 0.218 | -0.004 | -0.001 | -0.002 | 0.56 | 0.98 |
| Age, sex | 29 | 0.740 | 7989.1 | 0.196 | Age, sex, PWC170 | 0.740 | 7290.8 | 0.194 | 0.011 | 0.058 | 0.214 | 1.00 | 0.12 |

All P-values are italicized, with P-values less than 0.05 displayed in bold text.

AUC, area under the curve; BMI, body mass index; CI, confidence intervals; HDL-C, high-density lipoprotein cholesterol; IDI, integrated discrimination index; LDL-C, low-density lipoprotein cholesterol; LR, likelihood ratio; NRI, net reclassification improvement; PWC170, physical work capacity at 170 b.p.m.

their physical fitness measured as children and their CV health assessed 20–34 years later in young and/or middle adulthood. These data enabled novel longitudinal associations between childhood physical fitness and adult CV risk factors to be examined. Furthermore, a range of measures of physical fitness were assessed in childhood, including field-based and sub-maximal measures of CRF and different phenotypes of muscular fitness, including muscular strength (handgrip strength) and muscular power (standing long jump)—two measures of muscular fitness endorsed by North American experts from the National Academy of Medicine and European experts from the ALPHA project.

In conclusion, CRF and muscular fitness are independent health indicators that could complement other risk factors in childhood to identify individuals at increased long-term CV risk.

Supplementary material

Supplementary material is available at *European Journal of Preventive Cardiology*.

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Author contribution

B.J.F. contributed to the conceptualization of the paper, analysed the data, and wrote the manuscript. C.G.M. contributed to the conceptualization of the paper, provided statistical advice, assisted with the interpretation, and critically reviewed the manuscript. L.B. provided statistical advice, assisted with the interpretation, and critically reviewed the manuscript. G.R.T. contributed to discussion and critically reviewed the manuscript. T.D. and A.J.V. participated in the study design, contributed to the discussion, and critically reviewed the manuscript.

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Data availability

The data underlying this current study are available from the corresponding author on reasonable request.

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