Decline in physical fitness from childhood to adulthood associated with increased obesity and insulin resistance in adults

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Objective: To examine how child and adult fitness are associated with adult obesity and insulin resistance.

Research Design and Methods: Prospective cohort study.
Setting: Australia.
Participants: A follow-up cohort of 647 adults in 2004-6 who were participants of the Australian Schools Health and Fitness Survey in 1985 (aged 9 to 15 years) who had an anthropometry and cardiorespiratory fitness assessment.
Outcome measures: Insulin resistance was defined as a HOMA index above the 75th sex-specific percentile. Adults with a BMI $\geq 30\text{kg/m}^2$ were termed obese.

Results: Lower levels of child cardiorespiratory fitness were associated with increased odds of adult obesity (adjusted OR per unit increase = 3.0, 95% CI: 1.6 to 5.6) and insulin resistance (adjusted OR = 1.7, 95% CI: 1.1 to 2.6). A decline in fitness level between childhood and adulthood was associated with increased obesity (adjusted OR = 4.5, 95% CI: 2.6 to 7.7) and insulin resistance (adjusted OR = 2.1, 95% CI: 1.5 to 2.9) per unit decline.

Conclusions: A decline in fitness from childhood to adulthood, and by inference a decline in physical activity, is associated with obesity and insulin resistance in adulthood. Programs aimed at maintaining high childhood PA levels into adulthood may have potential for reducing the burden of obesity and type 2 diabetes in adults.
The increasing burden of adult obesity and type 2 diabetes has made the search for prevention more urgent. Trials indicate that the prevalence of obesity and incidence of type 2 diabetes can be reduced by physical activity interventions in adulthood even over 3 years.\(^1\)

The role of physical activity in childhood is unclear. With little cohort and no trial data, the decline in physical activity from childhood to adulthood has been linked to adult adiposity but the associations have been variable.\(^2\)-\(^6\) The inability to find a clear association may be due to measurement error in these studies, which compared questionnaire data over time.

Change in cardiorespiratory fitness in an individual is strongly correlated with a change in habitual energy expenditure and physical activity undertaken during leisure time.\(^7\) Data on change in cardiorespiratory fitness from one time point to another might be a better marker of change in physical activity.\(^8\) Change in fitness from age 17 to 25 has been more strongly associated with adult measures of adiposity than change in physical activity by questionnaire.\(^2\) No study has reported on the association of change in cardiorespiratory fitness between childhood and adulthood with adult insulin resistance, a type 2 diabetes precursor.

We examined the association of change in cardiorespiratory fitness from childhood to adulthood with obesity and insulin resistance in adulthood.

**RESEARCH DESIGN AND METHODS**

**Participants:** The Childhood Determinants of Adult Health (CDAH) study is a prospective cohort study.\(^9\),\(^10\) Baseline data were collected in 1985 on a representative sample of 8498 children aged 7 to 15 years as part of the Australian Schools Health and Fitness Survey (ASHFS). Sampling procedures and methods of data collection are presented elsewhere.\(^11\) Children who were aged 9, 12, and 15 years underwent additional measurements with 2595 completing a sub-maximal cardiorespiratory fitness test and an estimate of lean body mass. The follow-up study was performed from 2004 to 2006 across 34 clinics. In total, 60.8\% (n=5170) provided follow-up data, with 19.5\% (n=1658) unable to be traced, 9.6\% (n=817) did not respond to contact, 9.0\% (n=767) refused to participate and 1.0\% (n=86) deceased. Of the original sample with child fitness, 61.3\% (n=1590) participated in follow-up and 647 of these also had an adult measure of cardiorespiratory fitness and lean body mass at a clinic. The childhood characteristics of those with child fitness who also had adult fitness measured were very similar to those who did not, with the exception of socioeconomic status (SES). That is: mean age 11.8 years vs. 10.8 years; males 51.6\% vs. 50.6\%, mean BMI 18.5 vs. 18.2 kg/m\(^2\) and mean fitness 2.71 vs. 2.75 W/kg but differing for SES 22.8\% vs. 31.3\% in highest quartile, p<0.01). Further, the child to adulthood trajectory for BMI increase was very similar for these 647 compared with all in the follow-up (mean increase in BMI 6.4 vs. 6.9 kg/m2; p=0.62). The studies were ethically approved, with written informed consent.

**Outcome variables:** 

**Obesity**—Body mass index (BMI) was calculated using the formula: BMI = weight, kg/(height, m)\(^2\). Obesity in adulthood was defined as a BMI of 30 kg/m\(^2\) or more.

**Insulin resistance**: Fasting plasma glucose levels were measured by
the Olympus AU5400 automated analyser. Two methods of insulin determination were used during the follow-up study. Fasting plasma insulin was measured by a microparticle enzyme immunoassay kit (AxSYM, Abbot Laboratories, Abbot Park, Illinois, USA) and by electrochemiluminescence immunoassay (Elecsys Modular Analytics E170; Roche Diagnostics, Mannheim, Switzerland) with inter-assay standardisation.

Insulin sensitivity was estimated by the homeostasis model assessment (HOMA) index, defined as fasting insulin (µU/mL x fasting glucose (mmol/L)/22·5. Insulin resistance was defined as a HOMA Index ≥ 75th sex-specific percentile.

Predictor variable:

Cardiorespiratory fitness—Cardiorespiratory fitness was estimated at baseline and follow-up as physical working capacity at a heart rate of 170 beats per minute (PWC170) on a bicycle ergometer (Monark Exercise AB, Sweden) pedalled at a cadence of 60 revolutions per minute.

Baseline and follow-up cardiorespiratory fitness was expressed in relative terms as watts per kilogram (W/kg) of lean body mass. Relative cardiorespiratory fitness is preferred because the absolute workload (watts) achieved is a function of muscle mass.

Lean body mass in childhood and adulthood was calculated from body density and percent body fat equations that used baseline and follow-up measures of skin fold thickness. In 1985, tricep, bicep, subcapular, and suprailiac skin folds were measured at locations determined by reference to anatomical landmarks on the right side of the body using Holtain Calipers to the nearest 0·1 mm. Skin fold measures at follow-up of more than 40 mm were truncated and skin fold values were imputed from BMI and waist circumference. Body density was estimated from the log of the sum of four skin folds using age-specific regression equations. Calculations of body fat were made. Lean body mass was estimated by subtracting fat mass from total body mass.

Covariates:

Socio-economic status—Child residential postcode was used to derive area-level socio-economic status (SES) based on the Australian Bureau of Statistics index of relative socio-economic disadvantage derived from the 1981 population census.

Alcohol Consumption—Alcohol consumption at follow-up was calculated from an alcohol questionnaire using a frequency grid.

Smoking—Cigarette smoking at baseline and follow-up was measured by self-administered questionnaire. Those smoking daily were classified as regular smokers.

Dietary habits—Information about food habits were collected at follow-up. Scores from three questions linked to fat intake (milk type, meat fat, use of spreads) formed a variable for fat intake.

Physical activity—In the adult survey only, pedometers (Yamax Digiwalker SW-200) were worn during waking hours for seven consecutive days to measure ambulatory activity. For participants with four or more measurement days, the average number of steps per day was calculated. Physical activity was also measured by questionnaire in both childhood and adulthood. The associations for both childhood physical activity and change in physical activity were not statistically significant except for change in physical activity and obesity (p = 0·05).

Statistical analyses: The characteristics of subjects included in this
analysis were compared with other subjects using the t-test for continuous variables and the Chi-squared test for categorical variables. A life course analysis was taken to relate cardiorespiratory fitness to the outcomes of BMI and HOMA, obesity status and insulin resistance. Linear and logistic regression was used for the continuous or binary outcomes respectively. The coefficient (or odds ratio) for child fitness quantifies the total (i.e. mediated via adult fitness and unmediated) effect of poor child fitness. The coefficient for change in fitness quantifies the additional detriment that results from decreasing fitness between childhood and adulthood. Adjustment for confounders is listed in table footnotes.

Also, a composite fitness variable was created. Subjects who were in the lowest fitness category both in childhood and adulthood were classified as persistent low fitness (lowest tertile at both waves), those who dropped by one or two categories between childhood and adulthood were classified as decreasing fitness (decline of one or two categories), persistent moderate fitness (middle tertile at both waves) increasing fitness (increase of one or two categories), persistent high fitness (highest tertile both waves). The relationship between this profile and the number of steps at adulthood and fitness level at adulthood are examined with an analysis of variance. Tests for interaction did not show differential effects between males and females.

RESULTS

Table 1 shows that in childhood but not adulthood, males had higher mean values for fitness and lean body mass than females. Mean fitness increased for females but not males from childhood to adulthood and BMI increased substantially for both.

Table 2 indicates that there is a clear association between increasing composite child-adult fitness and mean step count (p=0.007). Pedometer step count was associated with adult fitness (p<0.001).

Figure 1 shows that for each unit increase in child fitness, adult fitness increased by 0.21 (95% CI: 0.14 to 0.28) units. Table 3 shows that subjects who were unfit as children had increased odds of being obese, and having insulin resistance. Similar findings were evident for serum insulin level (data not shown).

Fit children were more likely to be fit adults (Figure 1) and so fitness in childhood has an important indirect effect, mediated by adult fitness. The results also suggested that there were clear disadvantages for subjects who decreased their fitness levels between childhood and adulthood, with this predictor showing even stronger associations with adult outcomes than did child fitness. The estimated coefficients and odds ratios were similar to those from analyses in which further adjustments for smoking status and alcohol and fat intake in adulthood were made (data not shown).

Figure 2 shows that the proportion of subjects with obesity and the proportion of subjects with insulin resistance were higher in the decreasing fitness and persistent low fitness groups than in the persistent high fitness and increasing fitness groups. Taken together, these findings suggest that confounding by initial child fitness status or BMI does not explain the association of decreasing fitness with higher adult obesity and higher insulin resistance. The principal factor determining whether an individual has a low risk of obesity and insulin resistance in early adulthood is whether
they are at a relatively high level of fitness in adulthood. In order to assess the robustness of these estimates to loss to follow-up, population weighted analyses were implemented with respect to the following variables measured at baseline: gender, age, socio-economic status, smoking status, BMI and relative fitness. The weight for each subject was the inverse of the probability of providing follow-up data given their status on the above factors. The results for the weighted analyses were similar to the non-weighted ones, suggesting that there is no loss to follow-up bias related to lack of representativeness on the variables used to calculate the weights.

We restricted the analysis to non-obese children only and again found lower child fitness (adjusted OR 2.9; 95% CI: 1.8 to 4.8; p<0.001) and decreasing fitness (adjusted OR 3.9; 95% CI: 2.5 to 6.1; p<0.001) were associated with adult obesity, showing the findings did not reflect reverse causality.

The association between fitness decrease and insulin resistance persisted after adjustment for either child BMI or waist circumference. Even after accounting for adult obesity, poor child fitness or fitness decrease was associated with a higher risk of insulin resistance with adjusted odds ratios of 1.5 (95% CI: 1.0 to 2.3; p=0.06) and 1.6 (95% CI: 1.1 to 2.2; p=0.011) respectively.

CONCLUSIONS
The findings indicate that a decline in fitness and by inference a decline in physical activity from childhood to adulthood is a stronger predictor of adult obesity and insulin resistance than low levels of fitness in childhood. This is supported by data from one study which focussed on change in physical activity from childhood to early adulthood. These findings indicate that programs that encourage physical activity earlier in life are also likely to be important. Firstly, a fit child is more likely to be a fit adult partaking in more physical activity in adulthood. Child fitness is an important determinant of adult fitness at the population level. Further, after accounting for change in fitness over time, low fitness children were more likely to have unfavourable obesity and insulin resistance outcomes. Importantly, the findings here indicate that programs that help maintain fitness in those already fit and improve fitness in those who are unfit as children will be important.

Change in fitness is likely to be a good proxy for change in physical activity, as supported by the finding that physical activity measured by pedometer in adulthood was higher in the persistent high or increasing fitness groups. Alcohol consumption, smoking, and dietary habits of fat intake at adulthood were excluded as potential confounders of the observed associations. Bias due to subject selection is also unlikely to explain the results. The childhood characteristics of those with child fitness who also had adult fitness measured were very similar to those who did not, with the exception of socioeconomic status. Lower SES individuals in this cohort were more likely to become obese over time. The loss of these individuals from the decreasing fitness group would have the effect of biasing the association towards the null, thus the findings are likely to be conservative. The longitudinal fitness sample was similar to recent Australian surveys with regard to the proportion of subjects undertaking sufficient physical activity (males 42.4% vs. 44.1%; females 42.8% vs. 49%) and the proportion overweight or obese (male 55.8% vs. 57.7%; females 29.0% vs. 35.4%).
Furthermore, the results from the weighted analysis indicated the findings were robust and that loss to follow-up was unlikely to have influenced the findings.

The effect of a longitudinal fitness decrease on insulin resistance persisted after adjustment for child BMI, adult BMI or adult obesity status. This indicates that the effect of a decline in fitness on insulin resistance is not solely due to an associated lower adult BMI. Possible direct effects via changes in muscle metabolism, for example, must be considered.

In conclusion, these data strongly suggest that a decline in cardiorespiratory fitness from childhood to adulthood, and by inference a decline in physical activity, is associated with a higher prevalence of obesity and insulin resistance in adulthood. Programs aimed at maintaining childhood physical activity levels into adulthood have potential for reducing the burden of obesity and type 2 diabetes in adults.

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**Contributors:** TD was involved in the 1985 study design and TD, AV and PZ in the 2004-6 study design. CM and VC were involved in data collection. OU and RT undertook the statistical analysis. All investigators contributed to data interpretation and writing the report. All investigators had access to all data in the study and held final responsibility for the decision to submit for publication.

**Guarantor:** Terence Dwyer

**Conflict of interest statement:** All authors declare that the answer to the questions on your Conflict of Interest form are all “no” and therefore have nothing to declare.

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Table 1: Summary of study variables in childhood and adulthood: mean (standard deviation) except where stated otherwise

| Characteristic                                             | Males          | Females         |
|-----------------------------------------------------------|----------------|-----------------|
|                                                           | N Statistic    | N Statistic     |
| **Childhood (1985)**                                      |                |                 |
| Age, y                                                     | 334 11.9 (2.4) | 313 11.8 (2.4)  |
| SES status                                                | 324 31.2       | 305 31.5        |
| Highest quartile, %                                       |                |                 |
| 3<sup>rd</sup> quartile, %                                | 25.9           | 26.9            |
| 2<sup>nd</sup> quartile, %                                | 33.3           | 35.7            |
| Lowest quartile, %                                        | 9.6            | 5.9             |
| Relative cardiorespiratory fitness, W/kg                  | 334 3.02 (0.62)| 313 2.48 (0.65)|
| Lean body mass, kg                                        | 334 36.4 (11.3)| 313 31.7 (7.3) |
| Body mass index, kg                                       | 334 18.4 (2.7) | 313 18.5 (2.8) |
| Smoking prevalence, %                                     | 328 10.4       | 308 12.0        |
| **Adulthood (2004-2006)**                                 |                |                 |
| Age, y                                                     | 334 31.9 (2.5) | 313 31.7 (2.6)  |
| Relative cardiorespiratory fitness, W/kg                  | 334 3.07 (0.59)| 313 2.97 (0.69)|
| Lean body mass, kg                                        | 334 64.4 (7.6) | 313 45.0 (6.7) |
| Glucose, mmol/L                                           | 329 5.19 (0.42)| 306 4.83 (0.41)|
| Insulin, µU/ml                                             | 323 7.36 (5.27)| 301 6.66 (3.92)|
| HOMA index                                                | 323 1.73 (1.35)| 301 1.46 (0.93)|
| Body mass index, kg                                       | 334 26.4 (3.9) | 313 25.0 (5.5) |
| Regular smoking prevalence, %                            | 319 21.6       | 306 16.7        |
| Alcohol consumption in g/week, median (IQR)               | 284 47 (17 to 100)| 275 28 (11 to 83)|
| Physical activity, steps/day                              | 276 9171 (3802)| 258 9121 (3083)|
| Obese, %                                                  | 334 15.3       | 313 14.4        |
| Insulin resistance, %                                     | 323 24.8       | 301 24.9        |

Table 2: Mean (sd) daily step counts and relative fitness in adulthood according to changes in fitness from childhood to adulthood

| Category of fitness change | N   | Mean (sd) step counts | N   | Mean (sd) fitness, W/kg |
|----------------------------|-----|-----------------------|-----|-------------------------|
| Persistent unfit           | 82  | 8948 (2593)           | 89  | 2.33 (0.29)             |
| Decreasing fitness         | 167 | 8461 (3093)           | 163 | 2.65 (0.38)             |
| Persistent moderate fitness| 63  | 9300 (2921)           | 66  | 2.97 (0.18)             |
| Increasing fitness         | 148 | 9908 (4407)           | 164 | 3.45 (0.46)             |
| Persistent high fitness    | 74  | 9262 (3164)           | 77  | 3.81 (0.51)             |
| *P*-value                  |     | 0.007                 |     | <0.001                  |
Table 3: Effect of change in fitness from childhood to adulthood on obesity and insulin resistance in adulthood for all subjects

| Outcome | Predictor | Adjusted for sex and baseline age only | Fully Adjusted<sup>1</sup> |
|---------|-----------|----------------------------------------|-----------------------------|
|         |           | odds ratio | 95% CI | p value | odds ratio | 95% CI | p value |
| Obesity (Adult BMI ≥ 30kg/m²) | Poorer child fitness<sup>2</sup> | 3.0 | 1.8 to 5.1 | <0.001 | 3.0 | 1.6 to 5.6 | <0.001 |
| | Decreasing fitness<sup>3</sup> | 3.9 | 2.5 to 6.1 | <0.001 | 4.5 | 2.6 to 7.7 | <0.001 |
| Insulin resistance (Adult HOMA Index ≥ 75<sup>th</sup> sex-specific centile) | Poorer child fitness<sup>2</sup> | 1.9 | 1.3 to 2.9 | 0.001 | 1.7 | 1.1 to 2.6 | 0.01 |
| | Decreasing fitness<sup>3</sup> | 2.2 | 1.5 to 3.0 | <0.001 | 2.1 | 1.5 to 2.9 | <0.001 |
|          | coefficient | 95% CI | p value | coefficient | 95% CI | p value |
| Adult BMI, kg/m² | Poorer child fitness<sup>4</sup> | 1.30 | 0.56 to 2.04 | <0.001 | 0.96 | 0.34 to 1.58 | 0.002 |
| | Decreasing fitness<sup>5</sup> | 1.86 | 1.27 to 2.44 | <0.001 | 1.72 | 1.22 to 2.21 | <0.001 |
| Adult HOMA index | Poorer child fitness<sup>4</sup> | 0.26 | 0.08 to 0.45 | 0.007 | 0.18 | -0.0003 to 0.36 | 0.05 |
| | Decreasing fitness<sup>5</sup> | 0.38 | 0.24 to 0.52 | <0.001 | 0.33 | 0.19 to 0.48 | <0.001 |

Sample sizes were 601 for the analyses of obesity status and BMI; and 581 for the analyses of the HOMA outcomes.
<sup>1</sup>Adjusted for sex, age, SES at baseline and education level at follow-up. Analyses of obesity status and BMI additionally adjusted for BMI at baseline; analyses of HOMA outcomes additionally adjusted for waist circumference at baseline.
<sup>2</sup>Odds ratios for a one unit decrease in childhood fitness
<sup>3</sup>Odds ratios for a one unit decrease in fitness change
<sup>4</sup>Coefficient is the mean increase in the outcome for a one unit decrease in childhood fitness
<sup>5</sup>Coefficient is the mean increase in the outcome for a one unit decrease in fitness change
Figure legends

Figure 1: Scatter plot of adult fitness level versus child fitness level
Figure 2: Percentage of obese subjects and those with HOMA above the 75th percentile for each fitness change category
