

Tracking of muscular strength and power from youth to young adulthood: Longitudinal findings from the  
Childhood Determinants of Adult Health Study

Short Running Title: Youth to adulthood tracking of muscular strength and power

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## **Abstract**

**Objectives:** Low muscular fitness levels have previously been reported as an independent risk factor for chronic disease outcomes. Muscular fitness tracking, the ability to maintain levels measured at one point in time to another point in time, was assessed from youth to adulthood to provide insight into whether early identification of low muscular fitness in youth is possible.

**Design:** Prospective longitudinal study.

**Methods:** Study including 623 participants who had muscular fitness measures in 1985 (aged 9, 12 or 15 years) and again 20 years later in young adulthood. Measures of muscular fitness were strength (right and left grip, leg, shoulder extension and flexion measured by dynamometer, and a combined strength score) and power (standing long jump distance).

**Results:** Strength and power were relatively stable between youth and adulthood; the strongest tracking correlations were observed for the combined strength score ( $r=0.47$ ,  $p\leq 0.001$ ), right grip strength ( $r=0.43$ ,  $p\leq 0.001$ ) and standing long jump ( $r=0.43$ ,  $p\leq 0.001$ ). Youth in the lowest third of muscular fitness had an increased risk of remaining in the lowest third of muscular fitness in adulthood (strength: relative risk (RR)=4.70, 95% confidence interval (CI) (3.19, 6.92); power: RR=4.06 (2.79, 5.90)).

**Conclusions:** Youth with low muscular fitness are at increased risk of maintaining a low muscular fitness level into adulthood. These findings warrant investigation into the long term effects of early interventions that focus on improving low muscular fitness levels in youth which could potentially improve adult muscular fitness and reduce future chronic disease outcomes.

**Keywords:** physical fitness, exercise, hand strength, paediatrics

## Introduction

Muscular fitness is a unique fitness phenotype that incorporates strength, power and endurance<sup>1</sup>.

Observational studies have shown low levels of muscular fitness to be associated with increased disability, morbidity, and mortality<sup>2-4</sup> independent of cardiorespiratory fitness and measures of adiposity. In a recent analysis of almost 140,000 individuals from 17 countries of varying incomes (median age: 50 years old) in the Prospective Urban Rural Epidemiology study, muscular strength was shown to be as strong a predictor of all-cause and cardiovascular mortality as systolic blood pressure<sup>5</sup>. Consequently, the early identification and possible intervention of individuals with low muscular fitness may improve long-term health outcomes.

Because many chronic disease risk factors are established in childhood and adolescence (herein termed youth), studies have been undertaken to examine the extent to which risk factors measured in youth predict the same measure collected years later in adulthood. These *tracking* studies attempt to determine the stability of a risk factor over time. Risk factors that track sufficiently provide a means for early identification and possible intervention among those where the risk factor is present. Evidence for tracking of muscular fitness phenotypes is sparse, with most previous research examining tracking of muscular fitness phenotypes throughout youth alone<sup>6-8</sup>. However, longitudinal evidence that muscular fitness phenotypes track between youth and adulthood is limited<sup>9-11</sup>.

Using data from the Childhood Determinants of Adult Health (CDAH) Study, a 20-year prospective cohort beginning in youth, we aimed to determine the extent to which muscular fitness phenotypes of strength and power track from youth to adulthood.

## Methods

In 1985, a representative sample of 2,726 Australian school youth aged 9, 12 and 15 years participating in the Australian Schools Health and Fitness Survey (ASHFS) had field measures of muscular fitness as well as other health-related risk factors collected. Details on the ASHFS sampling strategy have been

published elsewhere<sup>12</sup>. In 2004-2006, the CDAH study conducted 34 follow-up clinics across Australia where participants from the 1985 ASHFS were invited to attend as young adults aged 26-36 years. Here, muscular fitness phenotypes and other risk factors were remeasured. Of those eligible from the baseline survey, 805 (29.5%) attended follow-up clinics with 623 (22.9%) providing muscular fitness measures. The remaining 182 had contraindications to completing the muscular fitness measures (reasons for exclusion included any neck or back pain, a resting systolic blood pressure >180 mmHg or a resting heart rate >100 beats per minute, had had a knee or hip replacement, were more than 3 months pregnant, weighed more than 160 kilograms or had a previous injury that could be exacerbated by performing a muscular fitness test). A flow chart of participation is presented in Figure S1. Inclusion into the study at baseline required both parental and youth consent, with written consent from the participant required at follow-up. The State Directory General of Education approved the baseline study and the Southern Tasmania Health and Medical Human Research Ethics Committee approved the follow-up study.

The muscular fitness phenotypes measured at both time-points were strength and power. Strength was estimated from maximum voluntary contractions of the right and left hand grip, shoulder extension and flexion, and leg extension, using isometric dynamometers (Smedley's Dynamometer, TTM, Tokyo, Japan). For each strength measure, the maximum of two attempts was used in the analysis. Right and left grip strength was measured as participants gripped the dynamometer with maximum force in one hand. Shoulder strength (flexion and extension) was measured as participants held the dynamometers in front of their chest with both hands parallel to the ground. Shoulder extension was tested as participants pulled the dynamometer as far apart as possible, whilst shoulder flexion was measured by pushing their hands as close together as possible. Leg strength was measured using a leg-back dynamometer by standing flat-footed on a platform with a straight back flat against a wall. A hand bar was held with an overhand grip, knees were flexed until an angle of 115° was measured, at which point the bar was attached to the dynamometer by a chain. The bar was then pulled as far upwards as possible by sliding their body up the wall. All five strength measures were combined into a single score of muscular strength using principal

component analysis, whereby an estimate of the first principal component of each of the five strength measures was obtained<sup>13, 14</sup>. Power was estimated from the best resulting distance in centimetres from two attempts of a standing long jump. The standing long jump required a two-footed take-off and landing. The standing long jump test is practical, time efficient and cost effective, and has been reported as a valid and reliable field based test measure power in youth<sup>15</sup>, whilst test-retest reliability of this measure has additionally been shown in adult cohorts<sup>16, 17</sup>. All individual and combined strength and power measures were adjusted for body mass by regressing body mass on each muscular fitness phenotype and using age and sex standardised residuals in the analysis<sup>13</sup>.

Body mass was measured to the nearest 0.5kg using regularly calibrated scales in youth and with Digital Heine portable scales (Heine, Dover, NH, USA) to the nearest 0.1kg in adulthood. In youth, height was measured to the nearest 0.1cm using a Kawe height tape, whilst body mass index (BMI) was calculated as height (kg) divided by height (m<sup>2</sup>). At the level of the umbilicus, youth waist circumference was measured to the nearest 0.1cm using a constant-tension tape. Residential postcodes were used to categorise socioeconomic position in youth, using the Australian Bureau of Statistics Socio-economic Index for Areas and 1981 census data; additional details have been previously described<sup>18</sup>. In this study, socioeconomic position is categorised as low, medium (grouping medium-low and medium-high) and high.

All statistical analyses were performed using Stata (Version 12.1, StataCorp, College Station, Texas). Participant characteristics at baseline and follow-up are presented as mean and standard deviation (SD) for males and females separately. All of the examined variables were normally distributed. Baseline characteristics of participants and non-participants were compared using t-tests for continuous variables and chi-squared tests for categorical variables. Non-participants were defined as those who provided a complete set of muscular fitness measures in youth and either did not participate at follow-up or lacked a full set of muscular fitness measures in adulthood. Tracking of strength and power are represented by

correlation and stability analyses. For the correlation analyses, the body mass adjusted phenotypes at youth and adulthood were ranked and Partial Pearson's correlations were performed between ranks in youth and adulthood. Each correlation was adjusted for length of follow-up, with the inclusion of sex and youth age in the model when appropriate (e.g. when sex or ages were combined). Stability tracking was estimated by categorising strength and power at both time-points into age- and sex-specific thirds and cross-tabbing youth thirds with adult thirds. The relative risk and 95% confidence intervals of being in each third of the adult muscular fitness phenotypes based on youth muscular fitness levels was estimated using a log multinomial regression model<sup>19</sup>. The highest third of the adult strength and power phenotypes and youth strength and power phenotypes was used as the referent group with each model adjusted for youth age, sex and length of follow-up. For each log multinomial regression model, we considered interactions between muscular strength and power thirds and sex, by fitting multiplicative interaction terms. No evidence of a significant interaction was found.

## **Results**

Pertinent baseline and follow-up characteristics of the 623 participants are presented in Table 1. Mean (SD) length to follow-up was 19.9 (0.6) years, ranging from 18.7-21.0 years. Compared with females, males had on average more muscular phenotypes in youth and adulthood.

On average participants had a higher combined strength score, a greater distance in the standing long jump test and had a greater proportion of people in high socioeconomic position compared to non-participants (Table S1). Whereas, non-participants had both larger measures of BMI and waist circumference compared to participants. At baseline, no other differences were found between participants and non-participants.

Table 2 shows the sex and age specific Partial Pearson's correlation coefficients for the tracking of each strength measure and standing long jump between youth and adulthood. Tracking tended to be stronger as baseline age increased, with those aged 15 years at baseline generally showing the strongest correlations.

When analysing the cohort as whole, females tracked more strongly than males in all upper body strength measures, whereas leg strength and standing long jump tracked more strongly in males. Right grip strength, the combined strength score, and standing long jump showed the strongest correlations.

Table 3 shows the relative risks and 95% confidence intervals of being in the middle and lowest third of adult strength and power according to youth strength and power thirds. The likelihood of being in the lowest third of adult power compared to the highest third, is 4.06 times higher for those in the lowest third in youth, compared to those in the highest youth third. This trend was similar for strength. The likelihood of remaining in the lowest strength third in both youth and adulthood, compared to being low in youth and high in adulthood, was 4.70 times greater compared with those who were in the highest youth strength third. This trend was reinforced by the proportion of participants who maintained the same strength and power third from youth to adulthood (remained in the lowest third between youth and adulthood: strength=56.7%; power=52.9%, as shown in Figure S2A and S2B and Table S2).

To account for differential loss to follow-up observed in Table S1 for the combined strength score, standing long jump test, waist circumference and socioeconomic position, inverse probability weighting was performed and the log multinomial regression models presented in Table 3 were repeated. The weighted analyses were consistent with our primary results, with an absolute difference in relative risk values of 0.35 for strength and -0.38 for power (strength: RR=5.05, 95% CI= (3.43, 7.43); power: RR=3.68, 95% CI= (2.60, 5.22)), and statistical significance remained ( $p \leq 0.001$ ).

## Discussion

The results of this tracking analysis showed that muscular fitness phenotypes tracked moderately between youth and young adulthood. Youth who were older at the baseline measurement tended to track the most, and females tracked more strongly in upper body strength measures, whereas males tracked stronger in the lower body strength and power measures. Furthermore, youth power and strength was shown to predict adult levels, with those in the lowest third in youth approximately four times more likely to maintain this level at adult follow-up compared with those in the highest third.

Overall, grip strength and the standing long jump were the individual muscular fitness measures that provided the strongest tracking correlations. These two fitness tests have previously been identified as valid field based tests to measure strength and power in youth<sup>1, 15, 20, 21</sup>. Subsequently, the observations of stronger tracking in these phenotypes may be indicative of reduced error in their measurement.

Previous data have shown that standing long jump tracks relatively consistently in youth<sup>6, 7</sup>, however these results have been limited by a short duration of follow-up (3-4 years). To our knowledge, no studies tracking standing long jump performance have spanned youth to adulthood. The Leuven Growth Study of Belgian Boys (N=173, baseline age of 13 years, follow-up duration of 17 years) and Flemish Girls (N=138, baseline age of 16.6 years, follow-up of 24 years) used vertical jump as a measure of muscular power. They showed correlations between baseline and follow-up of  $r=0.52$  (males) and  $r=0.59$  (females)<sup>10, 11</sup>, which is somewhat stronger than those observed for standing long jump in our study. The stronger correlations observed in the Leuven Growth Study may have been a result of the older average baseline age of participants compared with CDAH. For example, we observed the strongest tracking for standing long jump among those aged 15 years at baseline. Stronger tracking amongst those of older baseline age in our study and the Leuven study might be due to a more stable lean body mass and total body mass that coincides with later stage puberty compared with pre- and peri-pubertal youth. These factors are relevant as each muscular fitness measure assessed in this study was regressed on total body mass. Although we were unable to account for



pubertal status in our analyses because a measure of sexual maturation was not obtained at baseline, age-based groups are appropriate proxy measures for developmental stage<sup>22</sup>.

Grip strength has previously been shown to track reasonably well<sup>7, 8, 23</sup>. However, these earlier cohorts had a shorter duration of follow-up (3 to 7 years)<sup>7, 8, 23</sup>, were restricted to females<sup>7</sup>, or had a wide range of baseline ages (11-69 years)<sup>23</sup>. Our results are most consistent with a study by the Trois-Rivieres Growth and Development Study<sup>9</sup>. Among participants with a baseline age of 12 years (N=191), tracking correlations for peak handgrip force was higher amongst females ( $r=0.67$ ) compared with males ( $r=0.32$ )<sup>9</sup>. This is similar to the correlation for right grip strength (females:  $r=0.48$ ; males:  $r=0.30$ ) in our study where participants were of a comparable mean baseline age and with a similar length of follow-up (25 years vs. 20 years) to those in the Trois-Rivieres study. Due to its high correlation with gold standard measures of strength, including the 1 repetition maximum test<sup>24</sup> and isokinetic dynamometry<sup>25</sup>, grip strength is commonly used as a surrogate marker of overall strength.

The predictive utility of muscular fitness on future health outcomes has been shown in past observational studies<sup>14, 26, 27</sup>. These associations are supported by mechanisms that link muscle physiology with metabolic health related outcomes<sup>28, 29</sup>. This suggests the early identification and possible intervention of individuals with low muscular fitness could improve long-term health outcomes. In our study, there was some suggestion that muscular fitness phenotypes tracked stronger with increasing age, implying muscular fitness levels measured later in youth could be a strong predictor of adult levels. These findings potentially highlight ways those at increased risk of future adverse health outcomes could be identified.

These findings warrant investigation into whether interventions aimed at improving low muscular fitness levels in youth could potentially improve the level of muscular fitness maintained into adulthood. Previous intervention studies performed in youth have shown that adopting various resistance training protocols result in an increase in muscular fitness levels<sup>30-32</sup>. Indeed, in recent modifications to the World Health Organisation physical activity guidelines, increases to muscular

fitness levels by encouraging muscle strengthening exercise in youth, in addition to aerobic exercise, are supported<sup>33</sup>. However, we acknowledge muscular fitness phenotypes have both a behavioural and genetic component<sup>34</sup>. This genetic component may predispose one to a higher or lower muscular fitness level and this may affect the degree to which muscular fitness levels track over time, or the degree to which individuals respond to behavioural modification aimed to increase muscular fitness levels<sup>35</sup>.

Limitations of our study include the presence of differential loss to follow-up. Non-participants had lower strength, lower power, greater adiposity and were of lower socioeconomic position compared to participants at baseline. These differences could impact the generalisability of our results, although when we weighted our analyses on these factors only minor changes resulted, with a slight underestimation of the effect observed for strength and an overestimation of the effect observed for power. However, statistical significance remained. We additionally acknowledge that our study excluded participants who had contraindications to muscular fitness testing, although sensitivity analyses suggested this made little difference to tracking. Furthermore, muscular endurance was only measured at baseline, meaning we could not determine the tracking of this phenotype. Inherent difficulties arise upon comparing tracking studies. Differences in the modality of tests, duration of follow-up, the initial age at baseline and different statistical approaches taken<sup>6</sup>, make direct comparison difficult. However, general trends can still be interpreted. Strengths of our study included the use of valid fitness tests<sup>1, 20, 21</sup> and a long follow-up period, contributing tracking data from youth to adulthood.

## **Conclusion**

In conclusion, our findings show that measures of strength and power track from youth to adulthood. These data suggest that strength and power levels in youth form, in part, the basis for strength and power levels in adulthood and that those with low muscular fitness in youth are at increased risk of maintaining this level into adulthood. Given that low levels of muscular fitness in adulthood is an independent risk factor for several chronic diseases, our data warrant further investigation into

whether early intervention aimed at amending low youth muscular fitness levels could potentially reduce these future disease outcomes.

### **Practical Implications**

- Levels of muscular fitness track from youth to adulthood, whereby youth muscular fitness levels are predictive of adult muscular fitness levels.
- Muscular fitness levels have the potential to be used as a screening tool to identify those at increased risk of maintaining low levels of muscular fitness over time. While 50-60% of participants maintained a low muscular fitness level between the two time-points, there was some suggestion that muscular fitness levels measured later in youth might be a stronger predictor of adult levels.
- Youth muscular fitness levels are a potential target for intervention and prevention strategies aimed at improving future health outcomes.

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## Conflict of interest

The authors declare no conflict of interest.

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## Tables.

Table 1. Characteristics of participants at baseline and follow-up.

Characteristic	Sex	
	Male	Female
	Statistic	Statistic
n	322	301
<b>Youth</b>		
Age, years	11.9 (2.5)	11.8 (2.5)
Right grip strength, kg	25.6 (10.5)	20.5 (6.7)
Left grip strength, kg	25.1 (10.4)	19.6 (6.3)
Shoulder flexion, kg	21.1 (14.1)	17.8 (8.9)
Shoulder extension, kg	17.5 (9.3)	13.5 (6.0)
Leg strength, kg	116.7 (57.8)	81.9 (34.9)
Muscular strength score	0.00 (1.00)	0.00 (1.00)
Standing long jump, cm	161 (31)	142 (24)
Body mass, kg	44.2 (14.2)	41.8 (12.1)
<b>Adulthood</b>		
Age, years	31.8 (2.6)	31.6 (2.6)
Right grip strength, kg	48.7 (7.8)	29.9 (5.2)
Left grip strength, kg	46.9 (8.0)	28.1 (5.2)
Shoulder flexion, kg	50.1 (13.1)	25.7 (7.4)
Shoulder extension, kg	40.6 (10.4)	21.1 (7.2)



Leg strength, kg	168.6 (37.2)	91.8 (28.5)
Muscular strength score	0.00 (0.99)	0.00 (0.98)
Standing long jump, cm	188 (26)	135 (27)
Body mass, kg	86.0 (14.4)	68.7 (14.6)

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Data are mean (SD).

Table 2. Partial Pearson's correlation coefficients for tracking of muscular fitness phenotypes from youth to adulthood.

Baseline Age (years)	n	Right grip strength	Left grip strength	Shoulder flexion	Shoulder extension	Leg strength	Muscular strength score	Standing long jump
9								
Male	115	0.37‡	0.32†	0.09	0.34†	0.23*	0.28†	0.41‡
Female	113	0.43‡	0.32†	0.27†	0.35‡	0.24†	0.44‡	0.37‡
All	228	0.39‡	0.31‡	0.17†	0.34‡	0.23†	0.34‡	0.39‡
12								
Male	107	0.30†	0.38‡	0.19	0.43‡	0.48‡	0.46‡	0.48‡
Female	98	0.48‡	0.44‡	0.39‡	0.56‡	0.34†	0.58‡	0.27†
All	205	0.38‡	0.41‡	0.28‡	0.48‡	0.42‡	0.51‡	0.39‡
15								
Male	100	0.58‡	0.49‡	0.38†	0.47‡	0.43‡	0.59‡	0.53‡
Female	90	0.53‡	0.57‡	0.41‡	0.39‡	0.31†	0.54‡	0.51‡
All	190	0.56‡	0.53‡	0.39‡	0.43‡	0.37‡	0.57‡	0.52‡
All Participants								
Male	322	0.40‡	0.38‡	0.21‡	0.41‡	0.37‡	0.43‡	0.47‡

Female	301	0.48‡	0.44‡	0.35‡	0.43‡	0.29‡	0.51‡	0.38‡
All	623	0.43‡	0.41‡	0.27‡	0.42‡	0.34‡	0.47‡	0.43‡

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All correlation coefficients adjusted for length to follow up. Sex and youth age are included as adjustment factors when data are combined by sex and youth age.

\*  $p < 0.05$

†  $p \leq 0.01$

‡  $p \leq 0.001$

Table 3. Log multinomial regression between youth and adult muscular strength thirds and between youth and adult muscular power thirds.\*

Youth muscular strength/power third	Adult muscular strength				Adult muscular power			
	Middle third		Lowest third		Middle third		Lowest third	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Highest third	1	REF	1	REF	1	REF	1	REF
Middle third	1.21	0.94-1.57	2.58	1.70-3.92	0.94	0.72-1.22	2.61	1.75-3.90
Lowest third	0.87	0.65-1.17	4.70	3.19-6.92	0.92	0.71-1.21	4.06	2.79-5.90
<i>p<sub>trend</sub></i>	0.41		<0.001		0.58		<0.001	

\* All associations are adjusted for youth age, sex, and length to follow-up. The highest third of the adult muscular fitness phenotypes and youth muscular fitness phenotypes was used as the referent group.

Abbreviations: RR, relative risk; CI, confidence intervals.

**Online only supplement**

Table S1. Characteristics of participants and non-participants at baseline.

Characteristic	Participants	Non-Participants	p-value
	Statistics	Statistics	
n	623	2103	
Age, years	11.8 (2.5)	11.8 (2.4)	0.78
Male sex, %	322 (51.7)	1062 (50.5)	0.60
Right grip strength, kg	23.2 (9.2)	23.1 (8.9)	0.82
Left grip strength, kg	22.5 (9.1)	22.4 (8.6)	0.84
Shoulder flexion, kg	19.5 (12.0)	19.0 (11.5)	0.34
Shoulder extension, kg	15.6 (8.1)	15.7 (8.2)	0.79
Leg strength, kg	99.9 (51.1)	98.7 (47.7)	0.61
Combined strength score	0.08 (0.94)	-0.02 (1.01)	0.03
Standing long jump, cm	152.1 (29.7)	149.2 (28.8)	0.03
Height, cm	150.9 (14.5)	150.4 (14.3)	0.48
Weight, kg	43.0 (13.3)	43.7 (13.2)	0.28
BMI, kg/m <sup>2</sup>	18.4 (2.8)	18.8 (3.0)	0.002
Waist circumference, cm	64.5 (8.3)	65.6 (8.9)	0.006
Socioeconomic position, %			
Low	46 (7.7)	193 (9.5)	<0.001
Middle	365 (60.9)	1396 (68.4)	
High	188 (31.4)	451 (22.1)	

Mean (SD) for continuous variables or n (proportions) for categorical variables. P-value represented by a two-sample t test for continuous variables and chi-squared test for categorical variables.  
Abbreviations: BMI, body mass index.

Table S2. Proportion of participants in each adult muscular fitness phenotype third according to youth muscular fitness level.

		Third in Adulthood								
		All			Male			Female		
		Lowest third	Middle third	Highest third	Lowest third	Middle third	Highest third	Lowest third	Middle third	Highest third
Third in youth										
Muscular strength										
	Lowest third	56.7 (118)	28.4 (59)	14.9 (31)	53.7 (58)	31.5 (34)	14.8 (16)	60.0 (60)	25.0 (25)	15.0 (15)
	Middle third	31.3 (65)	39.4 (82)	29.3 (61)	31.1 (33)	40.6 (43)	28.3 (30)	31.4 (31)	38.2 (39)	30.4 (31)
	Highest third	12.0 (25)	32.4 (67)	55.6 (115)	15.7 (17)	30.6 (33)	53.7 (58)	8.1 (8)	34.3 (34)	57.6 (57)
Muscular power										
	Lowest third	52.9 (110)	32.7 (68)	14.4 (30)	58.7 (61)	27.9 (29)	13.4 (14)	47.1 (49)	37.5 (39)	15.4 (16)
	Middle third	34.1 (71)	32.7 (68)	33.2 (69)	25.9 (28)	39.8 (43)	34.3 (37)	43.0 (43)	25.0 (25)	32.0 (32)
	Highest third	13.0 (27)	34.8 (72)	52.2 (108)	13.6 (15)	31.8 (35)	54.6 (60)	12.4 (12)	38.1 (37)	49.5 (48)

Data are proportional (N).

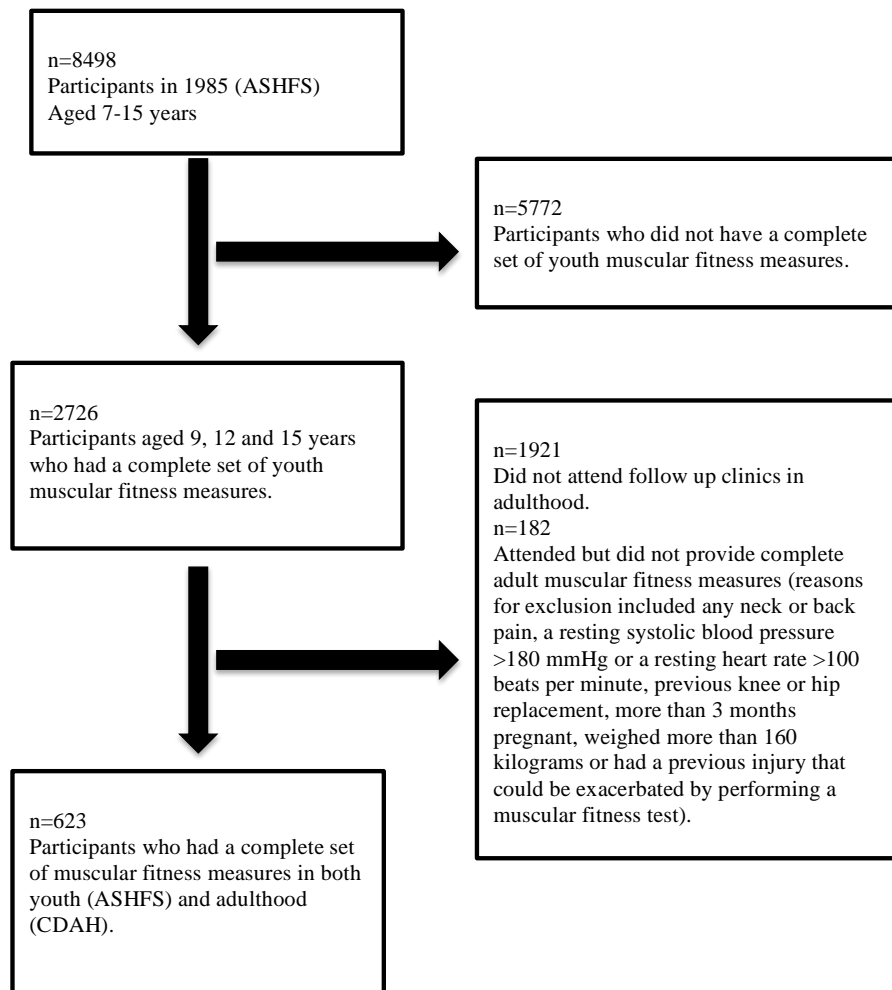


Figure S1: Participant flow chart for this study. Abbreviations: ASHFS = Australian Schools Health and Fitness Survey; CDAH = Childhood Determinants of Adult Health.

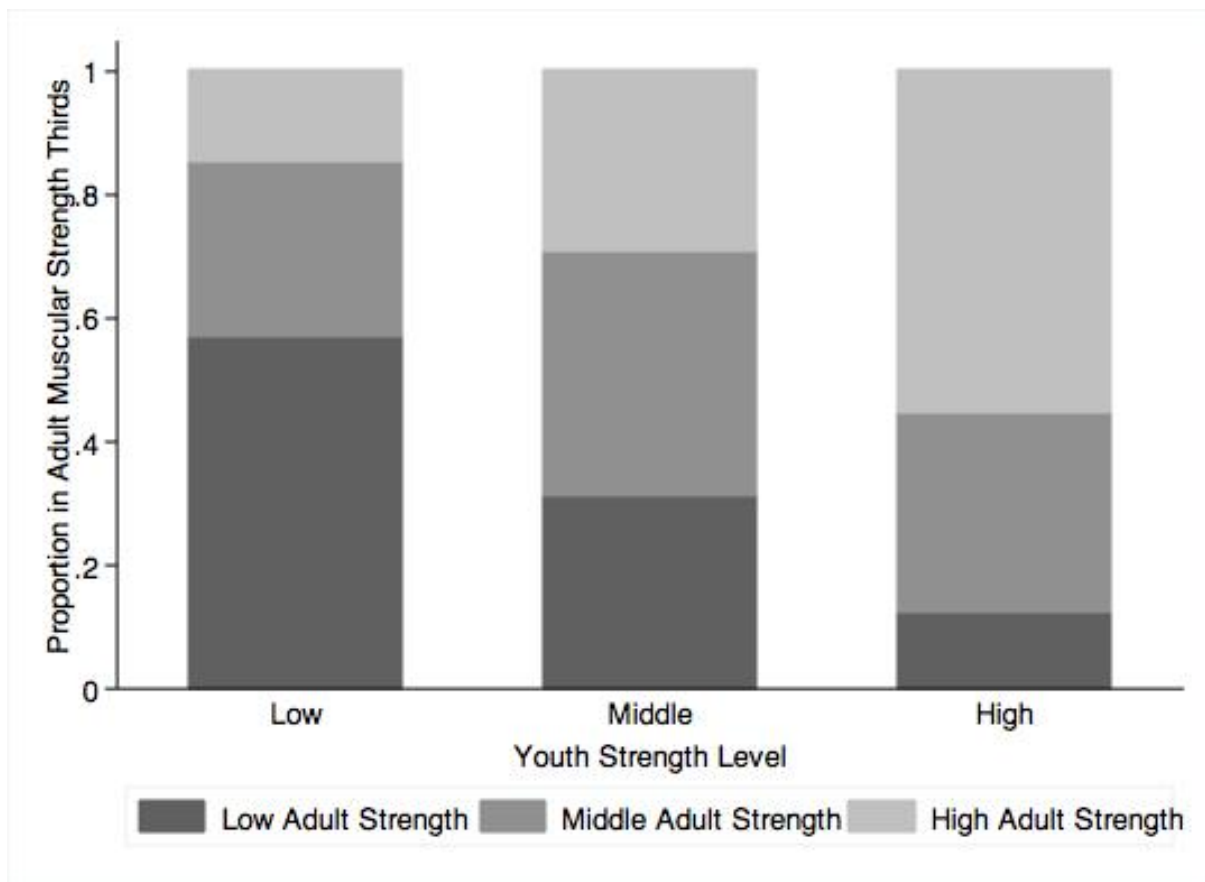


Figure S2A.



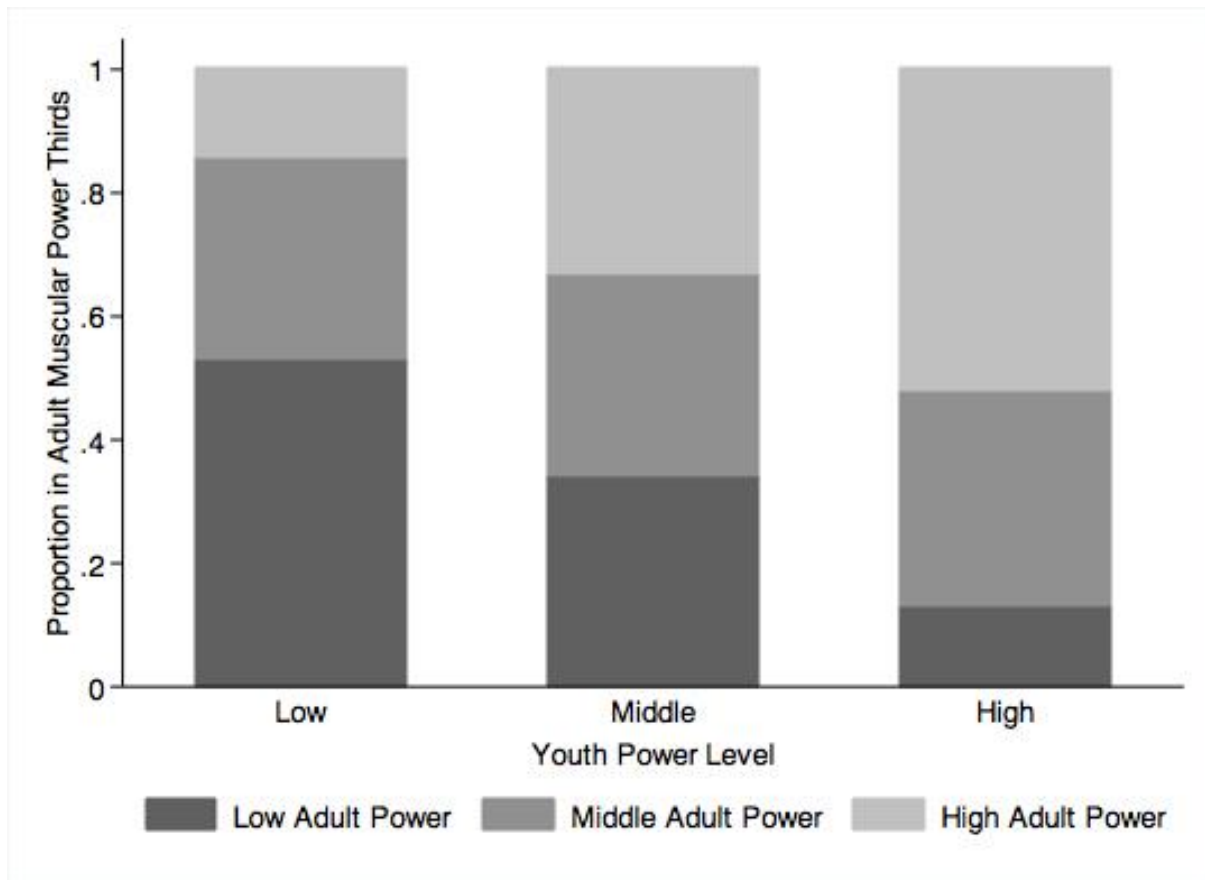


Figure S2B.

Figure S2. Proportion of participants in: (A) each third of adult muscular strength according to youth muscular strength thirds; and (B) each third of adult muscular power according to youth muscular power thirds. Number of participants in youth muscular fitness thirds was: low (n=208), middle (n=208) and high (n=207).