Intergenerational changes in adolescents' physical fitness and weight in New Zealand

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ABSTRACT

AIMS: This research examines fitness and body weight in two cohorts of adolescents, to determine continuity and changes in these measures across two generations.

METHODS: Height, weight and fitness were measured in a population-based cohort of 15 year-olds in 1986/7 (Dunedin Study, n=968). The same measures were obtained for their 15–16 year-old children between 2007 and 2015 (Next Generation Study, n=343). Fitness was defined as maximal aerobic capacity ($V'O_{2max}$). Height and weight were measured in all participants and fitness was adjusted for weight ($V'O_{2max}$/kg).

RESULTS: The Next Generation participants were, on average, heavier than the Dunedin Study participants had been, and had higher body mass index values (kg/m^2). Unadjusted $V'O_{2max}$ values for boys did not differ between generations, but were lower in Next Generation girls compared to Dunedin Study girls. For both sexes, the Next Generation participants had lower weight-adjusted $V'O_{2max}$ values than the Dunedin Study participants. Compared to their parents, weight-adjusted $V'O_{2max}$ values were approximately 25% lower in girls and 15% lower in boys.

CONCLUSIONS: Overall adolescents today appear to be less fit and heavier than their parents were at the same age. The decline in fitness over a generation is particularly evident in adolescent girls, although boys also have lower levels of fitness once body weight has been taken into account.

Physical inactivity is rising in many countries and is now the fourth leading risk factor for global mortality.[1] An inactive teenage lifestyle is associated with adult inactivity, which may have serious health implications. Large amounts of sedentary behaviour, such as watching too much television, have been linked to obesity and poor fitness in adult life,[2,3] whereas children who achieve and maintain physical fitness are likely to maintain a healthy weight.[4] There are other long-term benefits from physical activity observed in both cross-sectional and longitudinal studies: people who are physically active are less likely to develop osteoporosis, stroke, some forms of cancer and type 2 diabetes.[5] An active lifestyle is also associated with better mental health and improved academic achievement.[5]

While the current global epidemic of obesity is well recognised, declines in physical fitness over time have also been recognised,[6] but the relationship between these risk factors is not clear. We investigated generational changes in body weight and physical fitness in a cohort of 15 year-olds from 1986/7 and in their children when they were aged 15 (between 2007 and 2015). We anticipated that body weight and BMI values would be higher in the younger generation than their parents at the same age, and hypothesised that weight-adjusted fitness levels will have declined. However, we suspected that absolute aerobic capacity ($V'O_{2max}$) may not have changed because increased body weight also means a greater workload when moving around and heavier people should have stronger musculature and greater absolute $V'O_{2max}$ for a similar level of physical activity.

Methods

Participants

The Dunedin Multidisciplinary Health and Development Study (hereafter referred to as the "Dunedin Study") is a longitudinal investigation of health and behaviour in a cohort of individuals born in Dunedin in 1972/73.[7] One thousand and thirty-seven children (91% of those eligible) participated in the first follow-up at age three and these individuals have been followed ever since with regular assessments. Data from the assessments at age 15 years in 1986/7 (n=976) and at age 38 years in 2010/12 (n=961) are used in this analysis.

Since 2007, the Next Generation Study has assessed the biological and non-biological children of the Dunedin Study members. The Next Generation Study invites participants and their primary caregiver to a one-day multidisciplinary assessment, which largely replicates the assessment that their parent went through in 1986/7 as part of the Dunedin Study.[8] To be eligible for participation, teenagers must be the biological, step, foster or adopted children of a Dunedin Study member and be over 15 years and under 17 years of age. At the time of analysis, 235 of the Dunedin Study members (23% of the original 1,037 participants) had at least one child who consented to participate in the Next Generation Study (87% of those eligible). Of those Dunedin Study members with children in the Next Generation Study, 71 had two children, 17 had three children and one had four children or step-children in the study (343 Next Generation Study participants in total). At the time of their assessment, 277 were aged 15, and 66 were aged 16 years. Exercise test results were missing or excluded from 10 Next Generation participants due to pregnancy, health reasons or equipment malfunction. Hence 333 teenagers (157 girls and 176 boys; mean age 15.59, range 14.91–16.98; one participant was assessed at age 14 years and 11 months) had a valid exercise test while height and weight measures were available for 340 participants (Figure 1).

When members of the Dunedin Study had a same-sex child in the Next Generation Study, we also used paired-*t*-tests to conduct mother-daughter and father-son comparisons. If Dunedin Study participants had multiple same-sex children in the Next Generation Study, the child who was closest to 15 years old at the time of assessment was chosen as the member of the dyad; there were 125 mother-daughter dyads and 110 father-son dyads in total. Only dyads that were biologically related were analysed (ie, excluding step- and adopted children).

Ethical approval for both studies was obtained from the Lower South Regional Ethics Committee (LRS/06/10/048/AM01). Participants provided written consent at the time of testing.

Measures

Body mass index (BMI) in kg/m^2 was calculated from height and weight measurements using a stadiometer and calibrated scales. Maximal aerobic capacity was measured in both the Dunedin Study and the Next Generation Study via a sub-maximal exercise test on a cycle ergometer to estimate maximal oxygen consumption at peak exercise ($V'O_{2max}$ in L/min) using the modified Åstrand-Rhyming protocol.[3,9] As maximum oxygen uptake should be higher in heavier people, $V'O_{2max}$ values are often adjusted for weight. However, this method may over-adjust in very obese people,[10] thus $V'O_{2max}$ values are used both with and without adjustment for body weight.

Socio-economic status at age 15 was based on the income and education associated with their parents' occupation using the Elley-Irving scale for the Dunedin Study and an updated version of the Elley-Irving scale, the NZ Socio-Economic Index, for the Next Generation. In both studies, the highest category for either parent (1=high, 6=low) was recorded.[11,12] Ethnicity was self-identified at ages 26, 32 or 38 for the Dunedin Study and at age 15 for the Next Generation Study and recorded as Māori or non-Māori (nearly all non-Māori were New Zealand European, other ethnicities were uncommon). Maternal age at the participant's birth was recorded for both studies.

Analyses

We compared weight, height, BMI and fitness at age 15 between Dunedin Study members and Next Generation participants in four ways. First we compared the mean values and 95% confidence intervals between the Dunedin and Next Generation studies for each sex. Differences were

assessed using independent sample *t*-tests. Because variances were greater in the Next Generation Study, these *t*-tests did not assume equal variance. On average, the Next Generation participants were slightly older than the Dunedin Study participants were and therefore analyses were re-run on the sub-sample of the Next Generation cohort who were under the age of 16 at the time of their data collection.

Secondly we compared father-son and mother-daughter dyads, using paired *t*-tests (for these analyses Dunedin Study members with more than one same-sex child in the Next Generation Study were only paired with the child nearest to 15 years in age).

Because the Next Generation Study comprises children of Dunedin Study members who had children at younger ages (children born to older Study members had not yet reached age 15), the Next Generation participants are less representative of the general population than the Dunedin Study participants. A third analyses used propensity score matching to compare the Next Generation participants to 15 year-old Dunedin Study members.[13] Next Generation participants were matched to their same-sex nearest neighbours in the Dunedin Study according to maternal age, childhood socioeconomic status and ethnicity using the *pscore* command in Stata. This was followed by estimating the effect of being a Next Generation participant (ie, the difference from the matched Dunedin Study member using the *attnd* command) with bootstrapped standard errors to estimate 95% confidence intervals.

The fourth analysis fitted mixed linear regression models for each of the outcomes, adjusting for socioeconomic status and age (15 or 16 years) with a fixed effect for being a Next Generation participant and a random effect for family, using robust standard errors to calculate confidence intervals. These models allow us to use all available data from both cohorts while adjusting for clustering within family members.

Finally, sex-specific correlations between mothers and daughters and fathers and sons, were done for Dunedin and Next Generation Studies' weight, BMI and $V'O_{2max}$ values to determine whether levels of body weight and fitness correlated across the generations. Correlations between weight, BMI, and $V'O_{2max}$ from the Dunedin Study participants at ages 15 and 38 (data collected in 1986/7 and 2010/11) were also analysed, to determine whether body weight and fitness at age 15 weight are associated with weight and fitness in adulthood and therefore relevant to adult health. The $V'O_{2max}$ correlations were repeated with and without adjustment for body weight.

Analyses used Stata version 13 (College Station, TX).[14] Two-sided p values <0.05 were considered statistically significant. Where non-statistically significant results with p<0.1 were observed, and felt to be important for guiding further research and/or interpreting other results, they are described as 'non-statistically significant tendencies'. No formal adjustment for multiple comparisons was made in the analyses.

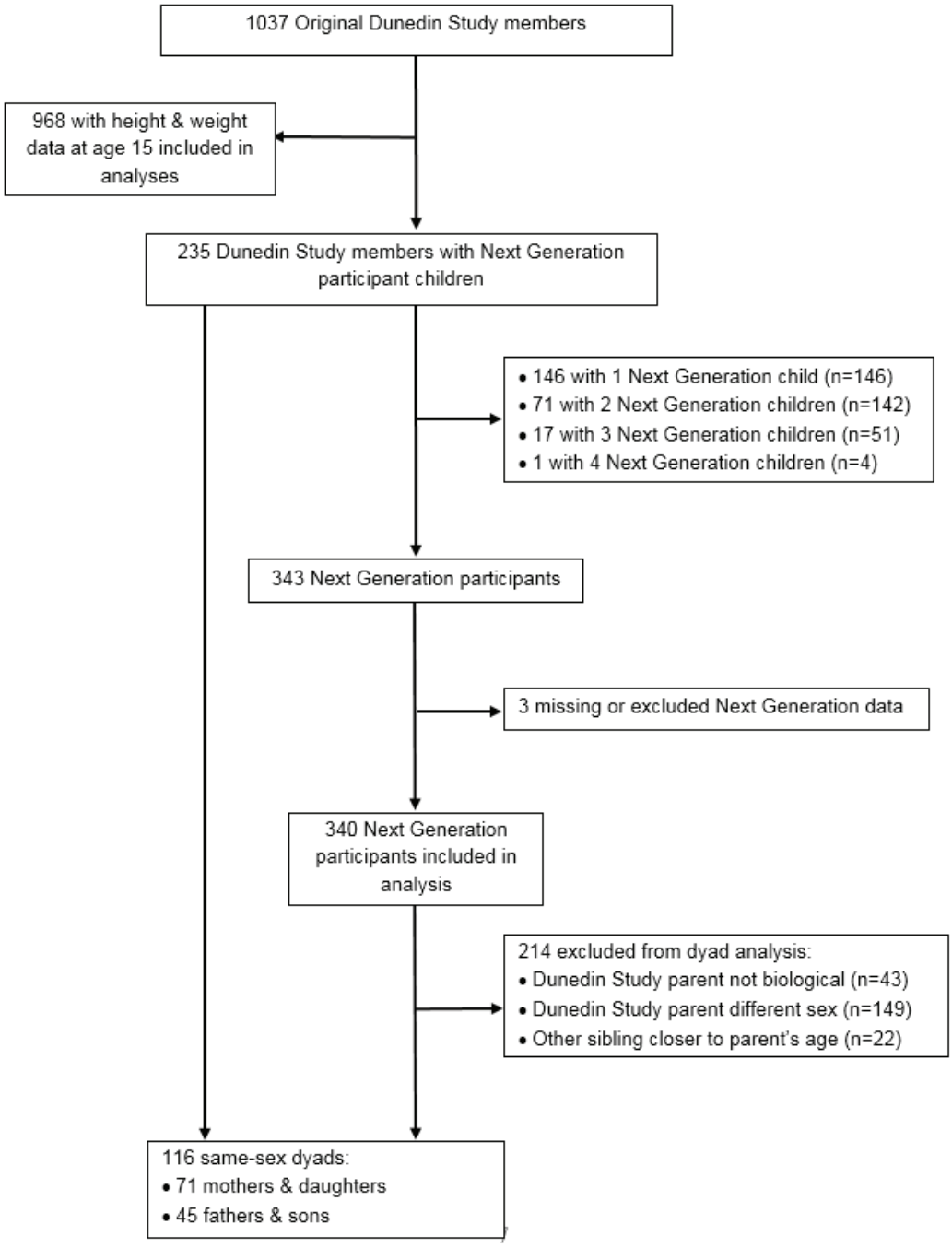
Results

A flow-chart of participants in the Next Generation study is shown in Figure 1. Of the 235 Dunedin study members with one or more Next Generation Study children, there were more mothers (n=134, 57%) than fathers (n=101, 43%). The median socioeconomic status of the Next Generation participants (n=343) was lower than the median socioeconomic status of the Dunedin Study members (n=875) had been at age 15 (3 vs 4, p<0.001).

Mean values for BMI, weight, height and both unadjusted and weight-adjusted $V'O_{2max}$ in each cohort are shown in Table 1. Independent *t*-tests were conducted to determine if the 16 year-old subsample of Next Generation participants differed from those under 16. The Next Generation 16 year-old boys tended to weigh more than those under 16 (74.6 vs 69.6kg, p=0.075) and had a non-statistically significant tendency towards higher BMI values (24.1 vs 22.4kg/m^2 p=0.069), but there were no age-related differences in weight for girls or height or $V'O_{2max}$ in either sex.

There were no significant differences in age 15 height, weight, BMI or unadjusted or weight-adjusted $V'O_{2max}$ between those Dunedin Study members who went on to become parents of a Next Generation Study member and those from the Dunedin Study who were not parents of a Next Generation Study member at the time of analysis (all p values >0.130).

Figure 1: Participant numbers included in analyses from both the Next Generation and Dunedin Studies.



Note numbers reflect maximum number of participants for an analysis: the number of participants in the analyses of each endpoint vary due to missing data; only 333 NG participants had valid exercise tests.

Table 1: Mean weight, height and fitness for each Study by sex with 95% confidence intervals.

		Dunedin Study			Next Generation Study					
Girls		**N**	**Mean (SD)**	**95% CI**	**N**	**Mean (SD)**	**95% CI**	**Mean difference**	**95% CI**	**p**
Weight	kg	464	55.8 (8.1)	55.1–56.5	159	66.2 (13.9)	64.1–68.4	10.4	8.1 to 12.7	<0.001
Height	m	469	1.63 (0.06)	1.63–1.64	159	1.66 (0.06)	1.65–1.67	0.03	0.02 to 0.04	<0.001
BMI	kg/m^2	464	20.9 (2.6)	20.7–21.2	159	24.0 (4.7)	23.3–24.7	3.1	2.3 to 3.9	<0.001
VO_2max	L/min	403	2.46 (0.38)	2.42–2.49	157	2.05 (0.53)	1.96–2.13	-0.41	-0.5 to -0.3	<0.001
VO_2max/kg	mL/min/kg	403	44.1 (4.5)	43.6–44.5	157	32.3 (9.2)	30.4–33.3	-12.2	-13.8 to -10.7	<0.001
Boys		**N**	**Mean (SD)**	**95% CI**	**N**	**Mean (SD)**	**95% CI**			
Weight	kg	498	57.6 (10.9)	56.6–58.5	181	70.7 (15.2)	68.4–72.9	13.1	10.6 to 15.5	<0.001
Height	m	499	1.69 (0.08)	1.68–1.70	181	1.75 (0.07)	1.74–1.76	0.06	0.05 to 0.07	<0.001
BMI	kg/m^2	498	20.0 (2.8)	19.8–20.3	181	23.0 (4.5)	22.4–23.7	3.0	2.3 to 3.7	<0.001
VO_2max	L/min	436	2.82 (0.57)	2.77–2.88	176	2.84 (0.84)	2.72–2.97	0.02	-1.2 to 0.2	0.771
VO_2max/kg	mL/min/kg	436	49.2 (5.7)	48.7–49.8	176	41.4 (12.7)	39.5–43.2	-7.9	-9.8 to -5.9	<0.001

P values from two-tailed independent t-tests. Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

Differences in weight, height and fitness between the cohorts

Mean BMI, weight and height for both sexes in the Next Generation participants were greater than in the Dunedin Study participants (Table 1). Both the unadjusted and weight-adjusted $V'O_{2max}$ values for the Next Generation girls were lower than the Dunedin Study girls. By contrast, the unadjusted $V'O_{2max}$ values for the boys did not differ between studies, but Next Generation boys had lower weight-adjusted $V'O_{2max}$ scores. This pattern of findings was unchanged when the 16 year-old Next Generation Study participants were excluded from analyses (Supplementary Table 1).

Table 2: Paired *t*-tests by sex for weight and fitness in the biological father-son and mother-daughter dyads from the Dunedin Study (DS) and Next Generation (NG) Studies.

			Mothers (DS)			Daughters (NG)			
		n	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean difference**	**95% CI**	**p**
Weight	kg	71	57.0 (8.1)	55.0–58.5	65.0 (14.7)	61.5–68.5	8.1	4.4 to 11.75	<0.001
Height	m	71	1.62 (0.06)	1.61–1.64	1.66 (0.07)	1.64–1.67	0.03	0.02 to 0.05	<0.001
BMI	kg/m^2	71	21.5 (2.6)	20.9–22.1	23.7 (5.0)	22.5–24.9	2.1	0.9 to 3.4	<0.001
VO_2max	L/min	62	2.46 (2.37)	2.37–2.55	2.06 (0.53)	1.93–2.20	-0.40	-0.6 to -0.2	<0.001
VO_2max/kg	mL/min/kg	62	43.5 (0.5)	42.5–44.5	33.0 (8.9)	30.7–35.3	-10.6	-12.9 to -8.2	<0.001
			Fathers (DS)			**Sons (NG)**			
Weight	kg	45	58.3 (10.7)	55.1–61.5	69.3 (16.0)	64.5–74.2	11.1	5.6 to 16.5	<0.001
Height	m	45	1.69 (0.07)	1.67–1.72	1.74 (0.08)	1.71–1.76	0.04	0.02 to 0.06	<0.001
BMI	kg/m^2	45	20.2 (2.7)	19.4–21.0	22.9 (4.5)	21.6–24.3	2.7	1.2 to 4.2	<0.001
VO_2max	L/min	37	2.92 (0.54)	2.74–3.10	2.84 (0.83)	2.56–3.11	-0.08	-0.4 to 0.2	0.613
VO_2max/kg	mL/min/kg	37	49.2 (5.7)	47.3–51.1	42.2 (13.2)	37.8–46.6	-7.0	-12.2 to -1.9	0.009

Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

Table 3: Propensity-matched analyses of height, weight and fitness between the Dunedin Study and Next Generation Study participants.*

Girls		Matched pairs	Mean difference	95% CI
Weight	kg	160	11.3	7.4 to 15.2
Height	m	160	0.03	0.01 to 0.06
BMI	kg/m^2	160	3.3	2.3 to 4.3
VO_2max	L/min	157	-0.37	-0.47 to -0.26
VO_2max/kg	mL/min/kg	157	-11.9	-14.1 to -9.7
Boys				
Weight	kg	181	10.4	7.2 to 13.6
Height	m	181	0.04	0.02 to 0.06
BMI	kg/m^2	181	2.5	1.6 to 3.7
VO_2max	L/min	176	-0.13	-0.34 to 0.08
VO_2max/kg	mL/min/kg	176	-8.5	-10.9 to -6.0

*Next Generation participants are matched to their same-sex nearest neighbours in the Dunedin Study according to maternal age, childhood socioeconomic status and ethnicity. Mean differences and 95% confidence intervals represent the mean differences between the measures in the Next Generation participants and the average of the measures in their matched nearest neighbours in the Dunedin Study. Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

The findings from the biological mother-daughter and father-son dyads across the studies, using paired *t*-tests are shown in Table 2 (note that these analyses are restricted to a single parent-same-sex child dyad: DS members with more than one same-sex child in the Next Generation Study are only paired with the child nearest to 15 years in age). For both father-son and mother-daughter dyads, mean weight, height and BMI were higher in the Next Generation participants. Both absolute and weight adjusted measures of fitness were lower in Next Generation girls than they had been in their mothers at age 15. Absolute levels of fitness (ie, $V'O_{2max}$ not adjusted for weight) were similar across generations within the same family for boys, although sons were less fit than their fathers had been at age 15 after adjusting for body weight (Table 2). Excluding 16 year-old Next Generation Study participants did not change this pattern of findings although the difference in weight-adjusted fitness among boys did not reach statistical significance (Supplementary Table 2).

Propensity score matching of Next Generation participants to their closest match among the Dunedin Study participants provided propensity scores that were balanced between the studies. The mean differences between the Next Generation Study participants and their matched nearest neighbours in the Dunedin Study Group are shown in Table 3.

For both sexes the weight, height and BMI were higher in the Next Generation participants. Among girls, both unadjusted and weight-adjusted fitness were lower in the Next Generation participants. Boys' unadjusted $V'O_{2max}$ values were similar for both generations, but boys' weight-adjusted fitness was lower in the Next Generation participants. Excluding 16 year-old Next Generation Study participants did not change this pattern of findings (Supplementary Table 3).

Finding from the mixed linear regression models were similar to those from the propensity analyses and are shown in Table 4.

Table 4: Mixed linear regression models with random effects for families to account for similarity between members of the same family. (Differences represent mean differences in outcome between Next Generation and Dunedin Study members after adjustment for age (age >16) and socio-economic status).

Girls		n	Difference	95% CI	p
Weight	kg	577	9.8	7.2 to 12.4	<0.001
Height	mm	577	0.29	18 to 40	<0.001
BMI	kg/m^2	577	2.8	1.9 to 3.7	<0.001
VO_2max	L/min	525	-0.39	-0.49 to -0.28	<0.001
VO_2max/kg	mL/min/kg	525	-11.5	-13.2 to -9.8	<0.001
Boys					
Weight	kg	626	11.8	9.3 to 14.4	<0.001
Height	mm	626	59	45 to 72	<0.001
BMI	kg/m^2	626	2.60	1.83 to 3.38	<0.001
VO_2max	L/min	573	0.02	-0.15 to 0.20	0.786
VO_2max/kg	mL/min/kg	573	-7.23	-9.58 to -4.87	<0.001

The sex-interaction terms for the GLMs were significant for height, and both VO_{2max} and VO_{2max}/kg (all p<=0.001), but were not significant for BMI (p=0.840) or for weight (p=0.137). Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

Correlations between height, weight and fitness

Height at age 15 years was correlated between generations, but there were no significant correlations between weight, BMI or either unadjusted or weight-adjusted $V'O_{2max}$ measures between generations (Table 5).

Among the Dunedin Study participants, absolute $V'O_{2max}$ values at ages 15 were moderately correlated with the values at age 38 in both sexes (females: n=367, r=0.43, p<0.001; males: n=395, r=0.39, p<0.001). Similarly, weight-adjusted $V'O_{2max}$ values were also correlated in both sexes (females: n=367, r=0.24, p<0.001; males: n=395, r=0.35, p<0.001).

Table 5: Pairwise correlations for height, weight and fitness between mother-daughter and father-son dyads from the Dunedin Study and Next Generation Study by sex.

Girls	n	r	95% Confidence intervals	P
Weight	71	0.18	-0.06–0.4	0.133
Height	71	0.52	0.32–0.67	<0.001
BMI	71	0.20	-0.04–0.41	0.096
VO_2max	62	0.05	-0.21–0.29	0.714
VO_2max/kg	62	0.16	-0.09–0.4	0.212
Boys				
Weight	45	0.11	-0.19–0.39	0.456
Height	45	0.51	0.25–0.7	<0.001
BMI	45	0.09	-0.21–0.38	0.546
VO_2max	37	0.09	-0.25–0.4	0.617
VO_2max/kg	37	-0.22	-0.51–0.11	0.188

Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

Discussion

This comparison of 15 year-olds across two generations has found that there has been a decline in adolescent physical fitness. At the same time we found increases in mean height, body weight and BMI. To our knowledge this is the first study to directly compare the physical fitness of two generations of 15 year-old New Zealanders. The findings support our hypothesis that physical fitness has declined over a generation. This finding is of concern because it indicates that the current generation of adolescents may have a higher burden of non-communicable disease due to poor fitness.

The generational decrease in fitness was most clearly seen among girls for whom there was a decline in both absolute aerobic capacity as well as aerobic capacity adjusted for body weight. Among boys there was little difference in absolute fitness between generations, but because the current generation were heavier, aerobic capacity adjusted for body weight also declined. This pattern of findings was unchanged when we restricted the analyses to compare the Next Generation participants with their same-sex biological parents and was further confirmed using propensity scores to match each Next Generation Study participant to same-sex participants of the Dunedin Study generation based on mother's age at birth, socio-economic status and ethnicity.

We observed a smaller generational change in fitness among boys than girls, with no change in absolute levels of $V'O_{2max}$. One reason for this may be might be that the sons in the Next Generation Study tended to be taller and heavier than their Dunedin Study fathers had been at age 15 whereas the differences observed between mothers and daughters were less marked. It is unclear why this is the case, but it is possible that the higher average age of the Next Generation participants means they have had more pubertal growth than was observed in the Dunedin Study sample. Because absolute aerobic capacity is related to body size, this may have confounded the findings and it is important to note that the weight-adjusted $V'O_{2max}$ values were significantly lower in Next Generation boys.

Another reason for the observed sex-difference may be that boys tend to be more physically active than girls.[15–19] Although physical activity declines during adolescence in both sexes,[16,20–22] this decline typically occurs between 9–12 years of age in girls, but between 13–16 years in boys.[23] Thus, the 15 year-old girls in our research are likely to have experienced several more years of adolescent inactivity than the boys of the same age, which could plausibly explain the greater generational change in fitness in girls.

Our results also show that the 15 year-old Next Generation participants (2007–2015) are substantially heavier than their parents were at the same age in 1987/88. This within-family change is in keeping with established trends: in New Zealand between 1989–1997 mean body weight increased by 3.2kg[24] and in many developed countries childhood obesity levels doubled between the 1960s and 1980s and have doubled again since.[25] Sedentary behaviours, such as screen use, are increasingly displacing physical activity and contributing to the epidemic of obesity.[26,27] Our findings indicate that these changes have been accompanied by a decline in physical fitness. A decline in children and adolescents' running performance has been observed in several countries including Australia and New Zealand over recent decades.[28,29] However, the extent to which these declines are due to an increase in overweight and obesity is difficult to determine from field running tests, whereas cycle ergometer tests are less sensitive to changes in body weight. A secular decline in the $V'O_{2max}$ of nine year-old Danish children was noted between 1985/86 and 1997/98 using a cycle test,[30] but no difference was found between three cohorts of Danish adolescents between 1983 and 2003.[31] We are not aware of other studies directly comparing objective cycle-ergometer tests of aerobic fitness between parents and offspring at the same age. Variability in how fitness has been measured in previous research has led to some authors to believe that fitness is hard to compare between different cohorts,[32] although there seems to be a consensus that children are less active and fit today than in the past.[33] Our findings support this consensus.

A surprising observation is that there were no significant correlations in weight, BMI or fitness between mothers and daughters or fathers and sons (Table 5). Although there was a moderately strong correlation for height, there seems to have been very little tracking of adolescent body weight or fitness between generations. Previous studies have mixed findings on the heritability of aerobic fitness. Some studies suggest that this may be 50% or higher, although much of this may be due to shared lifestyle factors rather than genetics.[34,35] However, other studies have found only weak correlations between parent and child fitness.[36]

In contrast to the lack of tracking of fitness between generations, there was a substantial tracking of fitness from age 15 to age 38 years among the Dunedin Study members, indicating that adolescent fitness may have long-term consequences for adult health. By necessity, the equipment used for the exercise test has changed, although both measures were based on the same exercise protocol to obtain a steady state heart rate. The fact that the exercise performance of the Dunedin Study participants at age 38 years was predicted by their age 15 test, suggests that changes in the equipment used do not explain the lack of correlation between generations.

A strength of this research is that the Dunedin Study sample is an unselected population-based cohort with a very high rate of participation. However, because the Dunedin Study members who started their family later in life do not yet have children who are old enough to participate in the Next Generation Study, the current Next Generation Study participants have parents who are younger than average compared to the population. The Next Generation Study participants were also more likely to come from lower socio-economic status families than the Dunedin Study cohort, reflecting the likelihood of having younger parents. We also note that a limitation of our independent *t*-test analysis of the whole cohort is that it assumes independence between the generations, which may be not the case. However, findings from these analyses are very similar to the three other methods of analyses using matched *t*-tests between parent-child dyads, propensity score, and linear mixed models that do not make this assumption. The propensity score analyses provided similar findings suggesting that selection bias is unlikely to explain our findings. Although the Next Generation participants tended to be slightly older than their parents at the time of data collection, excluding those over age 16, or adjusting for this in the mixed model, made no material difference to the results.

In summary, we have shown that the trend to increasing body weights among New Zealand adolescents has been accompanied by a decline in aerobic fitness. These trends are likely to result in an increased burden on health and society as a whole. Physical fitness in adolescence tracks into adulthood, and poor fitness is an established health risk. Measures to improve physical fitness among New Zealanders are urgently needed.

Appendix

Supplementary Table 1: Mean weight, height and fitness for boys and girls in each study. Analyses exclude Next Generation participants over 15 years old.

		Dunedin Study			Next Generation Study					
Girls		**N**	**Mean (SD)**	**95% CI**	**N**	**Mean (SD)**	**95% CI**	**Mean difference**	**95% CI**	**p**
Weight	kg	464	55.8 (8.1)	55.1–56.5	133	65.8 (13.8)	63.4–68.1	10.0	7.5 to 12.5	<0.001
Height	m	469	1.63 (0.06)	1.63–1.64	133	1.66 (0.06)	1.65–1.67	0.03	0.01 to 0.04	<0.001
BMI	kg/m^2	464	20.9 (2.6)	20.7–21.2	133	23.9 (4.7)	23.1–24.7	3.0	2.1 to 3.8	<0.001
VO_2max	L/min	403	2.46 (0.38)	2.42–2.49	131	2.06 (0.53)	1.97–2.15	-0.40	-0.5 to -0.3	<0.001
VO_2max/kg	mL/min/kg	403	44.1 (4.5)	43.6–44.5	131	32.2 (9.2)	30.6–33.8	-11.9	-13.5 to -10.2	<0.001
Boys		**N**	**Mean (SD)**	**95% CI**	**N**	**Mean (SD)**	**95% CI**			
Weight	kg	498	57.6 (10.9)	56.6–58.5	143	69.6 (13.6)	67.4–71.9	12.0	9.6 to 14.5	<0.001
Height	m	499	1.69 (0.08)	1.68–1.70	143	1.75 (0.07)	1.74–1.76	0.06	0.04 to 0.07	<0.001
BMI	kg/m^2	498	20.0 (2.8)	19.8–20.3	143	22.8 (4.1)	22.1–23.4	2.8	2.0 to 3.5	<0.001
VO_2max	L/min	436	2.82 (0.57)	2.77–2.88	142	2.84 (0.86)	2.69–3.00	0.02	-0.1 to -0.2	0.851
VO_2max/kg	mL/min/kg	436	49.2 (5.7)	48.7–49.8	142	41.8 (12.6)	39.7–43.9	-7.4	-9.6 to -5.3	<0.001

P values from two-tailed independent t-tests. Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

Supplementary Table 2: Paired t-tests by sex for weight and fitness in the biological father-son and mother-daughter dyads from the Dunedin Study (DS) and Next Generation (NG) Study. Analyses exclude Next Generation participants over 15 years old.

			Mothers (DS)		Daughters (NG)				
		n	**Mean (SD)**	**95% CI**	**Mean (SD)**	**95% CI**	**Mean difference**	**95% CI**	**p**
Weight	kg	60	57.4 (8.2)	55.3–59.5	65.0 (14.1)	61.3–68.6	7.6	3.8 to 11.4	<0.001
Height	m	60	1.62 (0.06)	1.61–1.64	1.66 (0.07)	1.64–1.67	0.03	0.02 to 0.05	<0.001
BMI	kg/m^2	60	21.8 (2.6)	21.1–22.4	23.6 (4.8)	22.4–24.9	1.9	0.6 to 3.2	0.005
VO_2max	L/min	54	2.48 (0.35)	2.38–2.57	2.08 (0.53)	1.93–2.22	-0.40	-0.6 to -0.2	<0.001
VO_2max/kg	mL/min/kg	54	43.4 (3.9)	42.4–44.5	33.1 (9.2)	30.6–35.6	-10.4	-12.9 to -7.8	<0.001
			Fathers (DS)		**Sons (NG)**				
Weight	kg	34	57.5 (9.8)	54.1–60.9	66.8 (12.8)	62.3–71.3	9.3	4.2 to 14.5	<0.001
Height	m	34	1.69 (0.07)	1.66–1.72	1.72 (0.08)	1.69–1.75	0.04	0.01 to 0.06	0.012
BMI	kg/m^2	34	20.1 (2.4)	19.2–20.9	22.4 (4.1)	21.0–23.8	2.4	0.9 to 3.9	0.003
VO_2max	L/min	27	2.83 (0.49)	2.64–3.02	2.78 (0.89)	2.43–3.13	-0.05	-0.4 to 0.3	0.763
VO_2max/kg	mL/min/kg	27	48.3 (4.0)	46.7–49.9	43.0 (13.8)	37.5–48.4	-5.3	-11.3 to 0.7	0.079

Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

Supplementary Table 3: Propensity-matched analyses of height, weight and fitness between the Dunedin Study and Next Generation Study.*

Girls		Matched pairs	Mean difference	95% CI
Weight	kg	134	11.1	8.1 to 14.2
Height	m	134	0.03	0.01 to 0.06
BMI	kg/m^2	134	3.3	2.3 to 4.2
VO_2max	L/min	131	-0.36	-0.48 to -0.23
VO_2max/kg	mL/min/kg	131	-11.6	-13.9 to -9.3
Boys				
Weight	kg	143	9.5	6.3 to 12.7
Height	m	143	0.04	0.01 to 0.06
BMI	kg/m^2	143	2.4	1.28 to 3.48
VO_2max	L/min	142	-0.11	-0.34 to 0.11
VO_2max/kg	mL/min/kg	142	-7.9	-10.4 to -5.4

*Next Generation participants are matched to their same-sex nearest neighbours in the Dunedin Study according to maternal age, childhood socioeconomic status and ethnicity. Analyses exclude Next Generation participants 16 years and older. Mean differences and 95% confidence intervals represent the mean differences between the measures in the Next Generation participants and the average of the measures in their matched nearest neighbours in the Dunedin Study. Positive mean differences indicate higher values in the Next Generation Study and negative differences indicate higher values in the Dunedin Study.

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