Secular trends and distributional changes in health and fitness performance variables of 10–14-year-old children in New Zealand between 1991 and 2003

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ABSTRACT

Background New Zealand children's health and fitness performance is declining over time, but whether this change is because of deterioration in all children's health and fitness performance or can be attributed to just a certain portion of the population, is unknown.

Objectives In this study, secular trends and distributional changes in health-related and performance-related fitness components among New Zealand primary school children aged 10 to 14 years between 1991 and 2003 were tracked.

Methods Health- and performance-related fitness parameters including height, weight, body mass index (BMI), flexibility, standing broad jump, 4×9-m agility run, abdominal curl-ups, and 550-m run were collected up to twice a year from 3306 children (10–14 years old) from a New Zealand school between 1991 and 2003.

Results Over the 12-year period, the boys' weight increased by 4.5 kg (95% CL 2.7 to 6.2, or 0.8% per year) and girls' by 3.9 kg (95% CL 2.0 to 5.9, or 0.7% per year). Mean BMI increased by 0.12 kg m^{-2} (0.6%) and 0.11 kg m^{-2} (0.5%) per year for boys and girls, respectively. Children's 550-m run performance declined by 1.5% and 1.7% per year for boys and girls, respectively. Little difference existed between children located in the highest performing and leanest percentiles in 1991 and 2003, but for children in the poorest performing and fattest percentiles, their results were substantially worse in 2003.

Conclusions These results suggest that the deterioration in the health-related and performance-related fitness components of New Zealand 10–14-year-olds is not homogeneous but skewed towards those children who are the heaviest and perform worst in fitness tests.

Previous research on health-related fitness parameters among children in New Zealand is limited but shows secular trends of increasing body mass[1,2] in conjunction with deteriorating aerobic fitness performance, muscular endurance and explosive muscular power.[3] Internationally, similar increases in body mass have been observed in children since the 1980s.[1,4,5] Secular trends of deteriorating health-related fitness performance have also been reported among children around the world,[1,5,6] with the most significant decreases observed in aerobic performance. However, trends in health-related variables reported as changes in mean body mass index (BMI) and mean aerobic fitness performance do not reveal possible changes in the distribution of BMI or aerobic performance within the population. Changes in such measures may come about because of a shift in the entire population under investigation or a change in a portion of the population. It is not clear whether New Zealand's entire childhood population is becoming heavier and less aerobically fit or whether only a portion of the children are becoming even heavier and more unfit, with the remaining children showing little secular change. The aim of this study was to track secular trends and distributional changes in body weight and physical fitness parameters among New Zealand primary school children aged 10 to 14 years.

MATERIALS AND METHODS

Health and fitness parameters of 1456 girls and 1850 boys aged 10–14 years were measured as part of one school's physical education programme from 1991 to 2003 (except for 2001–2002). All testing took place in either February/March/April or October/November of each year over a 2-year period (table 1). The tests were conducted by the physical education specialist teachers and included height, weight, 4×9-m agility run, curl-ups, standing broad jump and 550-m run and followed standard protocols[7] based on recommended tests.[8] Times for the 550-m run and the 4×9-m agility run were converted to average running speed. Children wore shorts and a light T-shirt for the tests and were required to have bare feet for the height and weight measurements. To calculate the prevalence of overweight and obesity, the international BMI cut-offs were used.[9] Children were measured either once (as in 2003) or twice a year (in the years from 1991 to 2000) during their years 7 and 8 of schooling.

Statistical analysis

Following ethical approval from Lincoln University Human Ethics Committee, the 12 years of data were analysed, retrospectively. All variables were analysed using Proc Mixed in the Statistical Analysis System V.8.2 (SAS Institute, Cary, North Carolina, USA). Repeated measure analyses were conducted with trial as the repeated (within-subject) measure and the year of each child's first trial as a covariate. The covariance structure chosen was compound symmetry (same correlation between all pairs of trials). The means of consecutive levels of trial were compared, and the change in the variables over the 12-year period was estimated from the solution of the covariate. The analysis modelled the change over the four trials and produced a mean change for each individual for each year. In this way, the change score produced over the 12 years did not only take into account the different children through the school over the 12-year period but also the change in the same children over the four trials they were at

Table 1 Breakdown of subject numbers for each year of testing and data points collected at each testing trial

	Subject numbers		Data points at each testing trial			
			Initial year		Following year	
	Boys	Girls	Trial 1	Trial 2	Trial 3	Trial 4
1991	294	217	240	252	74	98
1992	148	84	150	155	1	25
1993	164	86	2	184	76	55
1994	153	125	96	157	94	62
1995	189	185	279	258	43	33
1996	153	140	33	132	81	88
1997	227	150	133	164	78	60
1998	171	162	147	66	107	62
1999	191	149	130	162	104	26
2000	64	48	121	52		
2003	96	110	206			

Trials 1 and 2 correspond to February–April and October–November testing periods, respectively, in the first year of testing, and trials 3 and 4 correspond to the same testing periods in the following year. Data points do not always correspond to subject numbers since one subject may have as many as four individual data points (one in each trial).

school. Least-squares means (ie, means adjusted for any missing values using the fixed-effects model) for each trial and each year were estimated from a model wherein the year and its interaction with trial were included as nominal effects. All variables presented are least square means to avoid discontinuities due to missing values. Population distribution changes were analysed by initially calculating the mean value of the parameter (over all trials measured) for each individual. For each year, within the same sex, the health-related fitness parameters at nine distinct percentile points from the 1991 data and the corresponding percentiles from the same sex–age group in the 2003 data were compared. Reliability of the performance tests was analysed using a spreadsheet that produced intraclass correlation coefficients.[10] A type I error of 5% was chosen for declaration of statistical significance; precision of estimates were represented by the 95% confidence limits (CL, the likely range of true value).

RESULTS

550-m run

Average running speed decreased by 0.05 m s^{-1} (95% CL 0.04 to 0.06 m s^{-1}, $p<0.01$) and 0.05 m s^{-1} (95% CL 0.04 to 0.06 m s^{-1}, $p<0.01$) per year for boys and girls, respectively. These changes equate to a decrease in run performance of 1.5% (95% CL 1.3% to 1.9%, $p<0.01$) and 1.7% (95% CL 1.4% to 2.0%, $p<0.01$) per year for boys and girls, respectively. Run times were moderately correlated with increasing BMI ($r = 0.33$, 95% CL 0.29 to 0.36, $p<0.01$).

Agility

Average speed during the agility test decreased by 0.007 m s^{-1} per year (95% CL 0.003 to 0.01 m s^{-1}, $p<0.01$) for boys and 0.01 m s^{-1} per year (95% CL 0.006 to 0.01 m s^{-1}, $p<0.01$) for girls, which equates to a decrease of 0.2% and 0.4% per year for boys and girls, respectively. Agility scores among children were also positively correlated with BMI ($r = 0.29$, 95% CL 0.25 to 0.32, $p<0.01$ for boys and girls combined).

Standing broad jump

Distance travelled during the standing broad jump for girls in 2003 was 2.6 cm less (95% CL 7.9 to 2.7, $p = 0.3$) than their 1991 counterparts. Similarly, boys in 2003 jumped 6.2 cm less (95% CL 11.1 to 1.4 cm, $p<0.01$) than boys in 1991. These changes equate to a decrease in standing broad jump performance of 0.3% and 0.2% per year for boys and girls, respectively. A moderate negative correlation existed between BMI and distance jumped ($r = -0.20$, 95% CL -0.23 to -0.16, $p<0.01$).

Curl-ups and flexibility

In contrast, muscular endurance performance in the curl-up test improved significantly over time. On average, boys could complete 30 curls in 1991, which increased to 35 in 2003 ($p<0.01$) an improvement of 1.5% per year, whereas girls increased the average number of completed curls from 26 to 32 ($p<0.01$), an improvement of 2.1% per year. Similarly boys were 4.1 cm (95% CL 2.5 to 5.7 cm, $p<0.01$) and girls 2.7 cm (95% CL 0.9 to 4.5 cm, $p<0.01$) more flexible in 2003 compared to 1991, which equates to a performance improvement of 2.8% and 1.8% per year for boys and girls, respectively.

Stature

BMI increased by 0.12 kg m^{-2} (0.6%) per year for boys and 0.11 kg m^{-2} (0.5%) per year for girls over the 12-year period. This increase resulted in the mean BMI increasing from 19.2 and 19.8 for boys and girls, respectively, in 1991 to 20.6 and 21.1 in 2003. These increases amounted to an average 4.5-kg weight gain for boys and 3.9-kg increase for girls. Boys' height increased by 1.8 cm (95% CL 0.4–3.2 cm, $p<0.05$) and girls' by 2.4 cm (95% CL 0.9–3.9 cm, $p<0.01$) over the same period.

Overweight and obesity

Table 2 shows the change in the percentage of boys and girls in this study who were classified as normal, overweight and obese between 1991 and 2003. The biggest change is the sixfold increase (from 2% to 12%) in the number of boys classified as obese.

Distributional changes

Figure 1 is typical of all data and shows the distributional change in BMI and performance in the 550-m run. An upward shift in the curve suggests an increase in the value of the parameter at that particular percentile. The BMI values in the two cohorts were similar for children at the lower percentiles (from 1st to 50th percentiles) but the BMI scores were consistently higher in the 2003 compared to the 1991 cohort

Table 2 The proportion of children classified as normal, overweight or obese using the Cole *et al* cut-offs

	1991		1997		2003	
	Boy	Girl	Boy	Girl	Boy	Girl
Normal	84	84	66	77	71	67
Overweight	14	13	28	20	17	26
Obese	2	3	6	3	12	7

Data are percentages of boys and girls in each category.

in the 75th to 99th percentiles. For example, the average BMI for boys in the 75th to the 99th percentile was 22.9 kg m^{-2} in 1991, which increased to 27.6 kg m^{-2} in 2003 (an increase of ~20%). In the same way, children with low aerobic ability (high run times) showed the biggest upward shift in the percentile curves over the 12-year period, indicating that the slow children got slower (fig 1). A similar pattern was observed in the other health-related fitness parameters (table 3).

DISCUSSION

The main findings of this study are twofold: first, we have found that the secular trend of declining health-related and performance-related fitness in New Zealand children is progressing unabated. Second, the continuing decline in health-related and performance-related fitness appears to be associated with only a portion of the population rather than the whole population. We have shown that secular declines in health-related and performance-related fitness parameters, for example, BMI and 550-m run time, were apparent to a far greater extent in children in the higher percentiles of the distribution.

When interpreting these results, some caution should be used as this research was conducted on cohorts of children at one New Zealand school over a 12-year period. The findings therefore could not be considered representative of all New Zealand children. Changes to the demographics of the school's population, for example, the ethnic mix of students or their socio-economic status, could also confound the findings. While we do not have access to pre-2000 data, approximately 25% of the school's population in 2000 was classified as Maori or "other ethnicity", and by 2006, this figure had climbed to 40%. Any increase in the proportion of Maori (the indigenous population of New Zealand) or Pacific Island children in the school's population will particularly affect the BMI results and rates of obesity, since Maori and Pacific children have substantially higher BMI scores compared with European New Zealand children.[11] Additionally, since performance in fitness tests that require subjects to move their body weight over a distance (eg, 550-m run, agility test, standing broad jump) are moderately correlated to BMI, a higher population of Maori and Pacific Island children (with higher BMIs) may have also caused a

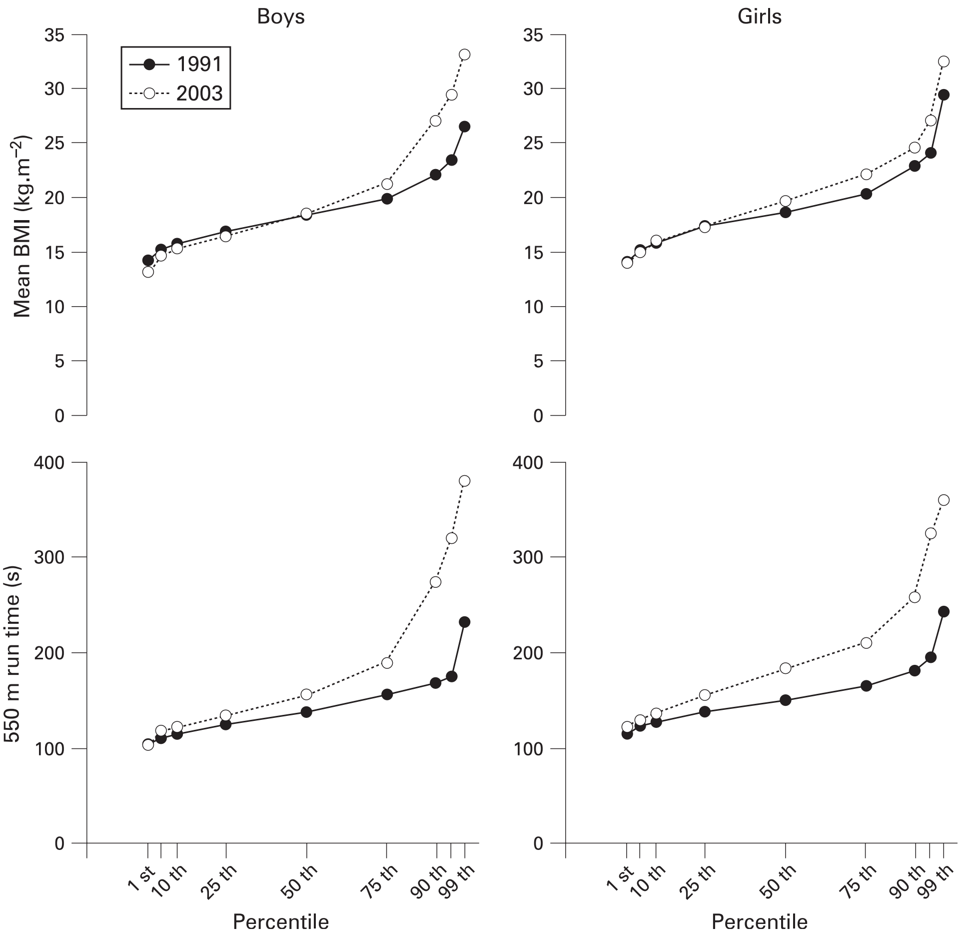

Figure 1 Percentile plots for BMI and 550-m run performance in the 1991 (closed circles) and 2003 (open circles) data sets. The plots are arranged so that a higher percentile score reflects a poorer BMI and 550-m run score.

Table 3 Percentiles for health-related and performance-related fitness tests in the 1991 and 2003 cohorts

		Percentile								
Parameter	**Year**	**1st**	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**
Boys										
Height (cm)	1991	135	141	144	148	153	158	163	166	175
	2003	130	139	142	147	153	157	163	169	186
Weight (kg)	1991	27	32	34	38	43	50	57	62	70
	2003	27	32	34	38	44	53	66	72	75
Agility (m s^{-1})	1991	2.2	2.7	3.0	3.1	3.3	3.5	3.6	3.7	3.8
	2003	2.5	2.7	2.8	2.9	3.2	3.5	3.6	3.6	3.8
Curl-up	1991	1	5	6	13	20	37	50	50	50
	2003	0	1	3	8	19	32	50	50	50
Stretch (cm)	1991	1	1	5	11	17	23	28	29	34
	2003	2	7	8	14	21	27	32	37	57
Jump (cm)	1991	115	133	145	161	184	202	217	226	244
	2003	115	127	132	142	166	195	215	229	240
Girls										
Height (cm)	1991	134	141	144	148	155	159	164	166	173
	2003	136	142	144	149	154	160	165	168	175
Weight (kg)	1991	29	33	35	39	45	50	56	60	88
	2003	29	32	35	39	47	54	61	68	81
Agility (m.s^{-1})	1991	2.5	2.7	2.8	3.0	3.1	3.3	3.4	3.5	3.6
	2003	1.7	2.4	2.5	2.8	3.0	3.2	3.4	3.4	3.6
Curl-up	1991	1	3	7	12	20	33	45	50	50
	2003	0	1	2	10	19	31	50	50	50
Stretch (cm)	1991	1	2	12	16	25	31	37	41	45
	2003	7	9	13	19	27	32	40	47	47
Jump (cm)	1991	99	118	133	150	167	186	201	205	220
	2003	78	121	131	145	161	180	200	211	220

The SE of measurement for performance tests between trials expressed as the intraclass correlation coefficient is given in table 4.

negative effect on performance in these tests. However, because we do not have the individual ethnic data, this is merely speculative and is an area for further research.

As socio-economic status is a determinant of physical inactivity,[12] for example, which, in turn, influences energy consumption and fitness parameters, changes in the socio-economic status of the population under investigation could influence the findings of this study. In New Zealand, the socio-economic status of each school's population is estimated using a rating or "decile" system. This is a 10-point scale based on parameters such as household income and educational achievement with 1 being low and 10 being high socio-economic status. The decile ranking for the school studied was 5 from 1991 to 2000 and then dropped one point to 4 from 2001, indicating a slight decrease in the overall socio-economic status of the school's contributing population, which may have contributed to the results witnessed.

The continuing secular increase in BMI along with the increased prevalence of overweight and obesity found in this study is disturbing. The uneven distribution of secular changes to BMI scores is a trend found internationally.[13 14] Investigating trends in height and weight in nationally representative surveys of 6–17-year-old US children and adolescents from 1963, Troiano and Flegal (1998) found that the heaviest children were becoming even heavier, but that the rest of the distribution of BMI showed little change over the years. While such information is important for health professionals to guide policy and intervention changes, it also requires explanation.

Common factors associated with the increase in body mass in today's society include the increased abundance of energy-rich foods, along with decreased physical activity and increased sedentarism; however, it is not clear why these factors and their environmental influences would have a greater or lesser impact on children's weight. It is unlikely that maturation change has had an effect on the outcomes of this study since researchers have indicated that although the age of puberty decreased rapidly through the 19th century,[15] it has since shown a plateau in the latter half of the 20th century and may in fact have increased in some areas.[16]

Increases in the BMI of only a proportion of the population could either be due to different environmental influences between children in the upper compared to the lower BMI percentile groups, or, alternatively, all children may have the same environmental influences but these influences affect the

Table 4 Reliability of test measurements between consecutive trials

Test item	**Trial 2–1**	**Trial 3–2**	**Trial 4–3**
Agility run	0.74 (0.71–0.77)	0.67 (0.62–0.72)	0.37 (0.28–0.45)
Curl-up	0.55 (0.49–0.59)	0.54 (0.47–0.60)	0.16 (0.06–0.25)
Stretch	0.69 (0.65–0.72)	0.64 (0.58–0.69)	0.39 (0.30–0.47)
Jump	0.73 (0.70–0.76)	0.65 (0.59–0.70)	0.61 (0.54–0.67)
550-m run	0.70 (0.66–0.73)	0.72 (0.60–0.77)	0.38 (0.29–0.46)

Data is the intraclass correlation coefficient (95% CL).

children in the upper BMI percentile cohorts more adversely than the children in the lower percentile cohorts. Differences related to socio-economic status would be an example of an environmental factor that could possibly be different between the two cohorts. International[17] and national[18] evidence suggests an association between BMI and socio-economic status particularly in girls,[19] and explains that this relationship is, in part, due to lower physical activity levels[17] and the poor quality diets of lower socio-economic families.[20] Parents in higher socio-economic brackets may be able to provide more resources for children to be physically active, provide better dietary options and advice, and devote more time to children's physical activities, thereby insulating them from ''obesogenic'' influences. Long working hours, low and usually two-income families, poor housing and physical activity infrastructure, little spare time, and greater consumption of cheaper, high-fat, energy-dense diets are factors associated with low socio-economic status and may well create an environment that promotes obesity. Since evidence suggests that children living in low socio-economic areas are more likely to be obese and overweight,[21] it becomes a cyclical effect ending in the fat children getting fatter. However, this argument is speculative since we are basing the results on a small change in an overall, somewhat crude, school decile rating rather than on individual subject's socio-economic status.

On the other hand, environmental influences may be similar between cohorts in the population but the children in the higher BMI percentiles respond differently to these environmental influences. The ''thrifty'' genotype hypothesis first proposed in 1962[22] may explain these differences in response. This hypothesis proposes that individuals predisposed to diabetes and obesity possessed a ''thrifty'' genotype that in the past would have favoured survival by facilitating fat deposition in times of food abundance and provides an energy buffer in times of food scarcity. However, under conditions in the late 20th and early 21st century where food is in abundance (and physical inactivity is rife), such a ''thrifty'' genotype is not advantageous and is likely to predispose individuals to obesity and diabetes. The continued secular increase in BMI levels in the upper percentiles of the childhood population in this study may be attributable to some degree to an increased proportion of children with this type of genetic makeup attending this school. Indeed, Maori and Pacific children who are over-represented in the higher BMI cut-off groups[23] are thought to possess such a gene.[22]

This study found that the previously reported decline in health-related and performance-related fitness in New Zealand children[3] is continuing unabated. This finding is in accordance with a number of studies from other countries on secular trends in aerobic performance.[24–26] Whether this decline in performance can be attributed to a decline in Vo$_2$max or other factors (eg, anaerobic capacity, maximal running speed or psychological influences) is less obvious. Studies on children from North America and the United Kingdom suggest Vo$_2$max (directly measured in the laboratory) has changed little over time.[27–30] On the other hand, Tomkinson and colleagues investigated the 20-m shuttle run performance in 129 882 children aged 6–19 years from 11 developed countries from 1981 to 2000 and found decreases in performance of 0.43% per year.[6] Given that the 20-m shuttle run is a valid estimator of Vo$_2$max,[6] these data would suggest secular declines in Vo$_2$max. While it is clear that children's aerobic performance has declined over the years, it is not clear whether this decline is caused by a decrease in children's Vo$_2$max, since this data is from very small, non-randomised subsamples of a particular population (children that volunteered for testing). In addition, comparing Vo$_2$max data from different laboratories is inadvisable given the different methodologies, equipment and laboratory personnel used.[30]

An important consideration when using fitness tests is the quality of the test item used to estimate performance. Poor validity reduces the usefulness of the test data, while poor reliability reduces the ability to track changes. Previous research suggests the test items used in this study have acceptable validity.[31] Reliability of the test items used in this study was similar to previously reported field tests on children[31–33] and reasonably high (except for the curl-up test) considering many of the children were probably going through puberty at the time of testing (table 4). An additional factor that probably influenced the reliability was the time between trials (at least 6 months apart), during which time children's physique (which would influence their test scores) may have changed considerably.

What could account for the observed decline in fitness parameters? Olds *et* al outlined a procedure to determine to what extent changes in fatness contribute to changes in fitness. Using this procedure, we matched the children in the 1991 and 2003 data sets for sex, age and BMI (fatness). Of the 511 children tested in 1991, 46 boys and 54 girls could be matched for age, sex and BMI (to within 1%) with an equal number of children from the 2003 data set (table 5). The 550-m run performance declines in the matched data set were then compared to the complete data sets (ie, all children in the 1991 and 2003 data sets) to estimate as to what degree the performance decline could be attributed to changes in fatness. From the complete data set, boys' mean running speed decreased significantly from 4.0 m s^{-1} in 1991 to 3.3 m s^{-1} in 2003—a decrease of 17.5%. Girls' mean running speed also decreased from 3.6 to 3.1 m s^{-1} over this period (a reduction of 13.9%). The drop in speed for the matched sample was 12.2% and 8.3% for boys and girls, respectively.

In summary, matching for fatness (BMI) accounted for approximately 60–70% of the decline in 550-m run performance.

Table 5 Mean age BMI and 550-m run performance speed for boys and girls in the matched and complete 1991 and 2003 data sets

	Matched data set				Complete data set			
	Boys		Girls		Boys		Girls	
	1991	2003	1991	2003	1991	2003	1991	2003
n	46	46	54	54	294	96	217	110
Age	11.7	11.7	11.6	11.6	12.0	11.5	11.8	11.5
BMI	18.2	18.3	19.0	18.9	18.6	19.9*	19.1	20.1†
550-m speed m s^{-1}	4.1	3.6*	3.6	3.3†	4.0	3.3*	3.6	3.1†

*Significantly different from boys in 1991.
†Significantly different from girls in 1991.

What is already known on this topic

The proportion of children classified as overweight or obese in developed countries continues to increase at an alarming rate, while tests of aerobic performance indicate children's fitness levels are trending downward.

What this study adds

The increase in fatness and decrease in fitness performance in children is not homogeneous across the population, but occurs to a far greater extent in the children who are already fat and score poorly in fitness performance tests.

Therefore, approximately 30–40% of the variance in fitness measures could be attributed to factors other than the change in BMI. These factors are likely to be environmental in nature.

Poorer nutrition and decreased physical activity may lead to less movement that produces a smaller training effect and lower fitness levels. There is evidence indicating a decrease in physical activity levels in New Zealand children aged 5–17 years between 1997 and 2001.[35] It may also be that less physical activity and movement, in general, may decrease the body's ability to move efficiently through changes in psychomotor activation. Recent research has found overweight or obese children who performed significantly worse during a 6-min run also had poorer gross motor skills.[36] The deterioration of such motor skills that are important in the development of efficient and effective movement patterns may also detrimentally affect fitness levels. Increased sedentarism (also witnessed in New Zealand children between 1997 and 2001[35] is also likely to decrease energy expenditure and may therefore contribute to the increased body mass reported in this study.

In contrast to the children's running and power performance, flexibility and muscular endurance performance improved over time. These results were surprising and may be attributed to various factors. The popularity of the more holistic approach to physical activity and exercise over the last decade has seen an increase in activities that have an emphasis on core strength, stability and flexibility.[37] Such exercises are finding their way into physical education curriculum[38] and may have influenced the children in this study. Other factors such as a change in the ergonomics of the schools' seats cannot be discounted, and further research is required to uncover the causes of this positive trend.

CONCLUSION

Secular trends of increasing BMI, and declining fitness performance among 10–14-year-old New Zealand children continues. However, we have found that the mean increase in children's BMI was not due to an overall increase in all the children but due to a disproportionate increase in the children who already had high BMI scores. This was also the case in most of the performance parameters, such that the poorest performing percentiles of the population are becoming even worse. The concern of such trends is for the subsequent development of chronic health conditions among individuals and throughout New Zealand as a whole.

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Competing interests None.

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