Physical Education Can Improve Insulin Resistance: The LOOK Randomized Cluster Trial

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[1]College of Medicine, Biology and Environment, Australian National University, Canberra, ACT, AUSTRALIA; [2]Academic Unit of Internal Medicine, Canberra Hospital, Garran, ACT, AUSTRALIA; [3]Australian National University, Fenner School of Environment and Society, Canberra, ACT, AUSTRALIA; [4]Centre for Research and Action in Public Health, Faculty of Health, University of Canberra, Bruce, AUSTRALIA; [5]School of Exercise and Nutrition Sciences, Deakin University, Burwood, Victoria, AUSTRALIA; and [6]Australian National University, Department of Psychology, Canberra, AUSTRALIA

ABSTRACT

TELFORD, R. D., R. B. CUNNINGHAM, R. M. TELFORD, R. M. DALY, L. S. OLIVE, and W. P. ABHAYARATNA. Physical Education Can Improve Insulin Resistance: The LOOK Randomized Cluster Trial. *Med. Sci. Sports Exerc.*, Vol. 45, No. 10, pp. 1956–1964, 2013. **Purpose**: As impaired glucose metabolism may arise progressively during childhood, we sought to determine whether the introduction of specialist-taught school physical education (PE) based on sound educational principles could improve insulin resistance (IR) in elementary school children. **Methods**: In this 4-yr cluster-randomized intervention study, participants were 367 boys and 341 girls (mean age = 8.1 yr, SD = 0.35) initially in grade 2 in 29 elementary schools situated in suburbs of similar socioeconomic status. In 13 schools, 100 min·wk^{-1} of PE, usually conducted by general classroom teachers, was replaced with two classes per week taught by visiting specialist PE teachers; the remaining schools formed the control group. Teacher and pupil behavior were recorded, and measurements in grades 2, 4, and 6 included fasting blood glucose and insulin to calculate the homeostatic model of IR, percent body fat, physical activity, fitness, and pubertal development. **Results**: On average, the intervention PE classes included more fitness work than the control PE classes (7 vs 1 min, $P < 0.001$) and more moderate physical activity (17 vs 10 min, $P < 0.001$). With no differences at baseline, by grade 6, the intervention had lowered IR by 14% (95% confidence interval = 1%–31%) in the boys and by 9% (95% confidence interval = 5%–26%) in the girls, and the percentage of children with IR greater than 3, a cutoff point for metabolic risk, was lower in the intervention than the control group (combined, 22% vs 31%, $P = 0.03$; boys, 12% vs 21%, $P = 0.06$; girls, 32% vs 40%, $P = 0.05$). **Conclusions**: Specialist-taught primary school PE improved IR in community-based children, thereby offering a primordial preventative strategy that could be coordinated widely although a school-based approach. **Key Words:** CHILDREN, EXERCISE, PHYSICAL ACTIVITY, FITNESS, PERCENT BODY FAT

Diabetes and its complications are set to be a major contributor to health costs in the 21st century (8), and evidence is emerging that related metabolic disorders may arise progressively through childhood (10,24,25). Given that physical activity (PA) is well established as an important lifestyle factor for the prevention and control of chronic disease such as type 2 diabetes mellitus (3), physical education (PE) and sport in schools are well placed to offer a convenient means of introducing an early preventive strategy to all children. However, with national and widely published assessments of literacy and numeracy in Australia and elsewhere, there have been increased pressures on teachers in recent years to spend more time in the classroom to improve school academic rankings. Consequently, and with some reports questioning the ability of PE (14) and even PA (20) to control the increased incidence of obesity, the incentive for teachers to focus more on PE in elementary schools may be diminished. Should evidence be found that PE can offset the risk of developing chronic disease such as type 2 diabetes, greater credence may be paid to the importance of PE in the elementary school curriculum.

Currently, although cross-sectional studies indicate that more physically active children tend to possess lower insulin resistance (IR) (4), there is little existing evidence of any sustained effect of PE or school-based PA interventions. One intervention targeting improving fitness in 35 middle school children provided encouraging results, but lack of a control group hindered any confident interpretation (5), and a large-scale middle school–based intervention for 2 yr

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involving PA and nutrition was unable to demonstrate any effect on fasting blood concentrations of insulin and glucose (9).

The objective of this study was to assess the effect of a recently developed specialist-taught PE program on the IR of elementary school children as they progressed from grade 2 (mean age = 8.0 yr) to grade 6 (mean age = 12.0 yr). A feature of this PE program (as distinct from a training program) was that it was well accepted by education authorities and already in operation in most Australian states. We set out to describe the effect of this 4-yr intervention in two ways: first, its effect on IR across the cohort in general; and second, its effect on the incidence of children with IR considered to constitute risk (34).

METHODS

Overview. The curriculum for government schools in this jurisdiction required 150 min per 5-d week to be allocated to sport and PE, this currently being conducted by general classroom teachers. A visiting specialist PE teacher was introduced into each of 13 schools to replace 100 min of the current general classroom teacher program. This intervention constituted two 50-min classes per week for 35 school weeks during a 4-yr period as the children progressed from grade 3 to grade 6. Sixteen schools continued with their current practice PE delivered by the classroom teachers, and these schools constituted the control group. Fasting blood glucose and insulin concentrations, body composition, fitness, and PA levels were measured in all intervention and control group children at baseline in the final term of grade 2, then in the corresponding periods of grades 4 and 6.

Design and sample selection. The participants, 367 boys and 341 girls (mean age = 8.1 yr, SD = 0.35), were part of the Lifestyle of Our Kids (LOOK) longitudinal study (28), which has investigated associations of IR (32) and cardiovascular risk factors (26), with PA and body composition as well as the effect of a PE intervention on academic performance and body composition (29). The current report describes the effect of the specialized PE intervention on IR. The general schema is outlined in Figure 1, which shows the flow of numbers of schools (cluster units) and children in intervention and control groups, together with measurements taken during each of the final 4 yr of elementary school (see Table, Supplementary Digital Content 1, http://links.lww.com/MSS/A276 CONSORT checklist for the randomized cluster designed study).

The intervention was conducted by visiting teachers with specialized university training in PE. A control group devoid of PE was neither practically nor ethically acceptable. Our control group constituted the current practice in these schools, where PE was conducted by the general classroom teachers who had little training in PE. In effect, this setup a comparison of specialist PE and the current practice of PE in the local jurisdiction elementary school system.

All grade 2 children in 30 fully government funded elementary schools situated in outer suburbs of the city of population approximately 240,000 at the commencement of the study in 2005 were invited to participate through the school principals; one school principal declined. The average family income in each of these suburbs approximated the Australian average, and an Australian government index of socioeconomic status showed these suburbs to be relatively homogeneous with an approximately 10% higher average

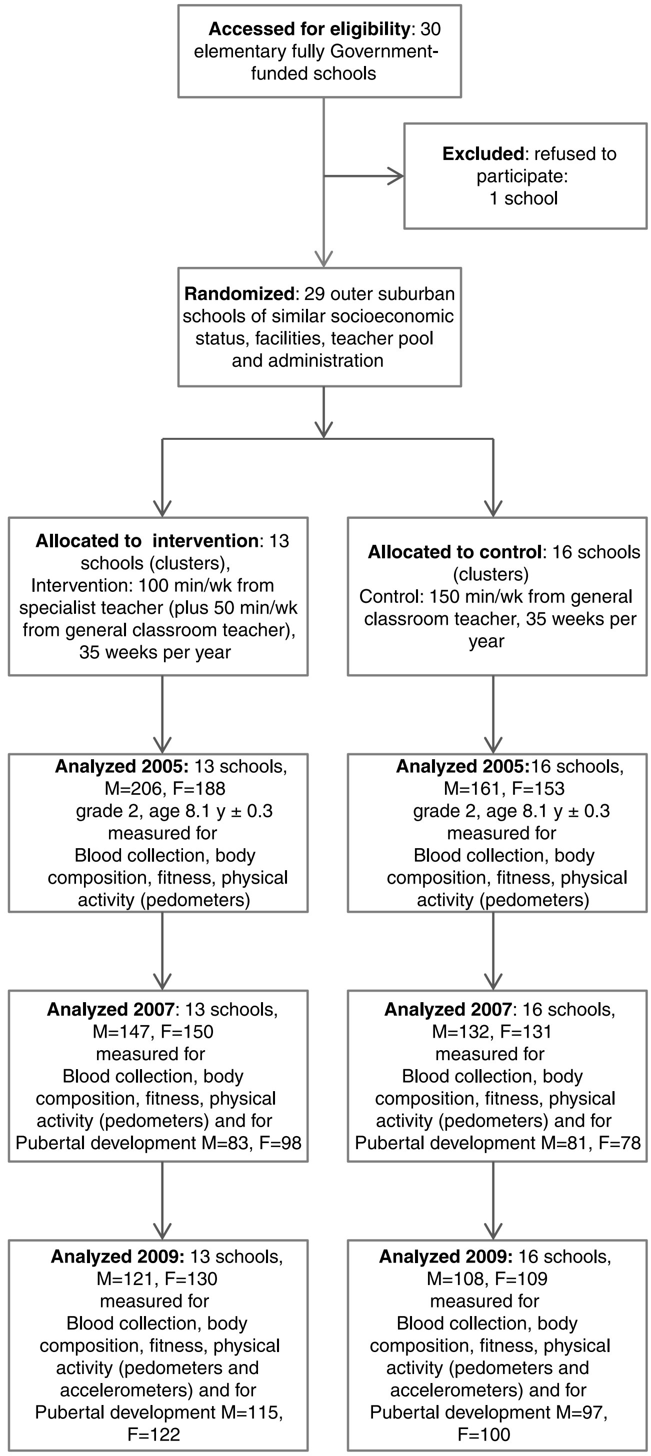

FIGURE 1—Overview of the randomized cluster design, showing the flow numbers of clusters (schools), children, and measurements. Details of attrition are summarized in the text.

index than the Australian average (1). The number of schools invited was based on an intended cohort of approximately 850 children. This number was determined by funding limitations and administrative arrangements with the hospital and the schools, where measurements were to be completed within a school term of 10 wk.

The avoidance of the potential contamination of the two programs required intervention and control classes to be situated in separate schools, hence our randomized cluster research design. Conditions of inclusion in the study were that children were in good health, able to participate freely in PE, and willing to undertake a series of venous blood collections for this component of the LOOK study. Notice of acceptance and written informed consent were received from the parents of 708 eligible children, representing 73% of those invited and approximately 25% of all grade 2 children in this government school system. After acceptance, the allocation of schools to the intervention or control groups was determined randomly, two members of the research team drawing from a shuffled set of 29 envelopes, each of which contained a school name. With three specialist teachers available for our study, on consideration of travel and administrative duties, we limited the number of schools in the intervention to 13, with two visiting teachers working in four schools each week and one teacher in five schools. The remaining 16 schools formed the control group, and they continued with their usual practice of PE conducted by the classroom teachers. Only children originally enrolled in grade 2 were involved in this study; no children being added in following years. For the duration of this study, there was no organized interschool sport nor any organized after-school PA programs undertaken by any of the participants in either group.

The intervention and control programs. Our intention was not to investigate a short-term training intervention but a multiyear program considered to be consistent with the broad educational aims of well-balanced PE, including, for example, the development of social skills and motor coordination. We also sought a PE intervention that was in current operation, well accepted by education authorities and readily available to elementary schools. A program delivered by specialist physical educators from the not-for-profit Bluearth Foundation (2) satisfied these criteria; this program having received consistent positive feedback from the principals, teachers, and students around Australia.

The specialist PE program did not have a specific aim to improve IR *per se*. Its main underlying objective was to provide every child with an enjoyable and positive experience of PA. The philosophy and practical elements of the specialist PE program are explained at the provider's Web site (2). Notable contrasts of the intervention and control programs relevant to the current study were as follows. The intervention program incorporated fitness work incidentally through balance and coordination activities and minor games, and specialist PE teachers participated in activities throughout the lesson; the control groups used more traditional fitness and stretching exercise, including running and walking around the oval, and the teachers rarely participated in activities. The intervention teachers planned each lesson and logged outcomes, maintained contact with the same children each year, and planned to increase PA each year; in the control group, there was little evidence of formal lesson plans or reports, and with teachers changing each year, little evidence of year to year coordination. Finally, the specialist PE teachers were responsible only for the PE classes, whereas the classroom teachers were responsible for teaching the entire elementary school curriculum. It is not surprising that the standard of PE conducted by classroom teachers in Australian primary schools has been questioned (22), with classroom teachers themselves expressing their own concerns about meeting curriculum requirements (23).

Measurements. Height, weight, and percent body fat (%BF) using dual energy x-ray absorptiometry (Hologic Discovery QDR Series; Hologic Inc., Bedford, MA) were measured at Canberra Hospital as previously described (30).

Morning fasting blood samples were collected by nursing staff experienced in pediatric phlebotomy in the school setting, after which breakfast was provided. Serum samples were mixed and allowed to clot for up to 30 min before centrifugation. Where there was doubt as to whether a child had fasted or refrained from vigorous exercise, blood was not taken, and a new appointment was made. Samples were centrifuged on site for 10 min at 2850 rpm (Spintron GT-25P; Spintron Pty Ltd., Australia) and either immediately frozen in dry ice and stored at $-80°C$ for subsequent analysis or taken to the pathology laboratories at Canberra Hospital for immediate analysis. Care was taken to maximize consistency of laboratory handling of samples. All samples were subject to the same procedures, which were carried out according to instrument manufacturers' standards, and biochemical analysis was performed within acceptable limits of internal quality control. Glucose concentration was measured by hexokinase colorimetric methodology on the Architect Ci8200 (Abbott laboratories, Abbott Park, IL). Insulin concentration was measured using microparticle enzyme immunoassay on the AXSYM (Abbott laboratories). The homeostatic model of IR (HOMA-IR) was our surrogate of IR, where HOMA-IR = [fasting insulin ($mU \cdot L^{-1}$) $\times$ fasting glucose ($mU \cdot L^{-1}$)] / 22.5. This measure has been validated for use with children (13,16) and has shown to be of acceptable reliability (19).

Cardiorespiratory fitness (CRF) was measured using the 20-m multistage running test in the schoolyard. This test involves running between two markers set 20 m apart in time to recorded vocal prompts that demand progressively faster speeds and is a well-established field test of CRF in children (33). PA was determined by the 7-d pedometer records (Walk 4 Life, Plainfield, IL), and a PA Index, approximately the square root of the average number of steps per day, was calculated for each child. This accounted for missing values and the skewed nature of the data and has been described in detail elsewhere (31).

A comparison of the intervention and control programs was achieved using the System of Observing Fitness Instruction

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Time (SOFIT) method (21). This is a systematic method where a group of trained observers follow the actions of individual children (and the teachers) during a lesson and record the duration of participation in various types of activities. For the purposes of the current study, these were then categorized as fitness work and PA of different intensities. In addition, all classroom teachers involved in the study were asked to indicate by questionnaire the time they allocated to PE and sport each year.

Pubertal development was determined by a self-assessment of Tanner stages of pubic hair, breast development, and date of menarche (27) using diagrams based on those previously described (7). In grade 4, the self-assessment took place at home with guidance from parents; and in grade 6, the self-assessment occurred in a hospital setting with guidance from an experienced teacher. The members of the research staff who performed the blood assays and body composition measurements were not involved with study design and coordination and were blinded as to whether participants belonged to the intervention or control group.

Statistical methods. Statistical modeling was used to determine the intervention effect on IR, that is, whether the specialist PE had any effect on IR during the 4 yr in comparison with the current practice PE. The model needed to account for the complexity of factors likely to influence IR at both the child and school (cluster) levels. Therefore, school, year, and subject were included in the model as random effects to account for the sample design and hence possible dependence structure in the data. Among the potential explanatory variables (fixed effects) explored for inclusion in the model were sex, school grade (age), %BF, PA, CRF, pubertal development, and socioeconomic status. The interaction between school grade and group (specialist PE or classroom teacher PE) represented the intervention effect. This model fits within the general framework of general linear mixed models (11). The statistical significance of an effect was assessed by calculating adjusted Wald statistics (18). Where necessary, variables were scaled by square roots or natural logarithms to better meet linearity assumptions. General model checking procedures were routinely used to identify aberrant data and to check the model assumptions.

In addition, we needed to compare the characteristics of the two PE programs using data from the SOFIT method of classifying the activities of the child and the teacher during the classes. Apart from the lesson length, which was compared by *t*-test for independent samples, the SOFIT data were nonparametric, and comparisons were conducted by Mann–Whitney *U* tests. Statistical procedures were carried out using the statistical package Genstat version13 (VSN International Ltd., Oxford, UK).

This study was approved by the Australian Capital Territory Health and Community Care Human Research Ethics Committee and the Ethics Committee at the Australian Institute of Sport. Parental consent was obtained for all measures in this study, and children understood that their participation was entirely voluntary and that they could withdraw at any time.

RESULTS

Characteristics of the participants. Characteristics of the study population at baseline are summarized in Table 1. Ninety-two percent of the children had one or both parents of Caucasian descent, 6% of Asian descent, and 1% of Indigenous Australian or Polynesian descent, and we had no data on the ethnicity of 1% of the families. There were no significant group differences in any of the baseline measures and no evidence of any group variation in pubertal development (Tanner stage) either in grade 4 or 6 (all $P > 0.3$). Table 2 provides a summary of the key variables categorized according to year of measurement and sex. To assist in characterizing this cohort, we carried out the BMI-based body composition classifications common to many international studies (6). For the girls in grade 2, 25% of intervention and 23% of the control group were classified in the overweight and obese categories; and in grade 6, the respective percentages were 22% and 23%. For the boys in grade 2, 19% of the intervention group and 20% of the controls were classified in the overweight or obese categories; and in grade 6, the respective percentages were 23% and 29%.

Attrition. Figure 1 illustrates the flow of observations in our study during the 4 yr. Twenty children withdrew from the study, and the remaining missed tests were due either to relocations to schools outside the study (n = 165), absences from school on test days (n = 40), and inadequate compliance to test procedures including failure to fast and technical difficulties with the blood collections (n = 21). Children who missed one or more assessments in a particular year

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TABLE 1. Comparison of the intervention and control groups at baseline, means ± SD classified by sex.

	Male, 2005, Grade 2		Female, 2005, Grade 2	
	Intervention, n = 206	Control, n = 161	Intervention, n = 188	Control, n = 153
Age (yr)	8.0 ± 0.3	8.0 ± 0.3	8.0 ± 0.3	8.0 ± 0.3
Height (cm)	130.5 ± 0.4	129.9 ± 0.4	128.4 ± 0.4	129.1 ± 0.4
BMI (kg·m^{-2})	16.9 ± 0.2	17.0 ± 0.2	17.2 ± 0.2	17.2 ± 0.2
Weight (kg)	29.8 ± 0.4	29.0 ± 0.4	28.6 ± 0.4	28.8 ± 0.4
PAI[a]	108.5 ± 0.9	107.5 ± 0.9	96.2 ± 0.9	98.5 ± 0.9
Sqrt CRF[b]	2.0 ± 0.03	2.0 ± 0.03	1.8 ± 0.03	1.9 ± 0.03
%BF[c]	22.8 ± 0.5	22.5 ± 0.5	27.9 ± 0.5	28.0 ± 0.5

There were no significant differences between the intervention and the control groups at baseline for any variable in either boys or girls (all $P > 0.3$).
[a]Physical activity index, approximately the square root of the average number of steps per day.
[b]CRF, the square root of the number of stages in the multistage run.
[c]Percent body fat as determined by DEXA scan.

TABLE 2. Unadjusted values of body size, percent body fat, physical activity, fitness and maturation, medians, and percentiles classified by elementary school grade, age, and sex.

		Grade 2, Age 8.1 ± 0.4 yr			Grade 4, Age 10.1 ± 0.3 yr			Grade 6, Age 12.1 ± 0.4 yr		
		M = 367, F = 341			M = 279, F = 281			M = 229, F = 239		
		5%	Median	95%	5%	Median	95%	5%	Median	95%
Height (cm)	F	120.1	128.6	137.3	130.3	140.5	150.3	141.5	154.1	164.7
	M	120.6	130.2	139.4	130.9	141.9	152.0	141.2	153.5	166.3
Weight (kg)	F	21.7	27.3	39.8	26.4	34.5	53.0	32.7	45.00	66.2
	M	22.5	28.0	38.6	27.2	35.5	50.3	33.2	44.75	66.5
BMI ($kg \cdot m^{-2}$)	F	14.1	16.6	22.4	14.5	17.7	24.7	15.2	19.0	26.2
	M	14.2	16.5	21.1	14.7	17.6	23.7	15.5	18.9	25.3
PAI (steps per day)[a]	F	80.1	97.3	113.4	78.8	93.5	110.7	77.1	91.4	106.5
	M	90.4	107.9	126.9	84.5	102.2	120.1	78.5	98.0	116.5
CRF (run stage)[b]	F	2.2	3.2	5.4	2.6	4.1	7.3	3.0	5.2	8.9
	M	2.2	4.1	6.9	2.8	5.4	8.7	2.9	6.2	10.1
%BF[c]	F	19.2	27.1	39.5	18.5	28.5	41.9	18.3	26.6	39.5
	M	15.3	21.8	34.3	15.6	23.9	36.7	14.2	23.5	38.6
Tanner stage[d]	F		Not assessed		1.0	1.5	2.6	1.5	2.5	4.0
	M				1.0	1.5	2.5	1.0	2.5	4.0

[a]PAI = physical activity index, approximately equal to the square root of average daily steps per day.
[b]CRF = cardiorespiratory fitness, the number of stages reached in the multistage run.
[c]%BF = percent body fat as determined by DEXA scan.
[d]Tanner stage = self-assessed pubertal stage ranking.

remained in the study and were included in the analysis, with the statistical model adjusted for missing values. A comparison of baseline data of children who remained in the study with those who left revealed no evidence of any bias of weight, body composition, or level of PA (all $P > 0.3$). The respective mean ± SE values were as follows: body weight (kg), boys = 28.8 ± 0.36 vs 29.0 ± 0.41, girls = 28.4 ± 0.38 vs 28.9 ± 0.41; %BF, boys = 22.6 ± 0.40 vs 22.7 ± 0.53, girls = 27.6 ± 0.42 vs 28.5 ± 0.50; and PA index (square root of average steps per day), boys = 108.1 ± 0.69 vs 108.1 ± 0.77, girls = 97.9 ± 0.73 vs 96.5 ± 0.78.

The better compliance to the self-assessed pubertal development in 2009 compared with 2007 was likely to have arisen from the respective settings at the hospital and the family home, the hospital setting in 2009 being more conducive to compliance, although age may have also been a factor.

Systematic observation of the two programs. Classroom teachers' responses to a questionnaire indicated that on average they allocated approximately 150 $min \cdot wk^{-1}$ to PE. SOFIT observations were recorded in 97 intervention classes and 97 control classes. These data revealed that mean face-to-face PE teaching time per class (the duration of the lesson proper not including preparation and packing up equipment) was greater in the specialist PE classes than that in the current practice PE classes (44.0 min, SD = 10.5 vs 28.6 min, SD = 8.4, $P < 0.001$). Specialist PE teachers spent more time than classroom teachers in each lesson on specific fitness activities involving strength and flexibility, speed and endurance (median 18 vs 2 min per lesson, $P < 0.001$) and more time in moderate and vigorous PA (median 17 vs 10 min per lesson, $P < 0.001$). Specialist teachers also participated more in class activities than the classroom teachers (12 vs 2 min per lesson, $P < 0.001$).

Intervention effects on IR. Table 3 presents the raw (unadjusted) values of HOMA-IR at each measurement period in the intervention and the control groups, along with the insulin and glucose concentrations. There was solid evidence of an intervention effect on IR, which we describe, first, in terms of the general pattern of change of IR during the 4 yr, second, in terms of the reduction in IR across the cohort during the 4 yr, and finally, in more clinically relevant terms of the intervention effect on the incidence of children with elevated values of IR.

First, with no significant differences at baseline ($P > 0.3$ for boys and girls separately and combined) and accounting for sex differences by fitting sex as a fixed effect, the specialist PE intervention lowered the pattern of development of IR for boys and girls combined ($P = 0.03$). There

TABLE 3. Unadjusted values of HOMA-IR, blood glucose, and insulin concentrations, expressed as medians, 5th percentile, and 95th percentile and classified by intervention group, control group, and sex.

		Male						Female					
		Grade 2		Grade 4		Grade 6		Grade 2		Grade 4		Grade 6	
No. Participants	Intervention Control	206 161		147 132		121 108		188 153		150 131		130 109	
		Median	5%–95%	Median	5%–95%	Median	5%–95%	Median	5%–95%	Median	5%–95%	Median	5%–95%
HOMA-IR	Intervention	0.9	0.3–2.1	1.3	0.5–3.4	1.5	0.8–4.0	0.9	0.4–2.6	1.7	0.7–3.9	2.6	1.2–4.4
	Control	0.9	0.3–1.9	1.2	0.6–3.1	2	0.9–5.5	1.1	0.5–2.6	1.6	0.6–4.1	2.7	1.2–7.4
Glucose ($mmol \cdot L^{-1}$)	Intervention	4.8	4.1–5.6	5.2	4.5–5.7	5.2	4.7–5.9	4.6	4.1–5.3	5.1	4.4–5.9	5.3	4.6–5.9
	Control	4.6	3.8–5.7	5.1	4.7–5.8	5.4	4.8–5.9	4.6	3.8–5.5	5	4.5–5.6	5.4	4.7–6.0
Insulin ($mU \cdot L^{-1}$)	Intervention	4.7	2.2–9.9	5.6	2.7–14.6	7	3.7–15.0	4.7	2.4–11.7	7.7	3.4–15.6	11.2	5.4–18.8
	Control	4.6	1.8–9.6	5.5	2.8–13.5	8.5	4.2–20.8	5.6	2.5–12.0	7.1	3.0–16.8	11.5	5.4–26.8

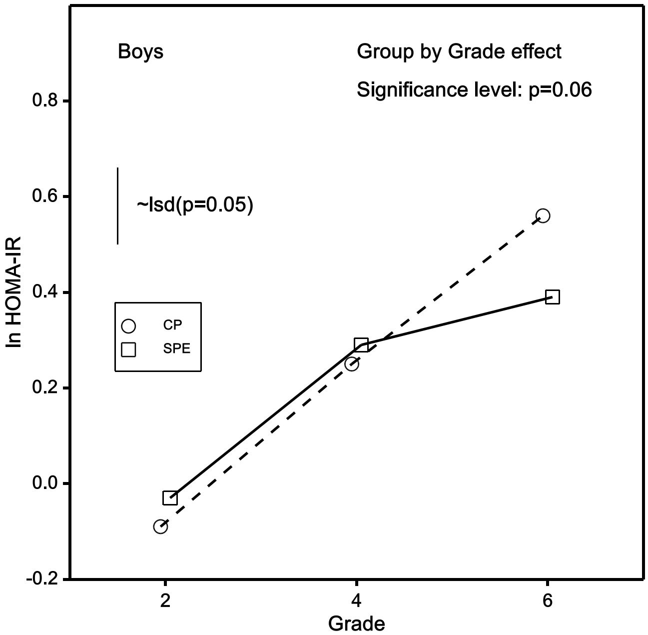

FIGURE 2—The pattern of change in IR (ln HOMA-IR) in the boys. This is classified by the specialist PE intervention (SPE), current practice control (CP) group and elementary school grade, and the intervention (grade × group) effect is shown.

was a sex interaction for IR, and we show the intervention effects on the patterns of change in (log of) IR in boys and girls separately in detail in Figures 2 and 3 (P = 0.06 boys and P = 0.05 girls). Second, by grade 6, the average HOMA-IR of the boys in the intervention group was 14% lower (95% confidence interval = 1%–31%, P = 0.06) than those in the control group; and for the girls, the corresponding relative reduction in HOMA-IR in the intervention group was 9% (5%–26%, P = 0.05). Third, with no difference in the percentages of elevated values at baseline, by grade 6, the percentages of children with HOMA-IR greater or equal to 3 (the suggested cutoff point associated with risk of metabolic dysfunction in 7- to 16-yr-olds [34]) were lower in the intervention group than that in the control group by 22% and 31%, respectively (P = 0.03 for combined data). Analyzing the boys and girls separately, these percentages were 12% and 21% (P = 0.06) for the boys and 32% and 40% (P = 0.05) for the girls.

***Post hoc* analysis.** The patterns of change shown in Figures 2 and 3 suggest that the effect of the intervention emerged mainly during the final 2 yr. In light of this pattern, together with the specialist PE teachers' *a priori* intention to increase the PA and fitness work as the children became older, we undertook a *post hoc* analysis of the change in IR in the intervention group compared with the control group. Although such analyses must be treated with some caution, there was a significantly greater reduction in IR during the final 2 yr in the intervention group compared with the control group (P = 0.03 for combined data, P = 0.02 for the boys, and P = 0.08 for the girls).

Mediation of the intervention effect on IR. In investigating potential mediators for the specialist PE intervention effect on IR, we first sought to determine whether there were any intervention effects on PA, CRF, and %BF. On examination of data during the full course of the 4 yr, there were no overall intervention effects on PA, CRF, or %BF (all $P > 0.3$). In any case, solid inferences about a mediator can only be made if introduction of that variable into our regression model results in a significant reduction in the intervention effect on IR; and introduction in turn of the variables PA, CRF, and %BF into our model describing IR had little effect on the strength of the intervention effect, thereby producing no solid evidence of mediation by any of these variables.

DISCUSSION

Our data provided evidence that two 50-min classes of specialist-taught PE conducted during the 4 yr of elementary school had a beneficial effect on the children's IR. These data indicated that the intervention, a balanced educational program as distinct from a training program, (a) attenuated the age-related pattern of increase in IR, (b) reduced IR by an average of 14% and 9% in boys and girls respectively, and (c) with no differences between the groups at baseline in grade 2, by grade 6, the overall incidence of children with elevated HOMA-IR (34) was 22% in the intervention group compared with 31% in the control group. Remarkably, and with practical significance for elementary school education policy makers, the intervention effect on IR was not gauged relative to a control group devoid of PE but relative to a group undertaking the current form of PE conducted by the classroom teacher.

Upon consideration of aspects of the PE intervention, which may have led to improved IR, we have already reported

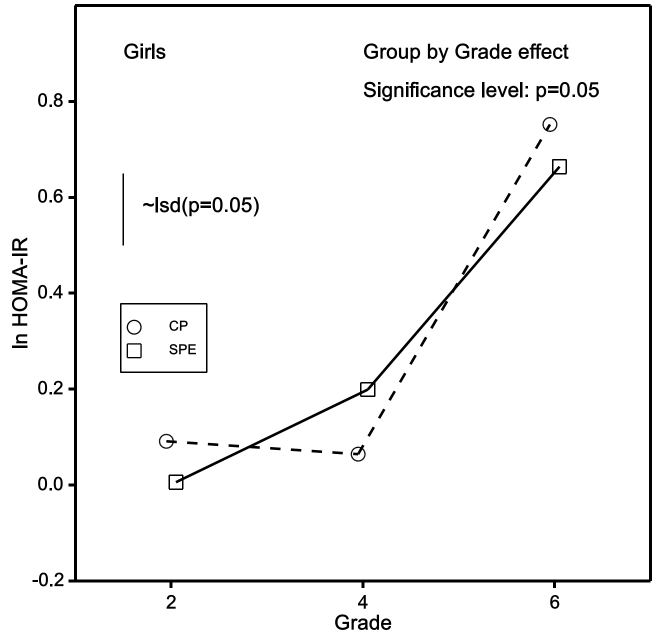

FIGURE 3—The pattern of change in IR (ln HOMA-IR) in the girls. This is classified by the specialist PE intervention (SPE), current practice control (CP) group and the elementary school grade, and the intervention (grade × group) effect is shown.

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evidence of longitudinal relationships between IR and PA in the boys between the ages of 8 and 10 yr (30) and subsequently that %BF emerged as a significant longitudinal explanator of IR between 10 and 12 yr in both boys and girls, with PA remaining significant in the boys (32). However, given the lack of an intervention effect on %BF during the full course of this study and the absence of any direct evidence for %BF as a mediator as explained in the Results section, our data suggest that change in %BF may not have been directly responsible for the intervention effect on IR.

On the surface, the same assertion might well apply to PA and CRF in terms of any mediation effect, as there was little direct evidence of an intervention effect on PA determined by daily step count or in CRF measured by the multistage running test. However, a more detailed analysis identified several putative mediators relating to the intensity and type of PA in the specialist PE program that may have exerted an effect on IR, particularly during the last 2 yr. First, the SOFIT data showed that specialist PE teachers incorporated more fitness work into each lesson than the classroom teachers. Second, a common feature of the fitness activity in every specialist PE lesson plan, and not present in the control program, was the emphasis on static and dynamic balance work, the execution of which required isometric and dynamic muscular contraction. In effect, these activities might be considered to constitute a moderate form of resistance training, and there is evidence that resistance training itself may be effective in improving IR (15). Third, the specialist teachers indicated their intention to increase the intensity of the fitness work as the children became older, and this was confirmed by their lesson reports in the latter years as well as through discussions with our research group midway through the program. As can be observed in Figures 2 and 3, together with the *post hoc* analyses, this increased emphasis on fitness coincided with the intervention being most effective in the last 2 yr. Although these considerations do not allow us to make confident inferences of a mediation effect of PA and fitness, considering the intervention was one of PE, they represent plausible mechanisms that may be addressed with further research. Pedometers would not have been capable of adequately reflecting the muscular activity associated with these activities, and our inability to detect significant intervention effects on PA might have reflected, at least in part, the lack of specificity of the step counts. Similarly, the multistage running test of CRF may have lacked the specificity to detect the changes in the particular type of muscular adaptation developed by the intervention PE program.

Nevertheless, our evidence suggests that specialist-conducted PE attenuated the progression in IR of the children, and many of the 12-yr-olds possessed elevated HOMA-IR levels. The question as to whether reducing elevated HOMA-IR in childhood decreases the risk of development of type 2 diabetes in later life has not been thoroughly investigated and requires further longitudinal work (12). However, with evidence that reducing adiposity during childhood and adolescence diminishes risk of type 2 diabetes in adulthood (17,35), it is not unreasonable to expect that a direct reduction in HOMA-IR during childhood to have a similar effect at least.

Strong aspects of our study include its 4-yr duration of the contemporary PE program, the cluster design offsetting potential program contamination, and the statistical model that accounted for potentially confounding covariates of IR. On the other hand, the study was likely to have been limited by a lack of specificity of the PA and fitness assessments, despite their objectivity. Our inability to incorporate a control group devoid of PE was also a limitation, although it did open a direct comparison of specialist PE with current practices in elementary school. A further limitation was that in contrast with the intervention classes, we were unable to select control group classes for observation at random. Given that at least a notice of 1 wk was required by control group schools, we cannot be sure that our observations of control classes were of typical content and duration. Finally, the participants in this study were mainly White, lived in a relatively affluent society, and attended a well-established government-funded education system, so our data may not be readily generalizable to children of varying racial–ethnic backgrounds and living conditions.

Of practical importance is whether the specialist PE program we investigated is readily implementable and sustainable within a system of elementary schools. This appears to be the case as the provider, the Bluearth Foundation, which set up the program in response to the absence of specialized PE in most Australian government-funded elementary schools, is currently in operation in many schools around Australia. The main barrier to engaging specialist physical educators in elementary schools is undoubtedly the cost, but this must be weighed up against our evidence that an elementary school in the contemporary setting without specialist PE places its pupils at a disadvantage, not only in terms of their health but also in relation to their academic development (29). A further disadvantage that came to our notice was a reduction in face-to-face teaching time brought about by classroom teachers having to organize PE lessons, including equipment setup in between class commitments. This may have contributed to their average PE lesson durations being two thirds that of the intervention teachers who were well prepared on arrival of the children. Educational policy makers may argue that even if they did provide one specialist PE teacher for a typical medium-sized school, this would provide specialist PE for each child on just one occasion per week when daily PE of 30 min is the usual curriculum requirement. The solution to this dilemma, apart from using multiple specialist PE teachers within a school, which may prove too costly at least in the short to medium term, is for the one specialist PE teacher in the school to provide ongoing professional development and assistance for each classroom teacher so that all PE classes approach specialist quality. To this end, the provider of the currently investigated program has developed a concurrent and hands-on professional development program for classroom teachers.

In conclusion, this 4-yr program of elementary school PE taught by specialist PE teachers had a beneficial effect on the IR of the children; the effect taking place mainly during the last 2 yr. This effect was especially impressive given that the control group consisted of current practice PE conducted by classroom teachers rather than one devoid of PE altogether. Given evidence that early control of IR can reduce the risk of type 2 diabetes in later life, well-designed and well-taught PE offers an opportunity to provide a primordial preventative strategy directed to all children through a community-wide approach.

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