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Relation of Academic Performance to Physical Activity and Fitness in Children

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The objective of this study was to examine the association of scholastic performance with physical activity and fitness of children. To do so, school ratings of scholastic ability on a five-point scale for a nationally representative sample of 7,961 Australian schoolchildren aged 7–15 years were compared with physical activity and fitness measurements. Consistently across age and sex groups, the ratings were significantly correlated with questionnaire measures of physical activity and with performance on the 1.6-kilometer run, sit-ups and push-ups challenges, 50-meter sprint, and standing long jump. There were no significant associations for physical work capacity at a heart rate of 170 (PWC_{170}). The results are concordant with the hypothesis that physical activity enhances academic performance, but the cross-sectional nature of the observations limits causal inference, and the disparity for PWC_{170} gives reason to question whether the associations were due to measurement bias or residual confounding.

A growing literature documents multiple physical and mental health benefits of physical activity in young people (12) and adults (18). It is also hypothesized that physical activity improves social and moral development of children, as well as academic performance. The relation of physical activity and fitness to academic performance is of special concern because school physical education programs can be questioned regarding their contribution to the primary academic mission of schools (15). Although physical education programs can be justified on the basis of their health benefits alone (13), it is important to understand any effects on academic achievement. It has been hypothesized that physical activity at school could enhance academic performance by increasing cerebral blood flow, enhancing arousal level, changing hormone secretion, and improving self-esteem, but none of these mechanisms has been adequately documented (15).

Controlled studies in Australia (4) and Canada (14) have examined the effects of health-related physical education on academic performance, though only

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one of them (4) involved randomization of subjects. In an Australian study of daily physical activity in primary schools, there were no differences in academic performance between students who were randomized to the program and those who were not (4). It is notable that devoting an extra hour per day to physical education did not diminish academic performance, and follow-up evaluation provided evidence of improved mathematics performance in the intervention group. In a multiyear Canadian study, students with enhanced physical education scored higher on report cards and standardized tests than those with regular physical education (14). These improvements occurred in spite of a 13% reduction in academic teaching time for students with enhanced physical education. A study in France in the 1950s also seemed to demonstrate that devoting extensive time to physical education did not interfere with academic performance (15).

The results of the controlled studies are promising, but it is difficult to draw firm conclusions from this small group of studies. In a recent review of mainly cross-sectional studies, Thomas et al. (17) concluded that there is a small association between physical activity and cognitive abilities, most consistently with math and reaction time. Investigation of academic achievement and physical fitness dates back to at least the 1940s (11). Unfortunately, most of the research in this area is from unpublished doctoral dissertations. The results are inconsistent.

Two published cross-sectional studies provide tentative support for an association. In a large study of primary school students, the sit-and-reach test was correlated with standardized achievement test scores (5). A study of college freshman women found strong correlations between a physical fitness index and an academic index (6).

Because of importance of any association between academic performance and physical activity or fitness, the long-term scientific interest in the issue, and the relevance to policies governing physical education in schools, more definitive studies are needed on this question. Some of the most significant unresolved issues include the relation of different components of health-related fitness with academic performance and how these associations may vary by age or sex. The present paper reports the relation of academic performance with physical activity and fitness in a large, nationally representative sample of Australian school children aged 7–15 years.

Methods

Participants

The Australian Schools Health and Fitness Survey was conducted in 1985. It is described in detail elsewhere (3). The study sample consisted of 9,000 schoolchildren between the ages of 7 and 15 inclusive (500 in each age/sex stratum). The subjects were selected using two-stage probability sampling.

The first stage involved the selection of schools. These were chosen with a probability proportional to the enrollment numbers of students aged 10 years in primary school and 14 years in secondary school. For logistical reasons, schools with total enrollments below 200 students were not included. This meant that 3.1% of secondary students and 9.9% of primary students were excluded from the possibility of selection. Eligible schools were listed in ascending postal code order to ensure a good geographical distribution and were then chosen using a random start, constant interval procedure. Of the 109 schools selected in the sample, 12 schools refused to participate and were replaced with 12 other schools from the sampling frame. The school response rate was 90.1% (109/121).

The second stage of sampling consisted of the random selection of 10 boys and 10 girls in each age group from each school. The sampling frame for this was the enrollment list, provided by each school, which contained the name, sex, grade, and age of all students in the school. Parent and child consent were required for a student to be included in the study and were obtained for 77.5% of students selected in the initial sample.

Outcome Factor

The scholastic ability of each subject was rated by a representative, usually the principal, of the school attended. The ratings were made on the same 5-point scale: Excellent, Above average, Average, Below average, or Poor. Data on school size and on physical education programs were recorded on a school's questionnaire.

Study Factors

The testing team consisted of 10 data collectors in each Australian state and territory. All of these personnel underwent a period of training in the use of standard protocols (1), and site visits were undertaken by the principal investigators to maintain standardization throughout the survey, which took approximately 3 months.

The tests conducted indoors included measurement of height and body mass, the standing long jump (muscular power), sit-ups and push-ups challenges (muscular force and endurance), sit and reach (joint mobility), dynamometry (muscular force and power), skin folds, and lung function. The standing long jump was measured as the longest of two jumps done from a 2-foot take-off. Sit-ups were done to a cadence of 20 per minute to a maximum of 100, with knees bent to 140° and the fingers moved up the thigh to the level of the patella. Measurements by dynamometry and of skin folds and lung function were performed on 9-, 12-, and 15-year-old subjects. The tests by dynamometry were right and left hand grip force with a hand grip dynamometer, shoulder extension and shoulder flexion with a push-pull dynamometer, and leg force with a back and leg dynamometer. Skin fold thicknesses were measured at 5 sites (triceps, biceps, subscapular, suprailiac, and midabdominal) with Holtain calipers. Lung function was assessed by a Vitalograph single-breath wedge spirometer adjusted to the student's height. The order of these indoor tests was varied from day to day, but with tests in bare feet grouped together.

The outdoor tests of all subjects were conducted afterward on the track, after a thorough warm-up. They were a 50-meter sprint (muscular power) across the wind in groups of four students and a 1.6-kilometer run (cardiorespiratory endurance) on a round or oval track 200m or 400m in circumference.

On the following day, physical work capacity was performed on 9-, 12-, and 15-year-olds using a Monark cycle ergometer in a continuous test with three ascending power outputs each of 3-min duration. In the last 20 s of each minute, the heart rate was measured with a stethoscope and a stopwatch timing 30 beats. The target heart rates were 115–130, 130–145, and 145–160 beats per minute. Once students had reached the required speed of 60 revolutions per minute, an initial load of 0.5 kp was applied. The heart rate obtained was used to select the second power output, and the heart rate then attained was used to select the third power output. If the last 2 min of any power output produced heart rates that differed by more than 5 beats, the student was given an further minute at that power output. This procedure was repeated until the last two consecutive heart rates indicated that steady state had been reached. The test was terminated if the heart rate exceeded 170 beats per minute. Individual regression lines were used to estimate physical work capacity at a heart rate of 170 (PWC_{170}).

In groups of four students per data collector, a questionnaire was administered to subjects aged 9 years or over. It sought information on the subjects' involvement in exercise and sport. An activity grid was used to record physical activities undertaken during the past week. The subjects were required to estimate the number of times, and the (average) length of time and (average) intensity of effort on each occasion, that they had cycled and walked to school, been involved in school physical education, engaged in a school sport, or undertaken other activities. Other questions inquired about usual activity during the morning recess break (Sit and talk to friends, Walk around the school, Run around playing sports/games, Read/study for the next classes, Nothing much, or Other) and during the luncheon break (Sit and talk to friends, Walk around the school, Ride or walk home for lunch, Train for school sports teams, Play sport/games on the oval or in the school grounds, Study or do homework, or Other).

The questionnaire also gathered information on demographic factors including date of birth and ethnicity; health-related behaviors including smoking and drinking; and attitudes toward school, exercise, smoking and health. Specific questions referred to self-assessed scholastic ability (Better than most, About the middle, or Not as good as most), the time that the subject went to bed and turned off the lights the previous night, the time that the subject awoke that morning, whether the subject had something to eat before school on 4 or more mornings per week (Yes or No), how well the subject could play a musical instrument (Never tried, Can't do, Can do about average, or Can do very well), the subject's date of birth, and whether the father and mother exercised 2 or more times per week (Yes, No, or Don't know).

The Australian Bureau of Statistics provided a general index of socioeconomic status for residential areas defined by postal boundaries. The index summarized information collected in the 1981 Population Census in relation to education levels and occupations of members of households, the economic resources of households, and indicators of living standards including house size, numbers of bedrooms, and motor vehicles.

Data Analysis

Consecutive integer scores were assigned to the school ratings of scholastic performance (1 = poor, 2 = below average, 3 = average, 4 = above average, 5 = excellent), self-assessments of scholastic ability (1 = not as good as most, 2 = about the middle, 3 = better than most), and self-assessments of usual health (1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = very good). The entries on the activity grid were used to estimate, by multiplying the number of sessions by the (average) time per session, the total time spent in each activity during the week.

The responses to the recess and lunchtime activity questions were reduced to three ordered categories (1 = not active, 2 = active, 3 = very active). Not active was equivalent to sitting, active was equivalent to walking, and very active was equivalent to running. The times the subject went to bed and awoke were expressed as minutes elapsed since 12.00 midday the previous day. Body mass index (BMI) was calculated as mass/height^2. For 9-, 12-, and 15-year-olds, fat mass was estimated from skin fold thicknesses at four sites using the procedures described in detail elsewhere (3). Lean body mass and percent body fat were calculated by subtracting fat mass from body mass and dividing fat mass by body mass, respectively.

Associations between scaled and ordered categorical variables were summarized with Spearman rank correlation coefficients. Linear regression analysis was used to estimate, for each age and sex, the association between the school ratings of scholastic ability and the measures of physical capacity and activity, but with two modifications made to take account of the complex sampling design (16). Firstly, each sampled individual was weighted by the number of Australian schoolchildren of the same age and gender in that state and school type (Government or non-Government school) that the subject represented. Secondly, the standard errors for the weighted least squares regression parameters were estimated by the jackknife method. Each school (the primary sampling unit) was dropped in turn, by setting to zero the weight for each participant from that school having the same age and sex and then adjusting the weights for the remaining subjects of that age and sex to what they would have been had that school not been sampled. The association parameter (β) was then re-estimated in each sample. The jackknife estimate of the variance used was:

$$\sigma^2 = \frac{m-1}{m} \cdot \sum_{i=1}^{m} (\beta_i - \mu)^2$$

where β_i (i = 1,2,...m) denotes the estimate of β with the ith school dropped, and

$$\mu = \frac{\sum_{i=1}^{m} \beta_i}{m}$$ denotes the mean of the β_i.

The results reported are estimated slope coefficients for the linear relationship between the dependent variable (scholastic rating) and independent variable (a measure of physical capacity or activity). Separate analyses were made for girls and boys in each year of age group. To control for differences in age within year-of-age groups, school type, and education system (each state and territory of Australia has its own education system), the slope coefficients were estimated with adjustment for age (days elapsed since last birthday), type of school, and state. The number of days elapsed since last birthday was entered as a linear predictor. Adjustment was made for type of school using a dummy (0/1) variable for Catholic non-Government schools and a second dummy (0/1) variable for non-Government schools of other denominations. Dummy variables were also entered for each state or territory other than New South Wales (the most populated state), requiring a total of 7 dummies. The effect of controlling for region in this manner would also take into account interstate differences in temperature, which may have confounded the associations of scholastic rating with some measures of physical fitness and activity. As a measure of endurance fitness, PWC_{170} was divided by lean body mass to adjust for stature. The logarithm of sit-ups was used in the regression analyses because the relationship of the school ratings with sit-ups was not linear.

Adjustment was made for height, BMI, percent body fat estimated from skin fold thicknesses, time to bed and length of sleep, whether or not the subject usually (four or more times per week) ate something before school, musical training (three dummy variables for levels other than "Can't do"), and parental exercise (two dummy variables were entered for levels other than "No"). The index of socioeconomic status, which is not an interval measure, was categorized into quarters, and dummy (0/1) variables were entered for categories other than the lowest.

Results

The scholastic ratings differed by gender (being higher for boys), days since last birthday (being higher for older subjects within each year-of-age group), type of school (being lower in Government or Catholic schools than in other non-Government schools), and region of Australia. The school assessments were associated with the students' own perception of their scholastic ability, with rank correlation coefficients in the range 0.3 to 0.5 (Table 1).

The school ratings of scholastic ability (scaled in increasing ability) were associated with measures of physical fitness, capacity, and activity. There were weak but consistent associations with the field tests of muscular force, endurance, and power. Some of these associations are shown in Table 2. Subjects with higher scholastic ratings took less time to complete the 50-meter run, completed more sit-ups, and leapt greater distances in the standing long jump. The associations of scholastic rating with push-ups and with sit and reach (a measure of joint mobility)

Table 1 Correlation Coefficients for the Associations of School Ratings of Scholastic Ability With Subjects' Self-Assessments of Scholastic Ability, in the Australian Schools Health and Fitness Survey (1985)

	Girls			Boys		
Age	r_s		(Num)	r_s		(Num)
7 years			(455)			(452)
8 years			(464)			(456)
9 years	0.29	***	(460)	0.38	***	(450)
10 years	0.44	***	(476)	0.44	***	(469)
11 years	0.43	***	(460)	0.51	***	(459)
12 years	0.35	***	(460)	0.46	***	(461)
13 years	0.33	***	(410)	0.43	***	(426)
14 years	0.45	***	(378)	0.49	***	(439)
15 years	0.47	***	(376)	0.49	***	(410)

Note: The correlation coefficients (r_s) are Spearman rank correlation coefficients. (Num) refers to the number of subjects with school ratings in each sex and age group. *** denotes $P < .001$.

Table 2 ***Correlation Coefficients for the Association of Scholastic Rating by the School With Measures of Physical Fitness, Capacity and Activity***

	Cardiorespiratory endurance		Muscular force and power			Physical activity	
	PWC_{170} per kg	1.6-km run	50-meter run	Sit-ups	Standing long jump	Lunchtime activity	Weekly exercise
Girls							
7 years		0.01	–.04	0.07	0.01		
8 years		–.17 ***	–.15 **	0.16 ***	0.09		
9 years	–0.04	–.03	–.06	0.19 ***	0.09	0.14 **	0.11 *
10 years		–.15 **	–.14 **	0.06	0.11 *	0.14 **	0.14 **
11 years		–.16 ***	–.10 *	0.05	0.18 ***	0.19 ***	0.12 **
12 years	0.03	–.15 **	–.08	0.15 **	0.13 **	0.01	0.07
13 years		–.12 *	–.14 **	0.19 ***	0.15 **	0.01	0.05
14 years		–.12 *	–.10	0.18 ***	0.11 *	0.12 *	0.10
15 years	0.04	–.06	–.13 *	0.12 *	0.18 ***	–.01	0.01
Boys							
7 years		–.06	–.07	0.04	0.06		
8 years		–.07	–.15 **	0.07	0.18 ***		
9 years	–.01	–.11 *	–.03	0.03	0.13 **	0.08 *	0.17 ***
10 years		–.16 ***	–.13 **	0.13 **	0.07	0.12 *	0.11 *
11 years		–.17 ***	–.17 ***	0.17 ***	0.19 ***	–.00	0.05
12 years	–.02	–.15 **	–.03	0.22 ***	0.16 ***	0.01	0.13 **
13 years		0.01	–.08	0.13 **	0.09	0.10 *	0.07
14 years		–.18 ***	–.19 **	0.20 ***	0.27 ***	0.18 ***	0.04
15 years	0.00	–.16 **	–.15 **	0.14 **	0.10 *	0.14 **	0.04

Note: Spearman rank correlation coefficients.
PWC_{170} per kg denotes physical work capacity at heart rate 170 beats per minute per kilogram of lean body mass.
*** denotes $P < .001$, ** denotes $P < .01$, * denotes $P < .05$. No adjustment has been made for multiple, preplanned comparisons.

were weaker. Those with sit and reach (data not shown) were strongest for girls, and those with push-ups (data not shown) were strongest for boys

The associations with the two measures of cardiorespiratory endurance were less consistent. There were significant associations with the 1.6-kilometer run (scaled in increasing time taken), but those with the objective measure of PWC_{170} per kg of lean body mass were weak and insignificant (see Table 2). The associations with the measures of hand, shoulder, and leg force for 9-, 12-, and 15-year-olds (data not shown) were generally positive, and largest for left grip ($r = .13$, $P < .01$), right grip ($r = .13$, $P < .01$), and shoulder flexion ($r = .19$, $P < .001$) for 12-year-old girls, shoulder extension ($r = .09$, $P = .05$) for 12-year-old boys, and shoulder extension ($r = .11$, $P = .02$) and shoulder flexion ($r = .10$, $P = .04$) for 15-year-old boys.

Questionnaire measures of physical activity were available for children 9 years or older. These measures included usual activity at recess and at lunchtime (ranging from sitting to running around), and minutes of physical exercise last week spent in travelling to school, in school physical education, in school sport, and in other activities. The statistically significant associations of scholastic rating with these measures were positive, indicating that children of higher scholastic ability were more active. The associations with lunchtime activity, and with minutes of physical exercise last week other than in travelling to school, are shown in Table 2. Those for recess activity were weaker than the associations for activity at lunchtime and are not shown. Removing from analysis those students who reported that they usually study or do home work, and those who reported usually eating or doing music practice, produced marginally stronger associations (data not shown). The associations with minutes of weekly activity were weaker, particularly for girls, when time spent travelling to school was added to the total for physical education, sport, and other activities (data not shown).

The two physical performance measures most consistently and strongly associated with the scholastic ratings were sit-ups and the standing long jump. The associations with sit-ups are depicted in Figure 1 for 13–15-year-olds.

To summarize the effects of adjusting for putative confounders, weighted least squares regression coefficients for sit-ups are shown in Table 3. These coefficients are the estimated slopes of the linear relationship between scholastic ability and the logarithm of sit-ups. The jackknife method was used in these analyses to estimate the variance of the slope parameter. It produced estimates of standard deviation that were on average 17.8% larger than the weighted least squares regression estimates. There was little difference between the weighted and unweighted estimates of variance.

The unadjusted slopes are shown in the first column of Table 3. The effects of adjusting for age (months since last birthday), type of school (Government, Catholic non-Government, other non-Government), and region of residence are shown in the second column. The slope estimates were diminished by more than 10% for 12- and 14-year-old girls but remained statistically significant nonetheless.

We adjusted for height to assess whether the associations for intellectual development might be independent of general musculoskeletal development. Despite the positive and significant associations of scholastic rating with height for 8-, 9-, 10-, 12-, and 13-year-old girls, and for 14- and 15-year-old boys (data not shown), additionally adjusting for height made little difference to the parameter

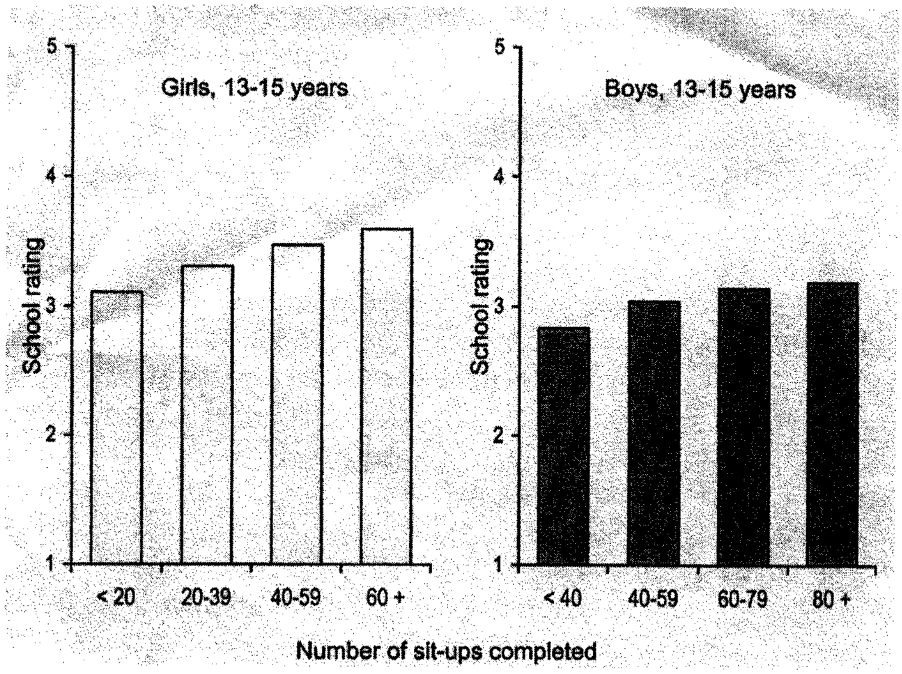

Figure 1 — Mean scholastic ratings of groups of 13–15-year-old subjects categorized by the number of sit-ups completed in the Australian Schools Health and Fitness Survey (1985).

estimates for sit-ups. This can be seen by comparing the fourth column of Table 3 with the third.

To take account of the effect of body fatness on physical performance, we adjusted for two measures of it. Body mass index (BMI) was negatively associated with scholastic rating and with the number of sit-ups completed in each age and gender group (data not shown). The associations of scholastic rating with BMI were statistically significant for 8-, 11-, 13-, and 14-year-old girls and for 9- and 11-year-old boys. The effect of adjusting the estimated association between scholastic rating and sit-ups for BMI is shown in column 5 of Table 3. The associations generally were diminished but not eliminated. A more direct measure of body fatness, percent body fat calculated from skin fold thicknesses, was available for 9-, 12-, and 15-year-olds. The results were similar: the adjusted parameter estimates were 25 ($P < .01$), 8, and 16 for girls aged 9, 12 and 15 years, respectively; and 0, 24 ($P < .01$), and 30 ($P < .01$) for the boys.

We examined a number of possible indicators of parental involvement in the intellectual and physical development of their children. Higher scholastic ability was associated with usually having something to eat before starting school, going to bed later for girls, being able to play a musical instrument, having a parent (the mother for girls and the father for boys) who exercised at least twice a week, and higher socioeconomic status based on residential postal code. Adjusting for these indicators had little effect on the estimated slope coefficients, however. The results of adjusting for not eating before school, the child's ability to play a musical instrument, and socioeconomic status can be found in Table 3 by comparing the final three columns with the fourth.

The associations of school rating of scholastic ability with standing long jump were positive for all but the 7-year-old girls. Controlling for the same puta-

Table 3 Regression Coefficients for the Association of Scholastic Ratings With Number of Sit-Ups Completed, Showing the Effects of Adjusting for Measures of General Musculoskeletal Development, Body Fatness, and Parental Involvement in the Intellectual Development of Their Children

	Not Adjusted	Adjusted for: Age, School, State	Height	BMI	Eat before school	Musical training	SES
Girls							
7 years	5	5	5	5			
8 years	15 **	14 **	12 *	13 *			
9 years	23 **	23 **	22 **	24 **	24 **	23 **	24 **
10 years	12	14	12	12	14	12	15 *
11 years	7	9	10	4	9	8	8
12 years	22 *	16 *	16	10	14	15	12
13 years	24 *	23 **	21 *	20 *	23 **	25 **	20 *
14 years	22 ***	19 **	19 **	17 **	19 **	18 **	18 **
15 years	19 *	18 *	19 *	17	17 *	17 *	19 *
Boys							
7 years	0	1	1	0			
8 years	7	7	7	7			
9 years	–1	1	2	0	1	5	4
10 years	15 *	15 *	13	13	15 *	14 *	15 *
11 years	25 ***	25 ***	24 ***	22 ***	26 ***	25 ***	25 ***
12 years	26 **	25 ***	25 ***	24 **	25 ***	25 ***	24 ***
13 years	16 *	16 *	16 *	17	16 *	16 *	18 *
14 years	36 **	33 *	33 *	34 **	32 *	35 **	32 *
15 years	30 **	30 **	29 **	30 **	30 **	30 **	29 **

Note: Slope coefficients x 10^2, estimated by weighted linear regression of the logarithm of sit-ups on scholastic rating. Age refers to adjustment for days elapsed since last birthday. School refers to adjustment for type of school attended (Government, Catholic, other non-Government). Information obtained by questionnaire (date of birth, whether the subject usually had something to eat before school, how well the subject could play a musical instrument, postcode) was not available for 7- or 8-year-olds.
*** denotes $P < .001$, ** denotes $P < .01$, * denotes $P < .05$.

tive confounders in some cases reduced, but did not eliminate, the associations of scholastic ability with long jump.

Discussion

The significant associations found for the school ratings of scholastic ability with the two measures of physical activity, together with those with a number of measures of physical fitness and capacity, are consistent with the hypothesis that physical activity enhances academic performance. All correlations were low, but large correlations should not be expected between these variables. Physical activity and fitness would, at best, make a modest contribution to academic performance.

Measures of cardiorespiratory endurance, muscular force and power, and physical activity were all related to scholastic ability. Thus, it cannot be concluded that only one component of fitness is related to academic performance. The conclusion that fitness and activity are related to academic performance is enhanced by the consistency with which each measure of the fitness components or physical activity were correlated with the school assessments of scholastic ability. The multiple measures can be considered as within-study replications of findings. The major exception was PWC_{170}, which is a measure of cardiorespiratory endurance that was not associated with the scholastic ratings.

Although there were some variations in correlations for boys and girls, and at different ages, the variations were less impressive than the similarity of findings across age and sex groups. The pattern of correlations was generally similar for boys and girls. There was not good evidence that any fitness measure was correlated with academic performance at one age but not another. For example, the standing long jump was not significantly correlated with academic performance among girls aged 7 to 9 years, but absence of association at these ages was not confirmed among boys. Correlations did not apparently increase or decrease across age for any measure. The only age-related trend in correlations was seen with weekly exercise, for which the correlations for boys and girls aged 13 to 15 were smallest. Thus, the general conclusion is that physical activity and fitness are weakly correlated with academic performance among girls and boys aged 7 to 15 years.

These data were collected on a representative sample of the school-aged population, and the response rates were good. It is therefore unlikely that the associations were due to a selection bias. In previous studies where similar findings have been obtained, the issue of selection bias cannot be as readily dismissed because the samples were not population-based.

A causal connection between physical activity and academic performance is plausible. Regular physical activity may reduce plasma noradrenaline (8). It may also increase the transfer of the serotonin precursor tryptophan across the blood-brain barrier, having a calming effect in children and enabling them to sit and concentrate on academic pursuits. The SHAPE study (4) demonstrated that the classroom behavior of 10-year-olds was improved in association with a program of daily physical activity. Research has also shown that blood flow to the cortex of the brain is increased following bouts of exercise (7). In a recent review, McAuley (10) concluded that a positive relationship exists between physical activity and self-esteem in children. Enhanced self-esteem may result in better classroom behavior and a greater desire to learn (2). Nearly all of the studies reviewed by Keays

(9) reported significant improvements in the attitudes, discipline, behavior, and creativity of school students following the implementation of physical activity programs.

The assessments of scholastic ability were made by trained teachers qualified to make them and using the same scale of ratings, and we presume that the ratings were based on the students' academic records and grade reports. There was no national competency testing in place in Australia at this time to standardize the measurements, but the internal consistency of the data was reassuring. The correlation coefficients for the school assessments with the students' own perceptions of their scholastic ability were of the order of 0.5, and associations with each of the physical activity/fitness variables were present for the student's own assessment of academic performance used in place of the principal's assessment. This allows some confidence that the school assessments were valid.

The limitations of this study's design are such that inference about a causal pathway is speculative if based on these data. The cross-sectional nature of the observations limits the extent to which causality can be inferred. In addition the disparity for PWC_{170} gives reason to question whether the link between the school ratings and the physical activity and fitness measures was due to some form of measurement bias or to confounding.

The field tests that were associated with the school ratings could have been influenced by the motivation of the subject. The only test with an objective component was the physical work capacity test on the cycle ergometer, PWC_{170}, which involved heart rate monitoring by the research team member at each level of effort expended. It may not have been associated with the school ratings in the absence of a putative motivation-related bias. Alternatively, the lack of any association may have resulted from the removal of confounding by body fatness. The measure used in analysis, PWC_{170} per kg lean body mass, was adjusted for body mass to remove confounding. In contrast, performances in the 1.6-kilometer run, 50-meter sprint, standing long jump, and sit-ups tests could all have been adversely affected by body fatness. Supporting the contention that the observed association of scholastic ratings with physical fitness and activity might be due to confounding by body fatness is the finding that the school ratings were not consistently associated with measurements of hand, shoulder, or leg muscle force made with a dynamometer. These measurements would not have been substantially confounded by fatness. Against this contention is the finding that adjusting for BMI had only minor effects on the parameter estimates for the relationship between school rating and sit-ups.

There are other potential causal pathways that should be considered to be possible sources of confounding. Genetic factors or fetal nutrition, for example, could be responsible for poor development of both the musculoskeletal and nervous systems. It is also possible that parents and families exert an influence in the development of physical and intellectual capacities. We were able to examine the latter possibility, albeit only indirectly, by controlling for various indicators of parental involvement including socioeconomic status estimated from residential address. Adjustment for each of these made little difference to the parameter estimate, but it is unlikely that these indicators captured adequately all the elements that we might wish to include.

Only a randomized trial with blinding could completely remove such possible confounding effects. The results of the only randomized trial conducted to date proved inconclusive, but increasing curricular time for physical education did not suppress academic achievement in that study. A study of similar design but of longer duration is needed before it would be possible to confidently assert that a pathway involving physical activity and fitness might contribute in an important way to scholastic performance.

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