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# Physical Activity and Blood Pressure in Primary School Children

## A Longitudinal Study

Gemma Knowles, Miranda Pallan, G. Neil Thomas, Ulf Ekelund, Kar Keung Cheng, Timothy Barrett, Peymane Adab

**Abstract**—High blood pressure (BP) is becoming increasingly common during childhood. Regular physical activity (PA) reduces BP in adults, but limited studies have reported inconsistent results among children. The aim of this study is to examine, for the first time, the cross-sectional and longitudinal associations between BP and objectively measured PA in young children of predominantly South Asian background. Data from the Birmingham healthy Eating and Active lifestyle for CHildren Study were analyzed. Five hundred seventy-four children, aged 5 to 7 years, underwent a series of measures at baseline and were followed up 2 years later. PA was objectively measured using accelerometry and converted to counts per minute (total PA, cpm), and time spent in moderate-vigorous PA (minutes per day). BP was measured by trained staff using standard protocols. Data were available for 512 children at baseline (mean age 6.5 years, range 5.4–7.8 years), and 427 of these children were followed up. Baseline total PA was inversely associated with diastolic BP at both baseline (adjusted regression coefficient:  $-0.75$  mm Hg [95% CI  $-1.33$  to  $-0.18$ ] per 20 cpm) and follow-up ( $-0.74$  mm Hg [95% CI  $-1.40$  to  $-0.08$ ]). All associations remained unchanged after further adjustment for weight status. This study strengthens evidence of a causal association between higher PA and lower BP in children as young as 5, independent of weight status. The results provide support for development of interventions to increase PA in young children. (*Hypertension*. 2013;61:70-75.)

**Key Words:** blood pressure ■ body mass index ■ child ■ physical activity

The prevalence of high blood pressure (BP), a major risk factor for cardiovascular disease (CVD), has increased among children and adolescents over the past few decades.<sup>1</sup> Elevated BP is known to track into adulthood,<sup>2</sup> and childhood hypertension is positively associated with risk of premature mortality, cardiovascular disease, and endothelial dysfunction.<sup>3-5</sup>

In adults, low physical activity (PA) levels are responsible for much of the burden of hypertension, and the BP-lowering effects of regular PA have been reported.<sup>6</sup> However, studies in children have reported inconsistent results. Some studies have reported no association between PA and BP,<sup>7-11</sup> whereas others have reported inverse associations between PA and systolic BP (SBP) or diastolic BP (DBP).<sup>12-17</sup> The relative importance of total volume of PA versus time spent in moderate to vigorous PA (MVPA), and whether or not these associations are independent of adiposity, is also unclear.<sup>14,16</sup> A better understanding of these relationships is necessary to inform the development of cardiovascular disease prevention interventions, specifically whether PA interventions should be considered, in children.

Differences in methodology may contribute to the inconsistent results in previous research. Accurate measurement of PA is difficult, particularly in children because of the unstructured nature of their activity patterns.<sup>18</sup> Until recently, most studies have used subjective methods of measuring PA, which are susceptible to recall bias and over-reporting, and are less accurate for estimating intensity and duration of PA. Objective methods of measuring PA, such as pedometers and accelerometers, offer a more accurate way of quantifying PA.<sup>18</sup> It is also possible that variations in study population may contribute to the inconsistent findings. Previous cohorts, in which discrepant results have been reported, have included a multiethnic UK population,<sup>14</sup> Danish,<sup>9</sup> Cypriot,<sup>11</sup> Irish,<sup>8,15</sup> and American<sup>10</sup> children, among others.

Studies assessing the associations between BP and objectively-measured PA are very limited in children during the first decade of life. One cross-sectional study found no association between BP and objectively-measured PA in a sample of 3- to 6-year-old children.<sup>7</sup> However, the duration of PA measurement in this study was short (24 hours) and may not reflect habitual PA. Several longitudinal studies have

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From the Department of Public Health, Epidemiology and Biostatistics, University of Birmingham, Birmingham, United Kingdom (G.K., M.P., G.N.T., K.K.C., P.A.); Department of Sport Medicine, Norwegian School of Sport Sciences, Oslo, Norway (U.E.); MRC Epidemiology Unit, Institute of Metabolic Science, Cambridge, United Kingdom (U.E.); and the School of Clinical and Experimental Medicine, University of Birmingham, Birmingham, United Kingdom (T.B.).

Correspondence to Miranda Pallan, Department of Public Health, Epidemiology and Biostatistics, University of Birmingham, Edgbaston, Birmingham, United Kingdom. E-mail [m.j.pallan@bham.ac.uk](mailto:m.j.pallan@bham.ac.uk)

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found inverse associations between subjective measures of PA and BP in adolescents,<sup>15,17</sup> but data are lacking for primary school aged children. To our knowledge, no study to date has examined longitudinal associations between BP and objectively-measured PA in prepubertal children. Furthermore, there are few published data on children of South Asian origin, despite lower PA levels and increased cardiovascular risk in this ethnic group when compared with their white British and African-Caribbean counterparts.<sup>19,20</sup>

In the present study, we therefore aimed to explore the cross-sectional and longitudinal associations between BP and objectively-measured PA in a cohort of UK primary school children with a high proportion of South Asians, to inform future interventions.

## Methods

### Subjects and Study Design

Data were available on 574 children (51.7% male, 86% South Asian, 5–7 years old at baseline) who were recruited for the Birmingham healthy Eating and Active lifestyle for CHildren Study (BEACHeS). This exploratory trial was set up to develop and test a childhood obesity prevention intervention that was culturally appropriate to the South Asian community but inclusive of all children. South Asian groups, which comprise one fifth of the population in Birmingham, are at increased risk of obesity and related comorbidities<sup>19,20</sup>; hence the focus on developing a culturally appropriate intervention for this ethnic group. Using ethnicity data obtained from the Local Authority, all schools with at least 50% of pupils from the South Asian ethnic group (defined as Pakistani, Indian, or Bangladeshi, including both first and second generation migrants) were identified and invited to participate. The first 8 schools to respond were recruited into the study. All children in years 1 and 2 (age 5 to 7) were eligible to take part. All eligible children whose parents consented underwent a series of anthropometric and BP measures, and PA monitoring at baseline ( $n=512$ ), and the same measures were repeated 2 years later ( $n=427$ ). Those lost to follow-up were either absent on the day of measurement or did not provide valid BP and PA data at both time points. Children from 4 of the schools were allocated to the intervention arm and the remainder to the control arm. Parental consent was obtained for all children. Ethical approval was obtained from the East Birmingham Local Research Ethics Committee (REC reference number: 06/Q2703/43).

### Anthropometric and BP Measurements

All measures were undertaken by staff trained specifically for the study, following a standard protocol. Standing height was measured to the nearest 0.1 cm using a Leicester Height Measure. Body weight was measured to the nearest 0.1 kg using a Tanita bioimpedance monitor. Body mass index (BMI) was calculated ( $\text{kg}/\text{m}^2$ ) and converted into SD scores (BMI  $z$  scores) using the age- and sex-specific UK national 1990 growth reference charts.<sup>21</sup> Participants were also categorized as non-overweight/obese or overweight/obese using the 85th percentile of the UK national 1990 reference data as the cutoff. Waist circumference and skinfold thickness at 4 sites (triceps, biceps, suprailiac, and subscapular) were measured. BP was measured at least twice, in the seated position, using a medically approved automatic digital BP monitor (BpTRU BPM 100) with a child or small adult cuff-size selected according to each child's size. A third BP reading was taken if an error message was displayed or if either of the first 2 values were outside of the normal range for the age of the child. The mean of 2 readings was calculated and in cases where 3 BP readings were taken, the 2 closest values were used to calculate the mean.

### Objective PA Measurement

PA was measured using the Actiheart activity monitor (CamnTech, Papworth, United Kingdom), which has been validated for use in children and adults.<sup>22–24</sup> The monitor was worn for 5 consecutive days,

including 2 weekend days, set up to measure body acceleration and heart rate at 30 second epochs. The accelerometry data were analyzed using software developed by the Cambridge Medical Research Council Epidemiology Unit ([http://www.mrc-epid.cam.ac.uk/Research/Programmes/Programme\\_5/InDepth/Programme%205\\_Downloads.html](http://www.mrc-epid.cam.ac.uk/Research/Programmes/Programme_5/InDepth/Programme%205_Downloads.html)). Total daily volume of PA was estimated from accelerometry data and expressed as average counts per minute (cpm). The mean duration of daily MVPA (min/day) was calculated using a cutoff of 400 cpm as the lower threshold for moderate intensity activity.<sup>25</sup> This value was derived from previous validation studies that compared the widely used Actigraph accelerometer with the Actiheart under laboratory conditions among children and adolescents.<sup>23</sup> These studies suggested that cpm derived from the Actigraph is  $\approx 5$  times greater than that derived from the Actiheart.<sup>23,26</sup> Compliance with PA guidelines was defined as those participating in at least 60 minutes per day MVPA as recommended by the World Health Organization.<sup>27</sup>

### Statistical Analysis

Associations between PA and SBP and DBP were assessed by multiple linear regression, with SBP or DBP as the dependent variable and total PA or MVPA as the explanatory variable. Cross-sectional models were adjusted for age and sex (model 1), ethnicity, height, the duration of PA measurement, and school (model 2). Further adjustment was then made for BMI  $z$  score to assess whether or not BMI was a mediating factor in the association (model 3). Longitudinal models were adjusted for age and sex (model 1), ethnicity, change in age, height at baseline, change in height, school, baseline BP, intervention or control group status, and duration of PA measurement (model 2). Further adjustment was then made for baseline BMI  $z$  score (model 3). There were no significant gender interactions in the associations between PA and BP, so the cohort were analyzed as a whole. Sensitivity analyses were undertaken: (1) using waist circumference or sum of 4 skinfolds, as indicators of adiposity instead of BMI  $z$  score, (2) using the second, rather than the mean BP reading, and (3) restricted to children with at least 3 days of PA data available. All statistical analyses were performed using SPSS version 17.0.

## Results

Of the original sample of 574 children who were recruited for BEACHeS, both BP and PA data were present for 512 children (89%) at baseline. Children included in the analysis were slightly older than the 11% for whom data were not available (0.19 years older,  $P<0.05$ ), but were similar in terms of activity levels, BP, ethnicity, and weight status. Of those children included in the baseline cross-sectional analysis, data were available for 427 children (83%) at the 2-year follow-up. Children who were followed up were more likely to be female (87% of girls versus 80% of boys) and of South Asian ethnicity (86% of South Asian children and 63% of non-South Asian ethnicity were followed up). Weight status, age, activity levels, and BP were similar among those who were retained and those who were lost to follow-up.

Participants' characteristics at baseline and follow-up are presented in Table 1. Total PA declined for both males and females between baseline and follow-up, and the proportion of participants meeting the current recommendation of 60 min/day MVPA also declined from just under half at baseline to just over a quarter at follow-up. Males were significantly more active than females at both time points ( $P<0.001$  for both). Mean SBP and DBP were comparable among males and females at baseline and follow-up. Among those included in baseline analyses, 8.6% of males and 15.6% of females were classed as hypertensive based on the US age-, sex- and height-specific cutoffs for BP in children ( $\geq 95$ th percentile),<sup>28</sup>

**Table 1. Participant Characteristics at Baseline and Follow-Up**

Variable	Baseline			Follow-Up		
	Male (n=268)	Female (n=244)	All (n=512)	Male (n=215)	Female (n=212)	All (n=427)
Age, y	6.5 (0.6)	6.5 (0.6)	6.5 (0.6)	8.4 (0.7)	8.4 (0.6)	8.4 (0.6)
Ethnicity						
Bangladeshi	40 (14.9)	33 (13.5)	73 (14.3)	36 (16.7)	33 (15.6)	69 (16.2)
Indian	16 (6.0)	9 (3.7)	25 (4.9)	14 (6.5)	7 (3.3)	21 (4.9)
Pakistani	175 (65.3)	174 (71.3)	349 (68.2)	145 (67.4)	151 (71.2)	296 (69.3)
African-Caribbean	24 (9.0)	10 (4.1)	34 (6.6)	15 (7.0)	6 (2.8)	21 (4.9)
White	3 (1.1)	6 (2.5)	9 (1.8)	2 (0.9)	5 (2.4)	7 (1.6)
Other	10 (3.7)	12 (4.9)	22 (4.3)	3 (1.4)	10 (4.7)	13 (3.0)
Height, cm	120 (6.3)	120 (5.9)	120 (6.9)	131 (6.7)	130 (6.7)	130 (6.7)
Weight, kg*	22.0 (19.8, 24.6)	22.2 (19.8, 24.7)	22.1 (19.8, 24.6)	27.2 (24.5, 31.9)	28.4 (24.1, 34.2)	27.7 (24.3, 33.5)
BMI, kg/m <sup>2</sup> *	15.2 (14.3, 16.6)	15.4 (14.4, 17.1)	15.3 (14.3, 16.7)	16.3 (14.6, 18.1)	16.6 (14.8, 19.5)	16.4 (14.7, 18.7)
Weight status†						
Not OW/OB	226 (84.3)	187 (76.6)	413 (80.7)	165 (76.7)	143 (67.5)	308 (72.1)
OW/OB	42 (15.7)	57 (23.4)	99 (19.3)	50 (23.3)	69 (32.5)	119 (27.9)
SBP, mm Hg	102 (8.9)	103 (9.1)	103 (9.0)	104 (11.0)	105 (10.6)	104 (10.8)
DBP, mm Hg	69 (8.4)	70 (8.0)	69 (8.2)	69 (9.7)	69 (9.4)	69 (9.5)
Total PA, CPM	85.9 (26.5)	77.4 (24.4)	81.8 (25.9)	77.8 (35.0)	61.7 (17.2)	69.8 (28.8)
MVPA, min/day	62.7 (29.2)	54.1 (24.4)	58.6 (27.3)	58.3 (22.0)	42.3 (16.2)	50.3 (20.9)
Meet PA guidelines‡	144 (53.7)	100 (41.0)	244 (47.7)	84 (40.4)	29 (14.1)	113 (27.3)

BMI indicates body mass index; OW/OB, overweight/obese; SBP, systolic blood pressure; DBP, diastolic blood pressure; and PA, physical activity.

All values are mean (SD) for continuous variables unless indicated otherwise.

\*Median (interquartile range) and frequency (%) for categorical variables.

†Categories based on the UK 1990 BMI reference curves.<sup>21</sup>

‡Based on current World Health Organization PA recommendations for 5 to 17 year olds (60 min/day moderate to vigorous PA).<sup>27</sup>

and the prevalence was 10.2% and 14.6%, respectively, at follow-up. The proportion of children who were overweight or obese increased from 15.7% to 23.3% among males and from 23.4% to 32.5% among females during the study period.

### Associations Between PA Levels and BP at Baseline

Baseline cross-sectional associations between PA and BP are shown in Table 2. There were significant inverse associations between DBP and both total PA (per 20 cpm:  $B=-0.75$ ; 95% CI  $-1.33$  to  $-0.18$ ) and MVPA (per 15 min/day:  $B=-0.55$ , 95% CI,  $-0.94$  to  $-0.16$ ) after adjustment for potential confounders. Associations remained significant after adjustment for BMI  $z$  score, and the size of effect was only slightly attenuated for both total PA ( $B=-0.71$ ; 95% CI,  $-1.28$  to  $-0.14$ ) and MVPA ( $B=-0.48$ ; 95% CI  $-0.87$  to  $-0.09$ ). There were no significant associations between SBP and PA. Similarly there was a statistically significant inverse relationship between total PA and diastolic hypertension at baseline (adjusted OR: 0.99 [0.98, 1.00] per single unit increase in cpm), but no association with systolic hypertension.

### Associations Between Baseline PA and Follow-Up BP

Associations between baseline PA and follow-up BP are shown in Table 3. There was a significant inverse association between baseline total PA and follow-up DBP ( $B=-0.74$ , 95% CI,  $-1.40$  to  $-0.08$ ), which persisted after adjustment for baseline BMI  $z$  score and other putative confounding factors.

There was a borderline significant inverse association between baseline total PA and follow-up SBP ( $B=-0.72$ , 95% CI,  $-1.45$  to  $0.01$ ;  $P=0.06$ ).

### Sensitivity Analyses

Sensitivity analyses using the second BP measurements rather than mean, alternative measures of adiposity, or restricted to children for whom at least 3 days of PA data were available

**Table 2. Baseline Cross-Sectional Associations Between PA and BP**

	Model	Total PA (per 20 cpm)		MVPA (per 15 min/day)	
		B (95% CI)	P	B (95% CI)	P
SBP	1	-0.17 (-0.77, 0.44)	0.59	-0.19 (-0.62, 0.24)	0.39
	2	-0.11 (-0.74, 0.51)	0.72	-0.19 (-0.62, 0.24)	0.38
	3	-0.04 (-0.65, 0.57)	0.90	-0.06 (-0.48, 0.36)	0.77
DBP	1	-0.66 (-1.20, -0.10)	0.02	-0.52 (-0.91, -0.13)	0.01
	2	-0.75 (-1.33, -0.18)	0.01	-0.55 (-0.94, -0.16)	0.01
	3	-0.71 (-1.28, -0.14)	0.01	-0.48 (-0.87, -0.09)	0.02

PA indicates physical activity; BP, blood pressure; MVPA, moderate to vigorous physical activity; SBP, systolic blood pressure; and DBP, diastolic blood pressure.

Model 1: adjusted for age and sex.

Model 2: adjustments as for model 1 plus ethnicity, height, school, and duration of PA measurement.

Model 3: adjustments as for model 2 plus BMI  $z$  score.

**Table 3. Associations Between Baseline PA and Follow-Up BP**

Model	Total PA (per 20 cpm)		MVPA (per 15 min/day)		
	B (95% CI)	P	B (95% CI)	P	
SBP	1	-0.74 (-1.52, 0.03)	0.06	-0.14 (-0.70, 0.42)	0.62
	2	-0.72 (-1.45, 0.01)	0.06	-0.19 (-0.71, 0.33)	0.48
	3	-0.68 (-1.41, 0.05)	0.07	-0.11 (-0.63, 0.41)	0.68
DBP	1	-0.93 (-1.62, -0.24)	0.01	-0.31 (-0.81, 0.19)	0.23
	2	-0.74 (-1.40, -0.08)	0.03	-0.20 (-0.67, 0.27)	0.40
	3	-0.73 (-1.39, -0.07)	0.03	-0.18 (-0.65, 0.29)	0.45

PA indicates physical activity; BP, blood pressure; MVPA, moderate to vigorous physical activity; SBP, systolic blood pressure; and DBP, diastolic blood pressure.

Model 1: adjusted for baseline age and sex.

Model 2: adjustments as for model 1 plus ethnicity, change in age, height at baseline, change in height, baseline BP, intervention/control group status, school, and duration of PA measurement at baseline.

Model 3: adjustments as for model 2 plus baseline BMI z score.

had no effect on the direction or overall magnitude of our findings (data not shown).

## Discussion

We found an association between higher levels of PA and lower BP in young children. Specifically, for every additional 20 cpm of total PA (equivalent to  $\approx 25\%$  increase in total PA on average), and every additional 15 min/day of MVPA, DBP was 0.75 mm Hg and 0.55 mm Hg lower, respectively. Total PA, but not MVPA, was also predictive of lower DBP at 2 years follow-up, with a 0.74 mm Hg reduction in DBP for every 20 cpm increase in baseline total activity. A near-significant association of a similar magnitude was observed between baseline total PA and follow-up SBP ( $P=0.06$ ). All associations were independent of BMI and other markers of adiposity.

Reasons for the lack of cross-sectional association between PA and SBP are unclear. Over a lifetime, age-related changes in SBP are relatively large, especially during childhood,<sup>29</sup> in comparison with DBP, which remains relatively stable. Thus, it is possible that associations between PA and SBP are not established at such an early age but become more evident during adolescence and adulthood, as reported previously.<sup>17</sup>

## Strengths and Limitations

To our knowledge, this is the first study to provide evidence supporting an association between objectively-measured PA and BP in children as young as 5 years old. Furthermore, it is the first objective longitudinal study in this age group that includes data on BMI and other measures of body fat, which therefore allowed us to examine the associations independent of weight status. Other strengths are the inclusion of children from minority ethnic groups, the relatively large sample size, and 83% follow-up over the 2-year period.

The present study also has a number of limitations. First, BP is highly variable with diurnal, seasonal, and biological factors affecting the accuracy of readings based on measurement at a single time point.<sup>30</sup> For the present study, errors were minimized by using standard protocols and trained personnel, and measures were repeated at least once. Furthermore, the

direction and strength of association were unchanged in the sensitivity analyses using the second BP readings, rather than the mean, supporting the validity of our observations.

A further limitation is the lack of complete baseline data for 11% of children recruited for the study. However, there were very minimal differences, in terms of socio-demographic and anthropometric characteristics between those with and without BP and PA data. Also, children were measured at different times of the year, and the duration of PA measurement varied between subjects; thus the PA data might not be fully representative of habitual PA. However, regression models were adjusted for duration of PA monitoring and the time of year at which children were measured. We also conducted a sensitivity analysis restricted to children for whom at least 3 days PA data were collected, and found the same associations (data not shown). Finally, it should be noted that data on other potential covariates, such as birth weight, dietary factors, and history of breast-feeding, were not collected in BEACHeS and therefore cannot be accounted for in this study.

## Discussion of Findings in Relation to Other Studies

Previous cross-sectional studies, which used objective measures of PA in children and adolescents, have reported conflicting results, with some showing an association with systolic or diastolic BP,<sup>12,14,16,31</sup> but others reporting no association.<sup>7,9,10</sup> Lack of consistency in methodology, duration of PA measurement, and the wide range of age groups included in previous studies make comparisons with this study difficult. One study of 3- to 6-year-old children found no association between PA and BP. However, the Caltrac accelerometer, used to measure PA, was only worn for a 24-hour period, and the sample size was relatively small ( $n=137$ ).<sup>7</sup> Craig et al<sup>10</sup> also failed to observe an association among PA, assessed using a combination of doubly-labeled water, indirect calorimetry and recall questionnaires, and BP in a small sample of 49 prepubertal girls. In contrast, the cross-sectional European Youth Heart Study (EYHS), in which PA was measured using the Actigraph accelerometer, reported an inverse association between PA and BP in a sample of 9-year-old and 15-year-old children ( $n=1732$ ).<sup>31</sup> Analysis of data on a subset of the EYHS (384 Danish 9-year-old children),<sup>9</sup> on the other hand, found an association between SBP and fitness, but not SBP and PA, possibly because of the reduced sample size.

Several cross-sectional studies<sup>12,14,31</sup> in older children and adolescents have shown inverse associations between BP and both total PA and MVPA (measured by accelerometry), including a large population-based study of 10- to 12-year-old children<sup>16</sup> and a multiethnic population of 9- to 10-year-olds in the United Kingdom (CHASE). Our study adds to the literature by providing evidence that these associations also exist in children as young as 5 years of age.

A longitudinal association between PA and future BP has been reported previously in studies using subjective measures of PA in adolescents,<sup>17</sup> including 1 study with a 50-year follow-up,<sup>32</sup> and 1 including children aged 8 to 13 years at baseline.<sup>15</sup> However, as far as we are aware, the present analysis is the first to describe the relationship in younger children, using more accurate measures of PA. Subjective measures of PA are subject to bias and have low accuracy in children; therefore confirmation

of this association using objective measures in our study further supports a causative mechanism. Our finding that the relationship between higher levels of PA and lower BP is independent of weight status is consistent with results from other studies in older children, including the large cross-sectional study by Leary et al,<sup>16</sup> and a longitudinal study of 12- to 17-year olds which used a subjective measure of PA.<sup>17</sup> As BMI is unable to distinguish between fat mass and fat-free mass, or to detect variations in fat distribution,<sup>33</sup> we also adjusted for waist circumference and sum of 4 skinfolds. This was done to address the potential mediating roles of body fat or central obesity in this sample of predominantly South Asian children, an ethnic group known to have elevated levels of body fat at a given BMI.<sup>34</sup> However, adjustment for these anthropometric markers did not alter the associations.

The importance of total PA versus MVPA has been debated and conflicting results have been reported. The findings of a recent study using objective PA in 11- to 12-year olds<sup>16</sup> supports the greater importance of total amount of PA, whereas other research has suggested that associations among BP, total PA and MVPA are similar.<sup>31</sup> Higher levels of vigorous PA, but not light-moderate PA, during youth and early adulthood have been associated with lower arterial stiffness at the age of 36, which suggests that intense PA has greatest influence on future cardiovascular health.<sup>35</sup> However, in that study, the influence of total PA was not examined, which makes comparison with our findings difficult. Further research is needed to clarify the importance of MVPA versus total volume of PA on future cardiovascular health. Nevertheless, these results further emphasize the need for maintaining high levels of PA throughout childhood and adolescence. In the present study, fewer than half the children met the current recommendation of 60 min/day MVPA at age 5 to 7, and the proportion was reduced to 14% among girls 2 years later.

### Perspectives

Our findings provide further evidence to support a causal relationship between higher levels of PA in young children and lower BP over time, which is independent of weight status. Assuming a causal relationship, these results suggest that a child achieving 90 minutes per day MVPA would have, on average, 2 mm Hg lower DBP than a similar child who does 30 minutes MVPA. An increase in total PA of 50 cpm per day, which in this sample of children is equivalent to the difference between the 5th and 75th centile, is associated with a 2 mm Hg reduction in current and future BP. Although this appears a small effect at first glance, a 2 mm Hg reduction in BP in adults is associated with a 6% reduction in CHD and 15% reduction in stroke-related events.<sup>36</sup> These results further emphasize the need to increase PA from a young age.

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### Disclosures

None.

### References

- Ostchega Y, Carroll M, Prineas RJ, McDowell MA, Louis T, Tilert T. Trends of elevated blood pressure among children and adolescents: data from the National Health and Nutrition Examination Survey 1988-2006. *Am J Hypertens*. 2009;22:59-67.
- Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation*. 2008;117:3171-3180.
- Franks PW, Hanson RL, Knowler WC, Sievers ML, Bennett PH, Looker HC. Childhood obesity, other cardiovascular risk factors, and premature death. *N Engl J Med*. 2010;362:485-493.
- MacMahon S, Peto R, Cutler J, Collins R, Sorlie P, Neaton J, Abbott R, Godwin J, Dyer A, Stamler J. Blood pressure, stroke, and coronary heart disease. Part 1, Prolonged differences in blood pressure: prospective observational studies corrected for the regression dilution bias. *Lancet*. 1990;335:765-774.
- Mahoney LT, Burns TL, Stanford W, Thompson BH, Witt JD, Rost CA, Lauer RM. Coronary risk factors measured in childhood and young adult life are associated with coronary artery calcification in young adults: the Muscatine Study. *J Am Coll Cardiol*. 1996;27:277-284.
- Fagard RH. Exercise is good for your blood pressure: effects of endurance training and resistance training. *Clin Exp Pharmacol Physiol*. 2006;33:853-856.
- Klesges RC, Haddock CK, Eck LH. A multimethod approach to the measurement of childhood physical activity and its relationship to blood pressure and body weight. *J Pediatr*. 1990;116:888-893.
- Boreham C, Twisk J, Neville C, Savage M, Murray L, Gallagher A. Associations between physical fitness and activity patterns during adolescence and cardiovascular risk factors in young adulthood: the Northern Ireland Young Hearts Project. *Int J Sports Med*. 2002;23 suppl 1:S22-S26.
- Brage S, Wedderkopp N, Ekelund U, Franks PW, Wareham NJ, Andersen LB, Froberg K; European Youth Heart Study (EYHS). Features of the metabolic syndrome are associated with objectively measured physical activity and fitness in Danish children: the European Youth Heart Study (EYHS). *Diabetes Care*. 2004;27:2141-2148.
- Craig SB, Bandini LG, Lichtenstein AH, Schaefer EJ, Dietz WH. The impact of physical activity on lipids, lipoproteins, and blood pressure in preadolescent girls. *Pediatrics*. 1996;98(3 pt 1):389-395.
- Lazarou C, Panagiotakos DB, Matalas AL. Lifestyle factors are determinants of children's blood pressure levels: the CYKIDS study. *J Hum Hypertens*. 2009;23:456-463.
- Mark AE, Janssen I. Dose-response relation between physical activity and blood pressure in youth. *Med Sci Sports Exerc*. 2008;40:1007-1012.
- Boreham C, Twisk J, van Mechelen W, Savage M, Strain J, Cran G. Relationships between the development of biological risk factors for

- coronary heart disease and lifestyle parameters during adolescence: The Northern Ireland Young Hearts Project. *Public Health*. 1999;113:7–12.
14. Owen CG, Nightingale CM, Rudnicka AR, Sattar N, Cook DG, Ekelund U, Whincup PH. Physical activity, obesity and cardiometabolic risk factors in 9- to 10-year-old UK children of white European, South Asian and black African-Caribbean origin: the Child Heart And health Study in England (CHASE). *Diabetologia*. 2010;53:1620–1630.
  15. Gidding SS, Barton BA, Dorgan JA, Kimm SY, Kwiterovich PO, Lasser NL, Robson AM, Stevens VJ, Van Horn L, Simons-Morton DG. Higher self-reported physical activity is associated with lower systolic blood pressure: the Dietary Intervention Study in Childhood (DISC). *Pediatrics*. 2006;118:2388–2393.
  16. Leary SD, Ness AR, Smith GD, Mattocks C, Deere K, Blair SN, Riddoch C. Physical activity and blood pressure in childhood: findings from a population-based study. *Hypertension*. 2008;51:92–98.
  17. Maximova K, O'Loughlin J, Paradis G, Hanley JA, Lynch J. Declines in physical activity and higher systolic blood pressure in adolescence. *Am J Epidemiol*. 2009;170:1084–1094.
  18. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. *Sports Med*. 2001;31:439–454.
  19. Bhopal R, Hayes L, White M, Unwin N, Harland J, Ayis S, Alberti G. Ethnic and socio-economic inequalities in coronary heart disease, diabetes and risk factors in Europeans and South Asians. *J Public Health Med*. 2002;24:95–105.
  20. Balarajan R. Ethnicity and variations in the nation's health. *Health Trends*. 1995;27:114–119.
  21. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. *Arch Dis Child*. 1995;73:25–29.
  22. Corder K, Brage S, Mattocks C, Ness A, Riddoch C, Wareham NJ, Ekelund U. Comparison of two methods to assess PAEE during six activities in children. *Med Sci Sports Exerc*. 2007;39:2180–2188.
  23. Corder K, Brage S, Wareham NJ, Ekelund U. Comparison of PAEE from combined and separate heart rate and movement models in children. *Med Sci Sports Exerc*. 2005;37:1761–1767.
  24. Brage S, Brage N, Franks PW, Ekelund U, Wareham NJ. Reliability and validity of the combined heart rate and movement sensor Actiheart. *Eur J Clin Nutr*. 2005;59:561–570.
  25. Mattocks C, Ness A, Leary S, Tilling K, Blair SN, Shield J, Deere K, Saunders J, Kirkby J, Smith GD, Wells J, Wareham N, Reilly J, Riddoch C. Use of accelerometers in a large field-based study of children: protocols, design issues, and effects on precision. *J Phys Act Health*. 2008;5 suppl 1:S98–111.
  26. Ridgway CL, Brage S, Sharp SJ, Corder K, Westgate KL, van Sluijs EM, Goodyer IM, Hallal PC, Anderssen SA, Sardinha LB, Andersen LB, Ekelund U. Does birth weight influence physical activity in youth? A combined analysis of four studies using objectively measured physical activity. *PLoS ONE*. 2011;6:e16125.
  27. World Health Organization (WHO). Global Strategy On Diet, Physical Activity and Health. 2004.
  28. National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents. The fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents. *Pediatrics*. 2004;114:555–576.
  29. Wills AK, Lawlor DA, Matthews FE, Sayer AA, Bakra E, Ben-Shlomo Y, Benzeval M, Brunner E, Cooper R, Kivimaki M, Kuh D, Muniz-Terrera G, Hardy R. Life course trajectories of systolic blood pressure using longitudinal data from eight UK cohorts. *PLoS Med*. 2011;8:e1000440.
  30. Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, Jones DW, Kurtz T, Sheps SG, Roccella EJ; Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Recommendations for blood pressure measurement in humans and experimental animals: Part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. *Hypertension*. 2005;45:142–161.
  31. Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S, Anderssen SA. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet*. 2006;368:299–304.
  32. Paffenbarger RS Jr, Wing AL, Hyde RT, Jung DL. Physical activity and incidence of hypertension in college alumni. *Am J Epidemiol*. 1983;117:245–257.
  33. Hall DM, Cole TJ. What use is the BMI? *Arch Dis Child*. 2006;91:283–286.
  34. Deurenberg P, Deurenberg-Yap M, Guricci S. Asians are different from Caucasians and from each other in their body mass index/body fat per cent relationship. *Obes Rev*. 2002;3:141–146.
  35. van de Laar RJ, Ferreira I, van Mechelen W, Prins MH, Twisk JW, Stehouwer CD. Lifetime vigorous but not light-to-moderate habitual physical activity impacts favorably on carotid stiffness in young adults: the Amsterdam growth and health longitudinal study. *Hypertension*. 2010;55:33–39.
  36. Cook NR, Cohen J, Hebert PR, Taylor JO, Hennekens CH. Implications of small reductions in diastolic blood pressure for primary prevention. *Arch Intern Med*. 1995;155:701–709.

## Novelty and Significance

### What Is New?

- As far as we are aware, this is the first study to explore the longitudinal associations between objectively-measured physical activity and blood pressure in children as young as 5 years of age.
- This is also the first study to focus on a predominantly South Asian cohort.

### What Is Relevant?

- This study provides evidence for longitudinal associations between higher physical activity and lower blood pressure in young children.

- Early-life physical activity interventions, which aim to prevent the development of high blood pressure, may reduce future prevalence of hypertension. This may be particularly important among minority ethnic groups who are predisposed to cardiometabolic diseases.

### Summary

Objectively-measured physical activity is associated with lower blood pressure in young children. This study emphasizes the need to increase physical activity from a very early age.