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Cross-Sectional and Longitudinal Associations Between Physical Activity and Blood Pressure in Adolescence: Birth Cohort Study

Pedro C. Hallal,

Post-graduate Program in Epidemiology, Federal University of Pelotas, Brazil.

Samuel Carvalho Dumith,

Dept of Social Medicine, Federal University of Pelotas, Brazil.

Felipe Fossati Reichert,

Dept of Physical Education, Universidade Estadual de Londrina, Brazil.

Ana M.B. Menezes,

Dept of Clinical Medicine, Federal University of Pelotas, Brazil.

Cora L. Araújo,

Post-graduate Program in Epidemiology, Federal University of Pelotas, Brazil.

Jonathan C.K. Wells,

Childhood Nutrition Centre, Institute of Child Health, London, United Kingdom.

Ulf Ekelund, and

MRC Epidemiology Unit, Cambridge, UK.

Cesar G. Victora

Post-graduate Program in Epidemiology, Federal University of Pelotas, Brazil.

Abstract

Objectives—To explore cross-sectional and longitudinal associations between self-reported and accelerometry-based physical activity (PA) and blood pressure (BP) between 11 and 14 years of age.

Methods—Prospective birth cohort study in Pelotas, Brazil. Participants were 427 cohort members who were followed up with at 11, 12, and 14 years of age, and had questionnaire data on PA and BP at 11 and 14 years, as well as accelerometry and questionnaire data on PA at 12 years. Outcome measures were continuous systolic and diastolic BP at 14 years, and change in BP from 11 to 14 years.

Results—PA was unrelated to systolic BP in any analyses. PA measured by accelerometry at 12 years, but not questionnaire-derived PA, was inversely associated with diastolic BP at 14 years of age in fully adjusted models. Those who exceeded the 300-minutes PA threshold at all 3 visits had a 2.6 mmHg lower mean increase in DBP from 11 to 14 years compared with those classified below the threshold in all visits.

Conclusions—Accelerometry-based PA was longitudinally inversely associated with diastolic BP. This finding was not evident when analyzing self-reported PA at a given age, suggesting a possible underestimation of the association when using subjective data.

Keywords

motor activity; adolescence; prospective studies

Although the short- and long-term benefits of adolescent physical activity (PA) on health are, in general, well established,¹ the association between adolescent PA and blood pressure (BP) remains controversial.^{2–7} There is some experimental evidence that exercise programs lasting 8 weeks or more can reduce systolic blood pressure (SBP) by 1% and diastolic blood pressure (DBP) by 3%,⁸ but sample size limitations from each individual study make these estimates imprecise. Unlike experimental studies where recruitment is targeted at patients already characterized by high BP, observational cohort studies are usually population-based and therefore include large numbers of normotensive adolescents. These studies therefore provide useful additional information, because the effect of PA on BP may vary according to baseline BP levels.

Observational studies on this association, however, have been criticized^{9,10} for 2 reasons: (a) most studies are cross-sectional,^{2,4–7} limiting the possibility of inferring causal relationships; (b) most of them used questionnaire-based estimates of PA,^{2–7} which may lead to misclassification and thus dilute the true effect of PA on BP. The aims of this study were (a) to explore cross-sectional and longitudinal associations between PA and BP between 11 and 14 years of age and (b) to evaluate whether objectively-measured and questionnaire-based PA are differently associated with BP in adolescence.

Methods

Description of the Pelotas 1993 Cohort

Pelotas is a 340,000-inhabitant city in the extreme south of Brazil. All children born in 1993 in the city hospitals to mothers resident in Pelotas ($n = 5265$), were eligible to take part in a birth cohort study.¹¹ All but 16 mothers agreed to participate. Systematic subsamples were followed up at 1, 3, 6 months, 1 and 4 years; the last 3 visits also included all subjects with a birth weight below 2500 g.¹¹ At the age of 11 years, all subjects belonging to the cohort study were sought and 4452 agreed to be interviewed. At the age of 12 years, those who had been interviewed in all previous visits were approached for a comprehensive study on body composition and PA.¹² Out of the subjects eligible, 90% could be measured.¹² At 14 years of age, all cohort participants were again sought, and 4325 could be traced. The analyses presented here are restricted to subjects with full data on exposure and outcome variables at 11, 12, and 14 years of age. Because the 12 years subsample was much smaller, our analysis sample represents only about 10% of the total cohort. In the 3 follow up visits, interviews were carried out face-to-face at the respondent's household. Each interview lasted, on average, 60 minutes in the 11 and 14 years visits, whereas it took on average 30 minutes in the 12 years study.

All phases of the study were approved by the Ethics Committee of the Federal University of Pelotas Medical School. Written informed consent was obtained from parents or guardians and verbal consent from the adolescents.

Physical Activity Measurements

For all 3 visits (11, 12, and 14 years of age), PA was measured by questionnaire. This instrument has been tested for reliability and validity against pedometry suggesting high reliability and moderate criterion validity.¹³ In brief, a list of sports and other physical activities was defined based on pilot data. Subjects were asked whether they practiced each of the activities over the last 7 days. For each physical activity reported, information on duration and weekly frequency was obtained. By multiplying the frequency by the duration of the activities reported, we obtained a total score in minutes per week. The physical activity questionnaire administration lasted, on average, 5 minutes. During the data collection at age 12 years, PA was also measured by accelerometry, using the Actigraph

model GT1M device. Adolescents wore the Actigraph on the hip from Wednesday to the following Monday, and they were encouraged to wear it 24 hours per day, except when showering, bathing, or swimming. In such cases, subjects were requested to fill a diary mentioning the time they spent swimming. Only 3 adolescents reported to do it. Data analyses included all days in which accelerometers were used. In a previous study we showed that compliance with the accelerometer protocol was very high in our sample.¹²

Blood Pressure Measurements

In all visits, a wrist-mounted digital (OMRON HEM 629, Beijing, China) sphygmomanometer was used to measure BP because it would not be feasible to visit the household with mercury manometers. The mean of 2 measurements, on average 40 minutes apart, was used in the analyses. Over the 15 minutes before each BP measurement, subjects were rested and fasted. Measurements took place with adolescents seated on a chair with support for their back, without legs crossed, and their right arm and wrist were used for the measurements. This technique was in accordance with the instructions in the user's manual.¹⁴ Blood pressure data were corrected using internally derived equations, based on a validation study with mercury sphygmomanometers.¹² BP data were expressed in mmHg.

Covariates

Covariates included sex, socioeconomic level at 11 years of age (based on a household assets index constructed with principal component analysis and divided into quintiles), and puberty status at 11 years of age (assessed using Tanner's stages by means of a confidential self-report questionnaire). Height and weight were also measured in all visits using standardized equipment, but data presented in Table 1 refer to the 14 years visit. Triceps and subscapular skinfold thicknesses were measured on the left side of the body using Holtain calipers (Dyfed, UK), and again data from the 14 years visit are presented in the table. All anthropometric measurements were taken twice and the average value was used in the analyses. When needed, a third measurement was used.

Data Analyses

All physical activity and blood pressure variables were divided into terciles for descriptive analyses. The range of values in each third was presented. Unadjusted and adjusted analyses for the associations between PA (categorized into terciles) and systolic and diastolic BP (continuous) were performed using linear regression models. BP distribution was symmetrical. The reference category was set as the lowest (least active) tercile. Longitudinal and cross-sectional associations were tested using 4 sets of statistical models: (1) the unadjusted analysis of the association between PA and BP; (2) in model 1, we tested whether adjustment for sex, socioeconomic level, puberty status, sum of triceps and subscapular skinfolds and height changed the magnitude of these associations; (3) in model 2, by including PA at 14 years, we tested whether the effect of earlier PA on BP was independent of current PA; (4) in model 3, we tested whether the associations were independent of baseline values of BP. The statistical significance was set at 5%, and all tests were 2-tailed.

Results

Of 427 adolescents followed up at 11, 12, and 14 years of age, 413 had complete data on PA at 11, 12 (by questionnaire and by accelerometry), and 14 years of age, as well as on BP. These subjects were similar to the remaining cohort members (N = 5249) in terms of sex (49.7% vs. 52.2% of males, respectively; $P = .2$), mean self-reported PA at 14 years of age (356 min/wk vs. 385 min/wk, respectively; $P = .2$), and BP at 14 years of age (systolic: 119.4 mmHg vs. 119.2 mmHg, respectively; $P = .7$; diastolic: 67.6 mmHg vs. 67.3 mmHg,

respectively; $P = .2$). Table 1 presents a description of the sample in terms of covariates, physical activity and BP.

Table 2 shows mean SBP according to subgroups of the PA variables. In the unadjusted analysis, SBP was positively related to PA at 12 (by questionnaire but not by accelerometry) and 14 years. Adjustment for sex, socioeconomic level, puberty status, sum of skinfolds, and height (model 1) inverted the direction of the associations, but none of them was statistically significant. When PA at 14 years was included in the regression (model 2), all coefficients were negative, but none were statistically significant. Further adjustment for SBP at baseline (11 years of age) moderately attenuated the magnitude of the negative coefficients. In summary, none of the PA variables was significantly associated with SBP.

In Table 3, the associations between objectively measured and self-reported PA with DBP are shown. In the unadjusted analysis, PA was inversely associated with DBP. After adjustment for potential confounders (model 1), all coefficients were attenuated. The only significant association following adjustment was observed for PA measured by accelerometry at 12 years of age. This inverse association remained statistically significant after further adjustments for confounding factors (model 2 and 3). Adolescents classified by accelerometry in the intermediate and most active terciles presented DBP values 1.27 and 1.71 mmHg lower than those classified in the least active tercile after adjustment for confounders. In summary, objectively measured PA at 12 years was significantly independently and inversely associated with DBP at 14 years of age, whereas questionnaire-based PA was not.

In Table 4, subjects are grouped according to the number of follow up visits in which they reported more than 300-minutes of moderate-to-vigorous PA per week, equivalent to 60 minutes for at least 5 days per week, as assessed by questionnaire. Similar to the previous analyses, higher levels of PA were inversely associated with DBP ($P < .001$ for linear trend), whereas there was no association with SBP. Those who exceeded the 300-minutes PA threshold at all 3 visits had a 2.6 mmHg lower mean increase in DBP from 11 to 14 years compared with those classified below the threshold in all visits.

Discussion

Although the preventive and curative effects of PA on BP are well-established among adults,^{15,16} whether this is also true for adolescents is debatable.^{17,18} Lack of consistency may be due to methodological issues. First, most observational studies on PA and BP relied on questionnaire-based estimates of PA; among adolescents, questionnaires tend to have higher reliability than criterion validity.¹³ Misclassification in PA will tend to underestimate the strength of the association with health outcomes. Second, in cross-sectional designs the outcome (BP) may influence the exposure (PA), because PA is recommended for lowering BP. We tried to address these limitations in our analyses.

Regarding the first issue, our results show that accelerometry-based PA estimates at 12 years were more strongly associated with BP than was the case for questionnaire-based PA. These findings are in accordance with a meta-analysis on the association between PA and coronary heart disease, in which the precision of the PA assessment methods was directly associated with the magnitude of the association with the outcome.¹⁹ Another study found a dose-response association between objectively measured PA and BP in young people aged 8 to 17 years.²⁰ These findings highlight the importance of collecting objective data on PA when examining its effects on health outcomes.

To address the second issue—reverse causality—we compared the cross-sectional associations between PA and BP at 14 years with the associations between earlier PA

estimates and current BP. The coefficients obtained from our longitudinal analyses of the effects of PA at 11 and 12 years on BP at 14 years were similar to those obtained from the cross-sectional analyses of PA and BP at 14 years. This suggests that in our adolescent population a causal association between PA and DBP exists.

Although regression coefficients were mostly in the same direction, the effect of PA on BP was consistently stronger for diastolic than for systolic pressure. The literature is not conclusive about this issue. Although some previous studies in adolescents reported stronger effects of PA on diastolic than on systolic BP,^{2,8} others did not.^{3,5,6}

Our finding that the association between objectively measured PA at 12 years and later DBP was independent of the sum of skinfolds and other confounding factors has implications for public health interventions. Although BP is associated with adiposity in adolescence,²¹ the treatment of obesity has very low success rates, hence public health policies aiming to benefit BP development via weight management may have low efficacy. Interventions to promote PA may offer a more realistic approach, and randomized controlled trials are needed to address this issue. Increases in diastolic BP from 11 to 14 years were lower among adolescents classified as sufficiently active during the 3 visits. This finding suggests that regular engagement in PA throughout adolescence may help prevent hypertension in the long-term, because there is evidence that BP tracks from adolescence to adulthood.²² PA practice must be encouraged at all ages, but special attention should be paid to adolescence, because there are several pathways by which adolescent PA can influence health, both in the short and in the long term.¹

The advantages of our study include its longitudinal design in a country experiencing rapid nutritional and epidemiological transitions, as extremely few such data are available from these settings. Only 10% of the cohort members were included in this analysis, because accelerometer data were collected only in a subsample followed up at 12 years of age. However, because subjects included in the analyses were mainly similar to the remaining cohort members with regards to the main variables of interest, it is unlikely that loss to follow up introduced significant bias. It would be ideal to have collected objective data on PA at all ages, to better understand the differences in longitudinal and cross-sectional associations between PA and BP. Our sample size was calculated for the main analyses using terciles, and therefore, the trajectory of PA analysis presented in Table 4 had lower statistical power.

We opted to express physical activity data in terciles for several reasons: (a) the asymmetry of the data (skewed to the right) impeded us from using the questionnaire-based variables on its continuous format; (b) using the standard cut-off of 300 minutes per week only would impede us from examining linear trend; (c) statistical power was enhanced using the terciles approach, because each group comprised 33% of the sample; (d) by using terciles, we could compare associations using different measurement scales—minutes per week in the questionnaire vs. counts in the accelerometer. To evaluate physical activity trajectories, however, we opted to use the well-established 300 minutes-per-week threshold, as shown in Table 4.

A final limitation of our study is that the questionnaire we used is very reliable, but presented low agreement with pedometer counts.¹³ Our validation study suggested, however, that although absolute values may be inaccurate, ranking of individuals by our questionnaire was acceptable.¹³ As an example of the lack of accuracy for the absolute numbers, most adolescents were classified below the 300 minutes threshold by questionnaire, but the opposite was observed for the accelerometry data. By using the terciles approach, the associations described here are just little influenced by the

measurement approach; and if they are, it is in the direction of the null hypothesis. We validated the questionnaire against pedometers because accelerometers were not available at that time due to costs constraints. The questionnaire does not gather information on intensity, because the pilot study showed that this concept was difficult to young adolescents.

Our study showed that objectively measured PA is associated with a beneficial trajectory of DBP development. This finding would not have emerged if we had relied on single point self-report measurements of PA. The beneficial effect of PA on BP development therefore suggests PA promotion may have long-term effects on the metabolic phenotype. Future longitudinal studies incorporating objective PA measurements, as well as randomized designs are warranted to test the effect of PA promotion on BP levels.

Acknowledgments

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Table 1

Description of the Sample Followed Up at 11, 12, and 14 Years of Age

Variable	Range	N	%
Sex			
Boys		223	52.2
Girls		204	47.8
Socioeconomic level at 11 y (quintiles)			
1st (poorest)		86	20.2
2nd		85	20.0
3rd		86	20.2
4th		84	19.6
5th (wealthiest)		85	20.0
Height at 14 y (terciles)			
1st	111.0–142.6 cm	144	33.7
2nd	142.7–148.8 cm	141	33.0
3rd	148.9–171.0 cm	142	33.3
Sum of triceps and subscapular skinfolds at 14 y (terciles)			
1st	6.95–15.3 mm	142	33.5
2nd	15.4–23.0 mm	142	33.5
3rd	23.2–85.2 mm	140	33.0
Physical activity at 11 y by questionnaire (terciles)			
Least active	0–89 min/wk	143	33.5
Intermediate	90–270 min/wk	145	34.0
Most active	>270 min/wk	139	32.5
Physical activity at 12 y by questionnaire (terciles)			
Least active	0–60 min/wk	159	37.2
Intermediate	61–300 min/wk	129	30.2
Most active	>300 min/wk	139	32.6
Physical activity at 12 y by accelerometry (terciles)			
Least active	0–397 min/wk	143	33.4
Intermediate	398–570 min/wk	142	33.3
Most active	>570 min/wk	142	33.3
Physical activity at 14 y by questionnaire (terciles)			
Least active	0–99 min/wk	149	34.9
Intermediate	100–360 min/wk	146	34.2
Most active	>360 min/wk	132	30.9
Systolic blood pressure at 14 y (terciles)			
Lowest	93–114 mmHg	138	33.4
Intermediate	115–123 mmHg	138	33.4
Highest	>123 mmHg	137	33.2
Diastolic blood pressure at 14 y (terciles)			
Lowest	51–64 mmHg	138	33.4
Intermediate	65–69 mmHg	138	33.4
Highest	>69 mmHg	137	33.2
Total		427	100.0

Table 2

Cross-sectional and Prospective Associations (β -Coefficients and 95% CI) Between Physical Activity and Systolic Blood Pressure (mmHg) at 14 Years of Age (N = 427)

Physical activity (terciles)	Mean (SD)	Unadjusted		Model 1 [*]		Model 2 [†]		Model 3 [‡]		
		β	95% CI	β	95% CI	β	95% CI	β	95% CI	
11 y (questionnaire)										
Least active	119 (11)	Reference		Reference		Reference		Reference		
Intermediate	119 (10)	0.61	−1.75; 2.98	−1.18	−3.43; 1.07	−1.18	−3.43; 1.07	−0.95	−3.11; 1.21	
Most active	120 (10)	1.24	−1.14; 2.61	−0.85	−3.16; 1.47	−0.89	−3.22; 1.44	−0.67	−2.89; 1.56	
12 y (questionnaire)										
Least active	117 (9)	Reference		Reference		Reference		Reference		
Intermediate	120 (10)	2.89	0.53; 5.25	−0.74	−3.04; 1.57	−0.74	−3.07; 1.60	−0.44	−2.65; 1.78	
Most active	121 (10)	3.35	1.06; 5.64	−0.58	−2.98; 1.83	−0.56	−3.05; 1.94	−0.57	−2.87; 1.74	
12 y (accelerometry)										
Least active	120 (10)	Reference		Reference		Reference		Reference		
Intermediate	119 (10)	−0.35	−2.73; 2.02	−1.01	−3.22; 1.20	−1.05	−3.26; 1.17	−0.80	−2.92; 1.32	
Most active	119 (10)	−0.70	−3.03; 1.72	−1.65	−4.02; 0.73	−1.87	−4.27; 0.52	−1.57	−3.85; 0.71	
14 y (questionnaire)										
Least active	117 (10)	Reference		Reference				Reference		
Intermediate	120 (10)	2.23	−0.08; 4.54	1.13	−1.06; 3.31			1.01	−1.09; 3.10	
Most active	121 (10)	3.40	1.02; 5.78	−0.65	−3.15; 1.84			−0.43	−2.83; 1.97	

* Adjusted for sex, socioeconomic level, pubertal status, height, and sum of triceps and subscapular skinfolds.

[†] Adjusted for variables in model 1 plus physical activity at 14 years.

[‡] Adjusted for variables in model 1 plus systolic blood pressure at 11 years of age.

Table 3

Cross-Sectional and Prospective Associations (β -Coefficients and 95% CI) Between Physical Activity and Diastolic Blood Pressure (mmHg) at 14 Years of Age (N = 427)

Physical activity (terciles)	Mean (SD)	Unadjusted		Model 1 [*]		Model 2 [†]		Model 3 [‡]		
		β	95% CI	β	95% CI	β	95% CI	β	95% CI	
11 y (questionnaire)										
Least active	68 (7)	Reference		Reference		Reference		Reference		
Intermediate	67 (6)	-0.60	-2.02; 0.81	-0.24	-1.76; 1.28	-0.22	-1.73; 1.29	-0.15	-1.60; 1.30	
Most active	67 (5)	-1.40	-2.82; 0.02	-1.04	-2.60; 0.52	-1.00	-2.57; 0.56	-0.94	-2.43; 0.55	
12 y (questionnaire)										
Least active	68 (6)	Reference		Reference		Reference		Reference		
Intermediate	67 (6)	-0.68	-2.11; 0.74	-0.72	-2.28; 0.84	-0.60	-2.17; 0.97	-0.37	-1.86; 1.13	
Most active	67 (6)	-1.00	-2.39; 0.39	-0.43	-2.05; 1.19	-0.20	-1.88; 1.48	-0.52	-2.07; 1.04	
12 y (accelerometry)										
Least active	69 (7)	Reference		Reference		Reference		Reference		
Intermediate	67 (6)	-1.65	-3.05; -0.25	-1.27	-2.76; 0.21	-1.26	-2.75; 0.22	-1.31	-2.73; 0.11	
Most active	66 (5)	-2.66	-4.06; -1.25	-1.71	-3.30; -0.11	-1.85	-3.45; -0.25	-1.56	-3.09; -0.04	
14 y (questionnaire)										
Least active	68 (7)	Reference		Reference				Reference		
Intermediate	68 (6)	-0.25	-1.63; 1.14	0.54	-0.93; 2.01			0.66	-0.75; 2.06	
Most active	66 (5)	-1.92	-3.35; -0.49	-1.31	-2.99; 0.37			-0.97	-2.58; 0.64	

* Adjusted for sex, socioeconomic level, pubertal status, height, and sum of triceps and subscapular skinfolds.

[†] Adjusted for variables in model 1 plus physical activity at 14 years.

[‡] Adjusted for variables in model 1 plus diastolic blood pressure at 11 years of age.

Table 4

Association Between Physical Activity Trajectories Measured by Questionnaire (11, 12, and 14 years) and Blood Pressure Change (mmHg) From 11 to 14 Years

Physical activity	Systolic blood pressure (mmHg)		Diastolic blood pressure (mmHg)	
	Adjusted mean change (14–11y) *	95% CI	Adjusted mean change (14–11y) *	95% CI
Trajectories [†]				
0	17.6	15.5; 19.8	5.2	3.6; 6.9
1	18.9	16.8; 21.0	4.4	2.9; 6.0
2	17.7	14.9; 20.5	4.2	2.1; 6.3
3	16.8	12.3; 21.2	2.6	–0.8; 5.9
Overall sample	18.0	16.8; 19.3	4.5	3.6; 5.5

* Adjusted for sex, socioeconomic level, pubertal status, height, and sum of triceps and subscapular skinfolds.

[†] 0: below the 300 minutes-per-week threshold in the 3 follow up visits. 1: below the 300 minutes-per-week threshold in 2 of the 3 follow up visits.
2: below the 300 minutes-per-week threshold in 1 of the 3 follow up visits. 3: above the 300 minutes-per-week threshold in all follow up visits.