Original Contribution

Declines in Physical Activity and Higher Systolic Blood Pressure in Adolescence

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The authors examined the potential association between changes in the number of moderate-to-vigorous physical activity (MVPA) sessions per week, adiposity, and systolic blood pressure (SBP) during adolescence. SBP and anthropometric factors were assessed biannually (1999/2000, 2002, and 2004) in a cohort of 1,293 Canadian adolescents aged 12–13 years in 1999. Self-reported 7-day recall data on MVPA sessions ≥5 minutes in duration were collected every 3 months over the 5-year period. Estimates of initial level and rate of decline in number of MVPA sessions per week from individual growth models were used as predictors of SBP in linear regression models. A decline of 1 MVPA session per week with each year of age was associated with 0.29-mm Hg and 0.19-mm Hg higher SBPs in girls and boys, respectively, in early adolescence (ages 12.8–15.1 years) and 0.40-mm Hg and 0.18-mm Hg higher SBPs, respectively, in late adolescence (ages 15.2–17.0 years). The associations were not attenuated by changes in body mass index, waist circumference, or skinfold thickness in girls during late adolescence. Although weaker, associations were evident in boys during late adolescence, as well as in both girls and boys during early adolescence. These results support prevention of declines in MVPA during adolescence to prevent higher blood pressure in youth.

adiposity; adolescent; blood pressure; exercise; motor activity

Abbreviations: BMI, body mass index; MVPA, moderate-to-vigorous physical activity; SBP, systolic blood pressure.

Physical inactivity in adulthood is associated with a 2-fold increase in the risk of elevated blood pressure and cardiovascular disease (1), yet the majority of adults in industrialized countries do not meet recommended physical activity requirements (2). Although physical activity levels are highest among youth, they decline markedly during adolescence (3, 4). Fewer than 10% of Canadian youth aged 5–19 years adhere to the current recommendations of at least 90 minutes of moderate-to-vigorous physical activity (MVPA), accumulated in bouts of at least 5–10 minutes, daily (5, 6).

Systolic blood pressure (SBP) increases by 1–2 mm Hg per year during childhood and adolescence (7). Prevention of declines in physical activity during adolescence is potentially a cost-effective strategy for preventing higher blood pressure in youth (8). Short-term (2–12 weeks) increases in physical activity levels have been observed to result in SBP reductions of 1–6 mm Hg (9, 10), at least in clinical populations of obese or hypertensive youth (11). However, no SBP reductions were observed in nonclinical populations of youth exposed to school-based interventions designed to increase participation in physical activity for at least 1 year (12, 13). There have been few investigations with longitudinal data in nonclinical populations of youth that have examined whether there is a relation between changes in habitual, rather than short-term, physical activity and SBP (14).

Adiposity is a strong predictor of SBP in youth, independent of physical activity (15). Since the inclusion of body mass index (BMI) has attenuated the association between physical activity and SBP in some cross-sectional pediatric studies (16, 17), it has been hypothesized that the relation between these 2 variables is mediated, at least in part, by adiposity (18). However, to our knowledge, no longitudinal study to date has assessed the role of changes in adiposity in the potential association between physical activity and SBP

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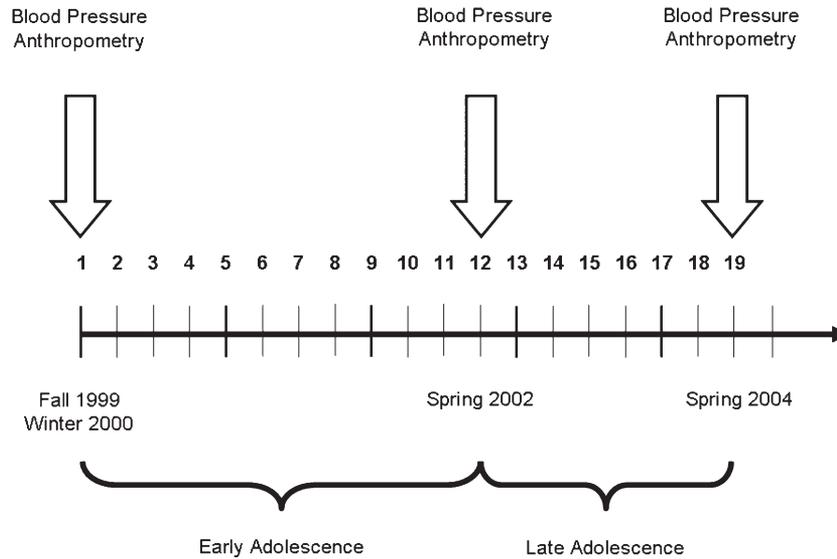
Figure 1. Data collection waves in the Nicotine Dependence in Teens Study, Montreal, Quebec, Canada, 1999/2000–2004. Follow-up took place every 3 months during the 10-month school year (September to June) for 5 years.

using several indicators of adiposity, such as BMI, waist circumference, and skinfold thickness.

Adolescence is a period of rapid growth and behavioral changes, during which blood pressure, height, weight, and body fat increase rapidly (19) and physical activity levels decline sharply (3). Increased understanding of the potential association between physical activity and SBP in general populations of youth is needed (20). Our objective in this study was to assess the potential association between changes in physical activity and blood pressure in adoles-

cents and to assess whether this potential association was mediated by changes in adiposity.

MATERIALS AND METHODS

Study population

The Nicotine Dependence in Teens Study is an ongoing prospective cohort study of 1,293 grade 7 students aged 12–13 years at baseline (55.4% of those eligible) who were

Table 1. Selected Characteristics[a] of Adolescent Girls and Boys at 3 Time Points[b] at Which Systolic Blood Pressure Was Measured, Nicotine Dependence in Teens Study, Montreal, Quebec, Canada, 1999/2000–2004

	Wave 1 (Fall 1999/ Winter 2000)		Wave 12 (Spring 2002)		Wave 19 (Spring 2004)	
	Girls (n = 617)	Boys (n = 575)	Girls (n = 491)	Boys (n = 462)	Girls (n = 410)	Boys (n = 389)
Age, years	12.7 (0.6)	12.8 (0.6)	15.1 (0.4)	15.2 (0.4)	16.9 (0.4)	17.0 (0.4)
Systolic blood pressure, mm Hg	104.4 (9.4)	105.3 (10.7)	103.8 (9.8)	108.7 (10.5)	106.0 (9.9)	114.6 (11.0)
Diastolic blood pressure, mm Hg	56.7 (6.4)	55.8 (6.1)	57.2 (6.3)	56.9 (5.6)	58.4 (6.1)	59.2 (6.4)
Height, cm	155.7 (6.7)	156.2 (8.7)	162.0 (5.9)	171.3 (7.3)	163.2 (6.0)	175.6 (6.5)
Weight, kg	48.6 (11.7)	49.1 (11.5)	56.6 (11.1)	63.5 (12.1)	59.2 (11.3)	69.8 (11.9)
Body mass index[c]	20.0 (3.9)	20.1 (3.8)	21.6 (3.8)	21.6 (3.6)	22.3 (4.1)	22.8 (4.1)
Waist circumference, cm	69.8 (9.8)	72.6 (10.3)	74.2 (9.2)	77.0 (9.3)	76.0 (9.2)	79.9 (9.3)
Triceps skinfold thickness, mm	14.9 (5.6)	13.3 (6.4)	19.5 (6.4)	12.8 (5.9)	22.4 (7.2)	14.3 (7.3)
Subscapular skinfold thickness, mm	10.8 (5.3)	9.6 (5.9)	14.1 (5.9)	10.4 (4.7)	16.9 (6.6)	13.5 (6.9)

[a] All data are presented as mean values, with standard deviations in parentheses.
[b] Early adolescence (ages 12.8–15.1 years): waves 1 and 12; late adolescence (ages 15.2–17.0 years): waves 12 and 19.
[c] Weight (kg)/height (m)^2.

recruited in fall 1999 from a convenience sample in 10 Montreal, Quebec, Canada, secondary schools (21). The schools were selected to include a mix of French- and English-speaking schools; schools located in urban, suburban, and rural areas; and schools located in high, medium, and low socioeconomic status neighborhoods. All students provided assent, and their parents/guardians provided signed informed consent. The institutional review boards at McGill University and the Centre de recherche du Centre hospitalier de l'Université de Montréal approved the study protocol. Of 1,293 students, 424 (32.8%) were lost to follow-up because they either refused to continue to participate ($n = 83$) or moved ($n = 341$). We used information from 19 waves of data collection undertaken during the first 5 years of follow-up (1999/2000–2004).

Students completed questionnaires at school every 3 months during the 10-month school year (September–June) in English or French. The questionnaires were translated from English into French and then back-translated, with adjustments made when the back-translation indicated divergent meaning. The number of MVPA sessions per week was assessed in each of the 19 waves of data collection between 1999/2000 and 2004. SBP and anthropometric factors were measured 3 times (fall 1999/winter 2000, spring 2002, and spring 2004).

The relations among physical activity, adiposity, and SBP in adolescence are confounded by pubertal maturation (22, 23). To mitigate the lack of measures of puberty in the Nicotine Dependence in Teens Study, we stratified the analyses by sex, because pubertal maturation begins and ends earlier in girls than in boys (22). Since almost all girls complete pubertal maturation by age 15 years (24), we also divided the follow-up time into 2 periods corresponding to early adolescence (mean age, 12.8–15.1 years) and late adolescence (mean age, 15.2–17.0 years), on the premise that results from the second period may be less confounded by pubertal maturation.

The analysis pertaining to early adolescence was based on SBP and anthropometric data collected in 1999/2000 and 2002 and on repeated assessments of MVPA sessions from 12 waves of data collected during this time. The analysis pertaining to late adolescence was based on SBP and anthropometric data collected in 2002 and 2004 and on repeated assessments of MVPA sessions from 8 waves of data collected during this time (Figure 1).

Measures

Students completed a 7-day recall checklist that asked them to report, for each day of the preceding week (Monday to Sunday), each activity they had engaged in for at least 5 minutes outside of regular school gym class. The checklist was adapted from the Weekly Activity Checklist (25) to reflect common activities engaged in by adolescents in Montreal. Readings from the original instrument were correlated with accelerometer-measured physical activity in youth ($r = 0.34$, $P < 0.01$), and its 3-day test-retest reliability was 0.74 (26). The test-retest reliability of the adapted checklist was examined in a subsample of 76 students, who completed it twice 2 weeks apart. The correlation between repeated
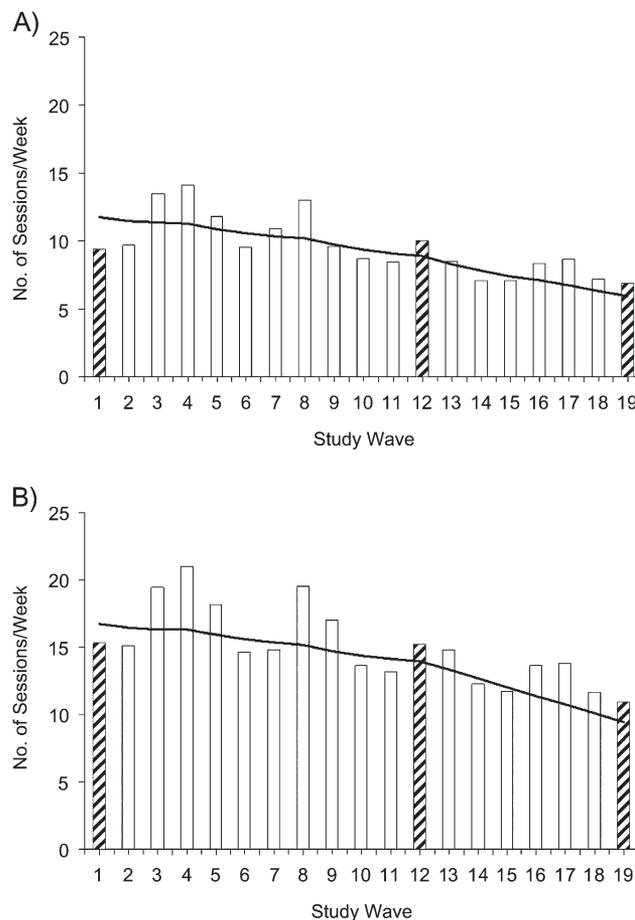

Figure 2. Observed and seasonally adjusted numbers of moderate-to-vigorous physical activity sessions per week during adolescence in A) girls and B) boys, Nicotine Dependence in Teens Study, Montreal, Quebec, Canada, 1999/2000–2004. The bars represent study waves 1–19, which occurred every 3 months during the 10-month school year (September to June) for 5 years. Patterned bars represent study waves during which blood pressure and anthropometric factors were measured. Study waves 1, 2, 6, 7, 10, 11, 14, 15, 18, and 19 occurred during the winter months (January to March). The line shows the best-fitted values for the number of moderate-to-vigorous physical activity sessions per week, adjusted for seasonal variation, from the individual growth models.

measures was 0.73, which is comparable to the correlation of 0.76 observed with repeated measures using accelerometers in youth (27). The adapted checklist also showed evidence of convergent-construct validity with energy intake (28). The number of MVPA sessions per week was calculated as the sum of 23 activities (29), defined as activities with estimated energy costs of over 4.8 metabolic equivalent values (30–32)—including bicycling, swimming/diving, basketball, baseball/softball, footfall, soccer, racket sports, ice/ball hockey, jumping rope, downhill skiing, cross-country skiing, ice skating, rollerblading/skateboarding, exercise/physical conditioning, ball-playing, track and field, playing games, jazz/classical ballet, outdoor play, karate/judo/tai chi, boxing/wrestling, mixed walking, and running/jogging.

Table 2. Estimated Mean Initial Level[a] and Mean Rate of Decline[a] in Number of Moderate-to-Vigorous Physical Activity Sessions per Week in Early and Late Adolescence Among Girls and Boys, Nicotine Dependence in Teens Study, Montreal, Quebec, Canada, 1999/2000–2004

	Total		Girls		Boys	
	β	95% CI	β	95% CI	β	95% CI
Early adolescence (ages 12.8–15.1 years)						
Initial level, β_{0i}	14.14	13.31, 14.98	11.73	10.80, 12.66	16.73	15.36, 18.09
Rate of decline, β_{1i}	−0.84	−1.10, −0.58	−0.75	−1.04, −0.46	−0.94	−1.38, −0.50
Late adolescence (ages 15.2–17.0 years)						
Initial level, β_{0i}	11.30	10.54, 12.07	8.87	8.06, 9.69	13.97	12.70, 15.25
Rate of decline, β_{1i}	−1.85	−2.17, −1.53	−1.49	−1.85, −1.14	−2.26	−2.80, −1.71

Abbreviation: CI, confidence interval.

[a] Mean initial level (β_{0i}) and mean rate of decline (β_{1i}) in the number of moderate-to-vigorous physical activity sessions per week, adjusted for seasonal variation, from individual growth models.

Blood pressure was measured in the sitting position on the right arm, after voiding and a 5-minute rest period, with an automated oscillometric device (Dinamap XL, model CR9340; Critikon Company LLC, Tampa, Florida) by technicians who had been trained and certified according to a standardized protocol (33). Oscillometric devices were calibrated against a mercury sphygmomanometer before each data collection period. A minimum of 3 blood pressure readings were recorded for each student at 1-minute intervals. If the difference between the second and third readings was greater than 20 mm Hg for SBP or greater than 10 mm Hg for diastolic blood pressure, fourth and fifth readings were taken. To reduce blood pressure reactivity/habituation (i.e., the ''white coat'' effect), the first reading was not considered (34). The mean value of the 2 readings with the least difference was calculated from the remaining readings.

Anthropometric measurements were taken with students dressed in light clothing without shoes, using a stadiometer (model 214 Road Rod; Seca Corporation, Hanover, Maryland) for height, a scale (floor model 761; Seca Corporation) for weight, Lange-type baseline skinfold calipers (AMG Medical, Inc., Montreal, Quebec, Canada) for skinfold thickness, and a standard tape measure for waist circumference (measured just above the uppermost border of the right ilium at the end of normal expiration). Measurements were recorded to the nearest 0.1 cm for height, 0.2 kg for weight, 0.1 cm for waist circumference, and 0.5 mm for skinfold thickness. Two measurements were obtained for each participant. A third measurement was taken if the difference between the first 2 measurements was greater than 0.5 cm for height, 0.2 kg for weight, 0.5 cm for waist circumference, or 1 mm for skinfold thickness. All anthropometric measurements were repeated systematically on every 10th student for assessment of interrater reliability (intraclass correlation coefficients were 0.99 for height and weight, 0.98 for waist circumference, 0.95 for triceps skinfold thickness, and 0.96 for subscapular skinfold thickness). For all anthropometric measurements, the mean value of the 2 measurements with the least

difference was calculated. BMI was computed as weight (kg)/height (m)[2]. Skinfold thickness was the sum of the triceps and subscapular skinfold thicknesses.

Statistical analysis

The mean number of repeated assessments of MVPA sessions per student was 9.5 (standard deviation, 1.96), out of a possible 12, in early adolescence and 6.7 (standard deviation, 1.37), out of a possible 8, in late adolescence. Repeated assessments of MVPA sessions for each student were analyzed using individual growth modeling (PROC MIXED in SAS 9.1; SAS Institute Inc., Cary, North Carolina), with the student's age representing time. To represent each student's pattern of number of MVPA sessions over time during early and late adolescence, estimates of initial level (i.e., intercept) and rate of change over time (i.e., slope) were derived from individual growth models for each student, for each of the 2 periods. Age was ''centered'' on 12 years for the early adolescence models and on 15 years for the late adolescence models to facilitate interpretation of the intercept as an estimate of physical activity at age 12 or 15 years, rather than at age 0 (35). Month of data collection was used to adjust for seasonal variation in the number of MVPA sessions (29).

The estimates of each student's intercept and slope for the number of MVPA sessions per week were then used as predictors of blood pressure at the end of early (mean age = 15.2 years) and late (mean age = 17.0 years) adolescence. These associations were examined using 2 sets of sex-specific linear regression models for each of the 2 study periods. Model 1 included estimates of initial level and rate of decline in the number of MVPA sessions per week; initial (baseline) SBP; initial BMI; initial height, change in height, and interaction between initial height and change in height; age at the time of SBP measurement; and smoking (self-reported number of cigarettes smoked in the past week (preceding data collection), averaged over follow-up). For examination of whether these associations were

Table 3. Factors Associated With Systolic Blood Pressure (mm Hg) at the End of Early Adolescence (Age 15 Years) in Girls and Boys, Nicotine Dependence in Teens Study, Montreal, Quebec, Canada, 1999/2000–2004[a]

	Model 1A[b]		Model 2A[c]		Model 1B[d]		Model 2B[d]		Model 1C[e]		Model 2C[e]	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Girls												
SBP, mm Hg												
Initial level	0.56	0.53, 0.58	0.55	0.53, 0.58	0.55	0.52, 0.58	0.56	0.53, 0.58	0.56	0.54, 0.59	0.57	0.55, 0.60
MVPA, sessions/week												
Initial level	−0.11	−0.15, −0.08	−0.12	−0.15, −0.08	−0.11	−0.15, −0.08	−0.11	−0.15, −0.08	−0.12	−0.15, −0.08	−0.10	−0.13, −0.06
Rate of decline	0.29	0.06, 0.52	0.30	0.07, 0.52	0.30	0.07, 0.52	0.33	0.10, 0.55	0.27	0.04, 0.50	0.17	−0.05, 0.40
Age, years	−0.06	−0.72, 0.61	−0.14	−0.79, 0.52	−0.09	−0.76, 0.57	−0.33	−0.99, 0.33	−0.13	−0.80, 0.54	0.29	−0.36, 0.94
Height, cm												
Initial level	0.13	0.06, 0.21	0.12	0.05, 0.19	0.12	0.05, 0.19	0.10	0.03, 0.17	0.15	0.07, 0.22	0.14	0.07, 0.21
Change in height	−0.24	−1.53, 1.06	−0.35	−1.63, 0.92	−0.26	−1.56, 1.03	−0.34	−1.62, 0.93	−0.17	−1.47, 1.12	0.44	−0.82, 1.69
Interaction	0.00	0.00, 0.01	0.00	0.00, 0.01	0.00	0.00, 0.01	0.00	0.00, 0.01	0.00	−0.01, 0.01	0.00	−0.01, 0.01
Smoking, cigarettes/week	0.02	0.00, 0.04	0.03	0.01, 0.04	0.02	0.00, 0.04	0.02	0.01, 0.04	0.02	0.01, 0.04	0.03	0.02, 0.05
BMI[f]												
Initial level	0.05	−0.02, 0.11	0.27	0.19, 0.35								
Change in BMI			2.74	2.02, 3.45								
Interaction			−0.08	−0.11, −0.05								
Waist circumference, cm												
Initial level					0.04	0.01, 0.06	0.15	0.12, 0.18				
Change in waist circumference							1.21	0.92, 1.50				
Interaction							−0.01	−0.02, −0.01				
Skinfold thickness, mm												
Initial level									−0.01	−0.03, 0.02	0.10	0.07, 0.13
Change in skinfold thickness											0.53	0.45, 0.61
Interaction											−0.01	−0.01, −0.01
R^2	0.30		0.33		0.30		0.33		0.30		0.35	
Boys												
SBP, mm Hg												
Initial level	0.54	0.52, 0.57	0.54	0.51, 0.56	0.55	0.53, 0.58	0.55	0.53, 0.58	0.56	0.53, 0.59	0.55	0.53, 0.58
MVPA, sessions/week												
Initial level	−0.02	−0.05, 0.00	−0.05	−0.07, −0.02	−0.02	−0.05, 0.00	−0.03	−0.06, −0.01	−0.02	−0.05, 0.00	−0.02	−0.05, 0.00
Rate of decline	0.19	0.03, 0.35	0.19	0.03, 0.35	0.19	0.03, 0.35	0.16	0.00, 0.33	0.18	0.02, 0.35	0.11	−0.05, 0.27
Age, years	0.51	−0.12, 1.14	0.78	0.16, 1.39	0.46	−0.18, 1.09	0.79	0.16, 1.41	0.38	−0.26, 1.01	0.31	−0.31, 0.93
Height, cm												
Initial level	0.11	0.03, 0.19	0.00	−0.08, 0.08	0.08	−0.00, 0.16	0.05	−0.03, 0.13	0.07	−0.01, 0.16	0.07	−0.01, 0.16
Change in height	0.60	−0.22, 1.42	−0.32	−1.14, 0.49	0.36	−0.46, 1.18	0.24	−0.58, 1.05	0.13	−0.70, 0.95	0.41	−0.40, 1.22
Interaction	0.00	−0.01, 0.00	0.00	−0.00, 0.01	0.00	−0.01, 0.00	0.00	−0.01, 0.00	0.00	0.00, 0.01	0.00	−0.01, 0.00
Smoking, cigarettes/week	−0.04	−0.06, −0.02	−0.03	−0.06, −0.01	−0.04	−0.06, −0.01	−0.03	−0.05, −0.01	−0.03	−0.06, −0.01	−0.02	−0.04, 0.00
BMI												
Initial level	0.28	0.20, 0.36	0.63	0.52, 0.74								
Change in BMI			3.87	3.02, 4.73								
Interaction			−0.13	−0.17, −0.09								

	Estimate	95% CI	Estimate	95% CI
Waist circumference, cm				
Initial level	0.05	0.03, 0.08	0.13	0.10, 0.17
Change in waist circumference			0.64	0.35, 0.92
Interaction			−0.01	−0.01, 0.00
Skinfold thickness, mm				
Initial level	0.00	−0.02, 0.02	0.07	0.05, 0.10
Change in skinfold thickness			0.64	0.55, 0.72
Interaction			−0.01	−0.01, 0.00
R^2	0.33 / 0.32		0.34 / 0.36	

Abbreviations: BMI, body mass index; CI, confidence interval; MVPA, moderate-to-vigorous physical activity; SBP, systolic blood pressure.

[a] "Initial" SBP, height, BMI, waist circumference, and skinfold thickness refers to the measured variable value at baseline data collection in 1999/2000 (wave 1). "Change" in height, BMI, waist circumference, and skinfold thickness represents the absolute difference between 1999/2000 and 2002 (waves 1 and 12). "Interaction" refers to the interaction between the initial level of each respective variable and the change in that variable between 1999/2000 and 2002 (waves 1 and 12). "Initial level" and "rate of decline" in number of MVPA sessions per week refer to individual β_{0i} and β_{1i} values, adjusted for seasonal variation, from the individual growth models (see Materials and Methods).

[b] Model 1A: SBP = MVPA β_{0i} + MVPA β_{1i} + initial SBP + initial height + change in height + height interaction + smoking + initial BMI.

[c] Model 2A: SBP = MVPA β_{0i} + MVPA β_{1i} + initial SBP + initial height + change in height + height interaction + smoking + initial BMI + change in BMI + BMI interaction.

[d] Models 1B and 2B were defined as above, except that waist circumference was used as a measure of adiposity.

[e] Models 1C and 2C were defined as above, except that the sum of skinfold thicknesses was used as a measure of adiposity.

[f] Weight (kg)/height (m)².

RESULTS

Selected characteristics of participants in whom blood pressure was measured are presented in Table 1. Despite seasonal variation (29), the mean number of MVPA sessions per week declined during follow-up in both girls and boys (Figure 2). Girls engaged in 11.7 MVPA sessions per week, on average, at age 12 years and 8.9 MVPA sessions per week, on average, at age 15 years. The number of MVPA sessions declined by 0.7 and 1.5 sessions per week, on average, in girls during early and late adolescence, respectively (Table 2). Boys engaged in 16.7 MVPA sessions per week, on average, at age 12 years and 14.0 MVPA sessions per week, on average, at age 15 years. The number of MVPA sessions declined by 0.9 and 2.3 sessions per week, on average, in boys during early and late adolescence, respectively.

Estimates of initial level and rate of decline in the number of MVPA sessions per week were inversely associated with SBP. In early adolescence, a decline of 1 MVPA session per week with each year of age was associated with 0.29-mm Hg and 0.19-mm Hg higher SBPs in girls and boys, respectively (Table 3, model 1A). In late adolescence, a decline of 1 MVPA session per week with each year of age was associated with 0.40-mm Hg and 0.18-mm Hg higher SBPs in girls and boys, respectively (Table 4, model 1A).

The association between changes in adiposity and SBP was significant in both early and late adolescence. In early adolescence, girls whose BMI increased by 1 unit, whose waist circumference increased by 1 cm, or whose skinfold thickness increased by 1 mm had 2.74-, 1.21-, and 0.53-mm Hg higher SBPs, respectively, than girls whose measurements did not increase (Table 3, models 2A, 2B, and 2C). Boys whose BMI increased by 1 unit, whose waist circumference increased by 1 cm, or whose skinfold thickness increased by 1 mm had 3.87-, 0.64-, and 0.64-mm Hg higher SBPs, respectively, than boys whose measurements did not. In late adolescence, girls whose BMI increased by 1 unit, whose waist circumference increased by 1 cm, or whose skinfold thickness increased by 1 mm had 1.50-, 1.49-, and 0.19-mm Hg higher SBPs, respectively, than girls whose measurements who did not (Table 4, models 2A, 2B, and 2C). Boys whose BMI increased by 1 unit, whose waist circumference increased by 1 cm, or whose skinfold thickness increased by 1 mm had 0.52-, 0.27-, and 0.14-mm Hg higher SBPs, respectively, than boys whose measurements did not.

The magnitude of the association between initial level and rate of decline in the number of MVPA sessions per

Table 4. Factors Associated With Systolic Blood Pressure (mm Hg) at the End of Late Adolescence (Age 17 Years) in Girls and Boys, Nicotine Dependence in Teens Study, Montreal, Quebec, Canada, 1999/2000–2004[a]

	Model 1A[b]		Model 2A[c]		Model 1B[d]		Model 2B[d]		Model 1C[e]		Model 2C[e]	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Girls												
SBP, mm Hg												
Initial level	0.58	0.55, 0.61	0.59	0.57, 0.62	0.58	0.56, 0.61	0.59	0.56, 0.62	0.60	0.57, 0.62	0.61	0.59, 0.64
MVPA, sessions/week												
Initial level	−0.05	−0.11, 0.01	−0.06	−0.12, −0.01	−0.04	−0.10, 0.01	−0.05	−0.11, 0.00	−0.04	−0.10, 0.02	−0.04	−0.10, 0.02
Rate of decline	0.40	0.13, 0.67	0.55	0.29, 0.81	0.40	0.13, 0.67	0.43	0.17, 0.69	0.45	0.18, 0.72	0.40	0.13, 0.67
Age, years	0.46	−0.32, 1.23	0.31	−0.44, 1.06	0.60	−0.17, 1.37	0.16	−0.60, 0.93	0.76	−0.02, 1.53	0.61	−0.16, 1.37
Height, cm												
Initial level	0.29	0.23, 0.35	0.20	0.14, 0.26	0.25	0.19, 0.31	0.18	0.12, 0.24	0.28	0.22, 0.34	0.26	0.20, 0.32
Change in height	20.06	14.43, 25.69	14.20	8.70, 19.70	19.05	13.42, 24.67	16.92	11.44, 22.40	18.59	12.92, 24.25	18.64	13.06, 24.21
Interaction	−0.12	−0.16, −0.09	−0.09	−0.12, −0.05	−0.12	−0.15, −0.08	−0.10	−0.14, −0.07	−0.11	−0.15, −0.08	−0.11	−0.15, −0.08
Smoking, cigarettes/week	0.02	0.01, 0.03	0.02	0.01, 0.03	0.02	0.01, 0.03	0.02	0.01, 0.03	0.02	0.01, 0.03	0.02	0.01, 0.04
BMI[f]												
Initial level	0.30	0.22, 0.37	0.26	0.18, 0.34								
Change in BMI			1.50	0.73, 2.27								
Interaction			0.11	0.08, 0.14								
Waist circumference, cm												
Initial level					0.11	0.08, 0.14	0.12	0.08, 0.15				
Change in waist circumference							1.49	1.07, 1.90				
Interaction							0.02	0.02, 0.03				
Skinfold thickness, mm												
Initial level									0.03	0.01, 0.05	0.06	0.03, 0.09
Change in skinfold thickness											0.19	0.10, 0.28
Interaction											0.00	0.00, 0.00
R^2	0.41		0.46		0.41		0.44		0.40		0.42	
Boys												
SBP, mm Hg												
Initial level	0.57	0.54, 0.60	0.59	0.55, 0.62	0.57	0.54, 0.61	0.58	0.55, 0.61	0.58	0.54, 0.61	0.59	0.55, 0.62
MVPA, sessions/week												
Initial level	0.00	−0.04, 0.04	0.00	−0.04, 0.04	0.00	−0.04, 0.04	0.01	−0.03, 0.05	0.01	−0.04, 0.05	0.02	−0.02, 0.06
Rate of decline	0.18	−0.04, 0.39	0.12	−0.09, 0.34	0.18	−0.04, 0.40	0.11	−0.10, 0.33	0.17	−0.04, 0.39	0.12	−0.09, 0.33
Age, years	−0.58	−1.44, 0.28	−0.16	−1.00, 0.69	−0.51	−1.37, 0.35	−0.29	−1.15, 0.56	−0.52	−1.39, 0.34	−0.24	−1.09, 0.62
Height, cm												
Initial level	0.02	−0.06, 0.09	0.05	−0.02, 0.12	0.00	−0.08, 0.07	−0.01	−0.08, 0.07	0.02	−0.06, 0.09	0.03	−0.05, 0.10
Change in height	0.76	−1.31, 2.82	0.60	−1.42, 2.63	0.83	−1.23, 2.90	0.73	−1.32, 2.78	0.56	−1.51, 2.63	1.03	−1.03, 3.08
Interaction	0.00	−0.02, 0.01	0.00	−0.01, 0.01	0.00	−0.02, 0.01	0.00	−0.02, 0.01	0.00	−0.02, 0.01	−0.01	−0.02, 0.01
Smoking, cigarettes/week	0.03	0.01, 0.05	0.06	0.04, 0.08	0.03	0.01, 0.05	0.05	0.03, 0.07	0.04	0.02, 0.06	0.04	0.02, 0.06
BMI												
Initial level	0.27	0.17, 0.36	0.30	0.20, 0.40								
Change in BMI			0.52	−0.31, 1.35								
Interaction			0.02	−0.01, 0.06								

Variable [a]	Model 1A [b], β (95% CI)	Model 2A [c], β (95% CI)	Model 1B [d], β (95% CI)	Model 2B [d], β (95% CI)	Model 1C [e], β (95% CI)	Model 2C [e], β (95% CI)
Waist circumference, cm						
Initial level			0.11 (0.08, 0.15)	0.13 (0.09, 0.16)		
Change in waist circumference				0.27 (−0.14, 0.69)		
Interaction				0.01 (0.00, 0.01)		
Skinfold thickness, mm						
Initial level					0.07 (0.04, 0.10)	0.06 (0.02, 0.09)
Change in skinfold thickness						0.14 (0.03, 0.25)
Interaction						0.00 (0.00, 0.00)
R^2	0.31	0.34	0.31	0.32	0.31	0.32

Abbreviations: BMI, body mass index; CI, confidence interval; MVPA, moderate-to-vigorous physical activity; SBP, systolic blood pressure.

[a] "Initial" SBP, height, BMI, waist circumference, and skinfold thickness refer to the measured variable value at data collection in 2002 (wave 12). "Change" in height, BMI, waist circumference, and skinfold thickness represents the absolute difference between 2002 and 2004 (waves 12 and 19). "Interaction" refers to the interaction between the initial level of each respective variable and the change in that variable between 2002 and 2004 (waves 12 and 19). "Initial level" and "rate of decline" in number of MVPA sessions per week refer to individual β_{0i} and β_{1i} values, adjusted for seasonal variation, from the individual growth models (see Materials and Methods).

[b] Model 1A: SBP = MVPA β_{0i} + MVPA β_{1i} + initial SBP + initial height + change in height + height interaction + smoking + initial BMI.

[c] Model 2A: SBP = MVPA β_{0i} + MVPA β_{1i} + initial SBP + initial height + change in height + height interaction + smoking + initial BMI + change in BMI + BMI interaction.

[d] Models 1B and 2B were defined as above, except that waist circumference was used as a measure of adiposity.

[e] Models 1C and 2C were defined as above, except that the sum of skinfold thicknesses was used as a measure of adiposity.

[f] Weight (kg)/height (m)².

week and SBP remained unchanged in late adolescence in girls after adjustment for changes in BMI, waist circumference, or skinfold thickness. However, the association was attenuated in boys (Table 3). The association between the rate of decline in the number of MVPA sessions per week and SBP was reduced after adjustment for changes in skinfold thickness (model 2C), but not after adjustment for the other adiposity indicators, in both girls and boys in early adolescence. Models that tested the associations between the number of MVPA sessions per week and diastolic blood pressure were less consistent but provided similar results (data not shown).

DISCUSSION

We examined the potential association among changes in the number of MVPA sessions per week, adiposity, and SBP during adolescence. Three key findings emerged from this study. First, declines in the number of MVPA sessions per week were inversely associated with SBP in youth. Second, increases in adiposity and declines in the number of MVPA sessions per week were each independently associated with higher SBP. Third, the associations between declines in the number of MVPA sessions per week and SBP were not mediated by contemporaneous changes in adiposity in girls during late adolescence. Albeit weaker, these associations were evident in boys during late adolescence, as well as in both girls and boys during early adolescence.

The results of this study add to the limited literature on the longitudinal association between physical activity and SBP in youth. In a study of 459 adolescents in Northern Ireland, changes in self-reported physical activity measured between ages 12 and 15 years were inversely related to changes in SBP (37). In the Dietary Intervention Study in Childhood, self-reported physical activity increased over 3 years of follow-up and was also inversely related to SBP in 663 youth with elevated cholesterol levels at baseline who were followed from ages 8–10 years to ages 11–13 years (38). Participation in MVPA declined over time in our study, and the rate of decline in late adolescence was twice that in early adolescence. This decline is consistent with the marked declines in physical activity previously reported in longitudinal studies of adolescents (3, 4).

To our knowledge, this study provides the first longitudinal evidence that declines in MVPA during adolescence are more pronounced in late adolescence and that a given decline in MVPA is associated with greater increases in SBP after age 15 years, even after adjustment for changes in adiposity and other covariates. This finding is consistent with a previous cross-sectional study demonstrating that the importance of physical activity in blood pressure control increases with age and becomes particularly important by age 15 years (39).

This study also provides the first longitudinal evidence that the relation between MVPA and SBP in youth is generally not mediated by some component of adiposity in girls during late adolescence. Previous longitudinal studies indicated that self-reported physical activity was inversely related to BMI (40) and that BMI was a strong predictor of

blood pressure in youth, independent of physical activity, accounting for a substantial proportion of blood pressure variability (16, 17). Although the inclusion of BMI attenuated the association between blood pressure and physical activity in some cross-sectional studies, we found that the associations remained unchanged after adjustment for change in BMI. Since the BMI measure does not discriminate between changes in muscle mass and changes in fat mass, we examined other indicators of adiposity, including waist circumference and skinfold thickness. Although changes in all 3 adiposity indicators were significantly related to SBP in our study, none mediated the associations of interest in girls during late adolescence. Since fat mass correlates closely with pubertal maturation and increases up to age 15 years (41), attenuation of the associations of interest by changes in adiposity indicators during early adolescence and in boys probably reflects confounding by pubertal maturation.

The key strength of this study was the large number of data points for the number of MVPA sessions. Since the beneficial effect of being physically active on blood pressure may not manifest quickly, it has been suggested that frequent assessments of physical activity over longer periods of time are required in order to adequately assess the longitudinal relations between physical activity and blood pressure in youth (42). However, few longitudinal studies have examined this association in general populations of youth using multiple data points. In this study, the large number of data points facilitated modeling of longitudinal patterns (trajectories) of the number of MVPA sessions in early and late adolescence using individual growth models.

A major strength of this study is that our measure of MVPA preceded the SBP measures. Longitudinal studies that relate changes in an outcome to time-dependent factors that change concurrently with the outcome have been criticized for their weak claims about the direction of causality (43). Our study design, however, allowed estimation of the longitudinal patterns of the number of MVPA sessions in early and late adolescence, which preceded SBP measurement at the end of each period. Therefore, our design may allow for stronger claims about the causal relations between physical activity and SBP in youth.

Our measure of MVPA sessions of ≥5 minutes' duration represents bouts of more intense activity that are accumulated over the course of the week. Recent evidence suggests that accumulating MVPA in short or medium bouts of 5 or more minutes is protective against overweight and elevated blood pressure in youth (44, 45). A minimum of 3 (and up to 5) SBP readings on each measurement occasion for each adolescent in the Nicotine Dependence in Teens Study is also a strength, since multiple readings improve the reliability of SBP, which can be challenging to measure in youth (46). Lastly, in addition to BMI, our study included waist circumference and skinfold thickness, which can better discriminate between changes in muscle mass and changes in fat mass than can BMI (47).

Although in previous studies investigators reported that the link between fitness and SBP was more robust than the link between physical activity and SBP (48, 49), low physical fitness is considered an indicator of genetic predisposition to low fitness levels and high cardiovascular risk and may not reflect individual physical activity behavior (47). On the other hand, physical inactivity is considered an indicator of unhealthy behavior (10). In a recent population-based cross-sectional study of objectively measured physical activity and SBP, Leary et al. (45) concluded that the quantity of exercise was more important than its intensity. Moreover, the most recent expert guidelines focus on the total amount of physical activity and exercise, rather than its intensity (50).

Limitations of this study include the use of MVPA measures based on self-report, which may be prone to recall and social desirability biases, leading to misclassification. Reporting of each MVPA session of ≥5 minutes' duration may have produced overestimation of physical activity levels. However, the requirement to recall all MVPA sessions over the past week is likely to have produced underestimation of students' activity levels. This possible misreporting may have changed the direction of the bias in either direction. Moreover, repeated assessments of physical activity over time reduce measurement error and generally provide a more valid estimate of physical activity levels in youth (51). Although our measure of MVPA was based on energy costs developed for adults, the energy expenditure in older adolescents (ages 15–18 years) is comparable to that observed in adults (32). A serious limitation of this study is the lack of a puberty measure. To mitigate the lack of data on puberty, we conducted sex-specific analyses and studied the associations of interest in both early and late adolescence, on the premise that the associations in girls and during late adolescence may be less confounded by pubertal maturation (24, 52). We also adjusted the associations under study for both height and changes in height, which we considered crude proxy measures of the maturation process (23), since the growth spurt in height begins and ends earlier in girls than in boys (24). In spite of this, the associations between changes in the number of MVPA sessions and SBP were strongest in girls during late adolescence.

In conclusion, declines in the number of MVPA sessions per week during adolescence were inversely associated with SBP in youth. A decline of 1 MVPA session per week with each year of age was associated with 0.29-mm Hg and 0.19-mm Hg higher SBPs in girls and boys, respectively, in early adolescence and 0.40-mm Hg and 0.18-mm Hg higher SBPs, respectively, in late adolescence. These associations were not attenuated by contemporaneous changes in adiposity in girls during late adolescence. Although weaker, these associations were evident in boys during late adolescence, as well as in both girls and boys during early adolescence. These results may have public health importance, because they suggest that by preventing declines in physical activity during adolescence through continued participation in MVPA, we may potentially prevent some of the blood pressure increases observed in youth.

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