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Intensity and frequency of physical activity and high blood pressure in adolescents: A longitudinal study

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Abstract

Despite limited evidence on the association between physical activity (PA) and blood pressure (BP) in youth, experts recommend that adolescents engage regularly in moderate-to-vigorous PA. We examined the relationships between PA intensity and frequency and the likelihood of having high BP in a population-based cohort of adolescents from Montréal, Canada. PA was self-reported every 3 months from grade 7 to 11, and BP was measured at ages 12.8, 15.2, and 17.0 years on average. We analyzed data from 993 participants (mean [SD] age = 16.0 [1.0], 51.6% female) with BP data at ages 15.2 and/or 17.0 years, using pooled ordinal logistic regression. BP (normal/elevated/hypertensive range) was the outcome, and past-year PA intensity and frequency were potential predictors. Eight percent of participants had elevated BP (120-129/<80), and 3.2% had BP in the hypertensive range (≥130/≥80). Participants engaged in a median (interquartile range) of 7.0 (4.5, 9.3) and 5.5 (2, 10.8) moderate and vigorous PA sessions/week, respectively. After adjusting for age, sex, mother's education, use of alcohol and cigarette consumption, engaging in PA more intense than light during the previous year was associated with a lower odds of having BP in the hypertensive range (ORs [95% CIs] = 0.93 [0.88, 0.97] to 0.97 [0.94, 0.99]). The relationships were not altered by adjusting for BMI. Our findings support recommendations that adolescents engage in at least moderate PA on a regular basis to prevent development of BP in the hypertensive range.

1 | INTRODUCTION

High blood pressure (BP) during childhood and adolescence tracks over the life course,[1] increasing the risk of hypertension[2,3] and cardiovascular disease[4] in adulthood. Bell et al[5] reported that 20% of 22 000 13- to 17-year-olds in the United States had elevated BP (≥120 to <130/<80 mm Hg) and 12% had hypertension (≥130/≥80).[6] Data from Europe are less reliable, although estimates of hypertension prevalence range from 2% to 22%.[7]

Prospective studies consistently demonstrate that physical activity (PA) protects against high BP in adults.[8] Indeed, PA has been labeled a "polypill" because of its preventive and therapeutic effects in slowing cardiovascular aging, enhancing physiological functioning, and lowering the global health burden of cardiovascular disease.[9-11] Based on this evidence in adults, experts in the United States and Canada recommend that children and adolescents reduce their cardiovascular risk by limiting sedentary activities and engaging in moderate-to-vigorous PA (MVPA). Youth ages 12-17 are advised to engage in ≥60 minutes of MVPA daily, perform vigorous activities on ≥3 days per week, and perform some PA on ≥3 days each week to strengthen bones and muscles.[12,13] Yet adherence to the guidelines among Canadian children (ages 5-11) and youth (ages 12-17) is poor, with fewer youth than children, and fewer girls than boys at each age meeting the guidelines.[14] Variation in PA over adolescence appears to be common,[15,16] and engagement in PA generally declines with age.[15]

Several longitudinal studies in youth have investigated the relationship between PA and the full range of BP (ie, studied as a continuous variable) with mixed findings.[17-22] In addition, one large cross-sectional study demonstrated an inverse relationship between daily engagement in PA and the odds of being hypertensive in youth ages 8-17.[23] Yet, despite the clinical significance of high BP in adolescence[2,3] and throughout the lifespan, no previous longitudinal study has examined the relationship between PA and the likelihood of having high BP (ie, studied as a categorical variable) in adolescents. The current study extends previous cross-sectional and longitudinal findings on PA and BP by exploring relationships between intensity and frequency of PA and the likelihood of having high BP, in a population-based cohort of adolescents.

2 | METHODS

We drew data from the longitudinal Nicotine Dependence in Teens (NDIT) Study of 1293 adolescents recruited in a purposive sample of ten public secondary schools in or near Montréal, Canada who were followed every 3 months between 7th (1999-2000) and 11th (2004-05) grades (total 20 cycles).[24] Self-report questionnaires were administered in-class in each data collection cycle; height, weight, and BP were measured in cycle 1 (7th grade; M [SD] age = 12.8 [0.5] years), cycle 12 (9th grade; M [SD] age = 15.2 [0.4] year), and cycle 19 (11th grade; M [SD] age = 17.0 [0.4] year). Parents/guardians provided informed consent, and participants provided assent at baseline. The study was approved by the Montréal Department of Public Health Ethics Review Committee, the McGill University Faculty of Medicine IRB, and the Ethics Research Committee of the Centre de Recherche du Centre Hospitalier de l'Université de Montréal.

2.1 | Study variables

2.1.1 | Blood pressure

SBP and DBP were assessed by trained technicians using standardized methods. Participants voided and rested for 5 minutes before BP was assessed while sitting, with an oscillometric device (Dinamap XL, model CR9340; Critikon Co) on the right arm, which rested at heart height on a table. Arm circumference determined cuff size (Brassard Baumanomètre): 16.0-22.5 cm, size 9 (adolescent), 22.6-30.0 cm, size 12 (adult), 30.1-37.5 cm, size 15 (large adult), 37.6-43.7 cm, size 17.5 (thigh). Oscillometric devices were calibrated against a mercury sphygmomanometer before each data collection. Up to five consecutive measures were obtained at 1-minute intervals, with the first reading discarded to account for BP reactivity. The mean of the two last readings was calculated.

Because of intra-individual variability in BP, clinical guidelines require repeated BP assessments over multiple visits to diagnose hypertension. Because we measured BP on a single day only, we classified BP as normal, elevated, or "hypertensive range" using standardized categories: normal BP = <120/<80; elevated BP = 120/<80 to 129/<80; hypertensive range = ≥130/≥80. For analyses, BP was treated as an ordinal variable.

2.1.2 | Physical activity intensity and frequency

Physical activity in the week preceding each data collection cycle was self-reported using a checklist adapted to the context of study participants, from a previously validated questionnaire.[25] The previous version of this checklist was significantly correlated with accelerometer-measured PA (r = .34) and its 3-day test-retest reliability was .74. Additionally, in NDIT the test-retest reliability of the adapted checklist was .73.[26]

Physical activity was assessed with "Think about the physical activity you did during the last week, outside of your regular physical education classes at school. For each activity that you performed *for 5 minutes or more at one time*, mark an 'X' to show the day(s) on which you did that activity." Twenty-nine activities were listed including walking, sports (eg, basketball, ice hockey, volleyball, gymnastics), general fitness and recreational activities (eg, bicycling, dance, general exercise, skiing, rollerblading, jumping rope, dodge ball, kick ball, catch), martial arts, and outdoor or indoor chores (eg, raking leaves, mowing, mopping, vacuuming, sweeping). Because all participants reported walking for at least 5 minutes daily, it was excluded when creating the PA variables. Each of the remaining 28 activities was classified according to intensity as light, moderate, or vigorous based on its MET equivalent, a measure of energy expenditure during an activity relative to the body at rest, using the 2018 age-graded Youth Compendium.[27] Activities generating 1.5-3.9 METs were classified as light (LPA), those generating 4.0-5.9 METs as moderate (MPA), those generating ≥4 METs as moderate-to-vigorous (MVPA), and those generating ≥6.0 METs as vigorous (VPA).

Because PA is subject to seasonal variation, we created variables representing PA intensity and frequency in the year preceding BP measurement (ie, cycles 9-12 for BP measured in cycle 12 and cycles 16-19 for BP measured in cycle 19). Four past-year intensity variables were created representing the mean number of sessions/week of at least five minutes of duration at each PA intensity level (LPA, MPA, MVPA, and VPA). Past-year frequency of PA was calculated as the mean number of days/week (0-7) during the preceding year on which participants engaged in at least one PA activity for ≥5 minutes of duration at any intensity level.

Covariates were selected based on their empirical relationship with PA and/or BP in adolescents and availability in the NDIT dataset. Demographic variables included sex, age, and mother's education (no university vs some university) as a measure of socioeconomic status. Lifestyle variables included cigarette consumption and alcohol use. Since excess body weight is likely related to PA and causally related to high BP in adolescents, we included body mass index (BMI percentile) in a sensitivity analysis. Finally, to account for participants whose BP was high at the inception, we included SBP at baseline as a covariate in a second sensitivity analysis.

2.1.3 | Cigarette consumption

In each cycle, participants provided data on cigarette consumption for each of the three preceding months including number of days on which the participant had smoked each month, and usual number of cigarettes smoked per day on the days on which the participant had smoked. These two measures were multiplied and averaged over each month interval to represent average monthly cigarette consumption in each cycle. Test-retest reliability (intraclass correlation coefficient) of average monthly cigarette consumption based on the 3-month recall was 0.64. A mean past-year (ie, mean for cycles 9-12 and mean for cycles 16-19) cigarette consumption variable was created for each participant.

2.1.4 | Alcohol use

Frequency of drinking alcohol was assessed in each cycle by "During the past 3 months, how often did you drink alcohol (beer, wine, hard liquor)?", with response options (*never* [1], *a bit to try*, *once or a couple of times a month*, *once or a couple of times a week*, *usually every day* [5]). A past-year (ie, mean for cycles 9-12 and mean for cycles 16-19) alcohol use variable was created for each participant.

2.1.5 | Body mass index

Height (to the nearest 0.1 cm) and weight (to the nearest 0.2 kg) were measured twice by trained technicians using a stadiometer (model 214 Road Rod; Seca Corp.) and scale (floor model 761; Seca Corp.), with participants in light clothing without shoes. A third measurement was taken if the difference between the first two exceeded 0.5 cm (height) or 0.2 kg (weight). Measurements were repeated systematically on every 10th participant; inter-rater reliability for both height and weight was 0.99. BMI was computed using the mean of the two measurements with the least difference, as weight/height^2 (kg/m^2) and was converted to a *z*-score based on national sex- and age-specific growth curves.

2.2 | Statistical analyses

To examine the relationship between BP and PA in the past year, the analytic sample was restricted to participants with BP measurements in either cycle 12 or 19, or both. We compared baseline characteristics of participants retained for analyses to those not retained with *t* tests, chi-square, or Mann-Whitney *U* tests, as appropriate.

We pooled PA and BP measures over cycles 12 and 19 and examined relationships between intensity and frequency of past-year PA and BP. We estimated a model regressing BP categories on each of the five PA exposures (ie, LPA, MPA, MVPA, VPA, and frequency of PA) using ordinal logistic regression, which simultaneously estimated the cumulative probabilities that a response on the outcome falls in or below each consecutive category of the outcome. Because the outcome (BP) has three categories (ie, normal, elevated, or hypertensive range), the model simultaneously describes two relationships: the association between the exposure (PA) and the odds that BP > normal (ie, either elevated or hypertensive vs normal) and BP > elevated (ie, hypertensive vs either normal, or elevated). A key assumption of ordinal regression is that the effect of the exposure is the same for each cumulative probability (ie, a proportional odds model).[28] Partial proportional odds models were estimated when that assumption was not met.[29] All analyses included clustered standard errors to account for the intra-individual correlation of repeated measures.

We estimated unadjusted models that included only the PA exposure of interest, and then a model adjusted for sex, age, mother's education, average past-year drinking frequency, and average past-year monthly cigarette consumption as covariates. Sensitivity analyses further adjusted for BMI percentile and baseline SBP, respectively. The models were then estimated with a sex-by-PA interaction term and an age (median split) by PA interaction term to explore potential sex and age differences in the association between PA and BP.

Data analyses were undertaken in 2019 using the gologit2 module[30] for Stata (version 14.2, revision 19, 2018; Stata Corp.) and IBM SPSS Statistics for Windows (version 24, 2016; IBM Corp.).

3 | RESULTS

Table 1 compares baseline characteristics of participants retained and not retained in the analyses. Compared to the 300 participants excluded from the analyses because of missing data on BP in both cycles 12 and 19, the 993 participants (76.8% of 1293 participants) retained were younger, less likely to be Francophone, more likely to have been born in Canada, and more likely to have a university-educated mother. They engaged in PA at any intensity level on more days/week but in fewer MPA sessions/week, monthly and smoked fewer cigarettes. Retained and non-retained participants did not differ by sex, baseline SBP or DBP, BMI percentile or frequency of engagement in LPA, MVPA or VPA.

TABLE 1 Baseline characteristics of participants retained and not retained, Nicotine Dependence in Teens study (Canada), 1999-2005 (n = 1293)

	Retained (n = 993)	Not retained (n = 300)
Age (years), M (SD)	12.7 (0.44)	13.0 (0.78)
Female, %	51.6	52.7
Francophone, %	28.4	35.7
Born in Canada, %	93.7	87.0
Mother university-educated, %[a]	45.8	31.9
Systolic blood pressure, M (SD) mm Hg	105.0 (10.1)	106.1 (10.4)
Diastolic blood pressure, M (SD) mm Hg	56.5 (6.3)	57.2 (6.10
BMI percentile[b], M (SD)	57.5 (29.8)	59.4 (28.8)
Intensity of physical activity[c,d] Mdn (IQR)		
Light	6.0 (2.0, 9.0)	6.0 (1.0, 8.5)
Moderate	3.0 (1.0, 7.0)	5.0 (1.0, 8.0)
Moderate-vigorous	9.0 (4.0, 17.0)	10.0 (5.0, 19.0)
Vigorous	5.0 (2.0, 11.0)	6.0 (2.0, 12.0)
Days of physical activity[e], Mdn (IQR)	5.0 (4.0, 6.0)	3.0 (1.0, 4.0)
Drank at least monthly, %	10.3	18.7
Mean number of cigarettes consumed in past month, Mdn (IQR)	0.0 (0.0, 0.0)	0.0 (0.0, 0.5)

[a]Of participants with complete data on mother's education; 10.7% of retained vs 69.7% of non-retained were missing data.

[b]Based on age and sex.

[c]Mean number of sessions of at least five minutes of duration at each intensity level in the past week.

[d]Intensity measured in units of metabolic equivalent of task (MET): light = 1.5-3.9 METs, moderate = 4-5.9 METs, moderate-to-vigorous = ≥4 METs, vigorous = ≥6 METs.

[e]Number of days in the past week engaged in any physical activity except walking.

The proportion of participants with hypertensive range BP was relatively low (3.2%, n = 32); 8% (n = 79) of participants had elevated; and 84.8% of participants (n = 842) had normal BP. Participants engaged in a median (interquartile range) of 2.0 (0.5, 4.8), 7.0 (4.5, 9.3), and 5.5 (2.0, 10.8) sessions of LPA, MPA, and VPA weekly, respectively, and did PA at any intensity level on 5.3 (3.8, 6.3) days per week on average.

Table 2 presents the proportion of participants with normal, elevated, or hypertensive range BP as a function of PA intensity and frequency. PA intensity and frequency are reported in tertile groupings based on number of sessions/week (for intensity) and days/week (for frequency). With the possible exceptions that: (a) the proportion of participants with normal BP increased with increasing MPA and (b) the proportion of participants in the hypertensive range tended to decline as PA tertile increased for LPA, MPA, and MVPA, there did not appear to be trends in the data suggestive of a strong linear relationship between PA and BP. Table S1 presents median and interquartile range for SBP and DBP in tertile groupings of PA intensity and frequency.

In unadjusted analyses, past-year engagement in PA at any intensity other than light was protective against having BP in the hypertensive range rather than normal or elevated BP (Table 3). After adjusting for age, sex, mother's education, past-year drinking frequency, and past-year monthly cigarette consumption, the odds of hypertensive range BP were reduced by 3%-7% for each additional session (≥5 minutes of duration) per week of PA. Frequency of PA (ie, engaging in any PA except walking for more days/week) was not related to BP. The relationship at all intensities was robust after adjusting for BMI, and for MPA and MVPA after adjusting for baseline SBP (Table S2). None of the age-by-PA or sex-by-PA interaction terms were statistically significant.

4 | DISCUSSION

The novel finding in this study, that engaging in any level of PA more intense than light over the past year is associated with a lower odds of having BP in the hypertensive range, suggests that PA may protect against high BP in adolescents. This is important because youth might alter their odds of developing hypertension by making small changes to daily PA patterns. British 15-year-olds spent approximately half their time in LPA, compared to only 4% of their time in MPA and <1% of their time in VPA,[31] and the proportion of Unites States adolescents who engaged in ≥60 min/d of MVPA remained around 9% from age 16 to 18.[32]

Using the reported prevalence of hypertension of 12% in adolescents,[5] and considering our finding that one additional session of at least 5 minutes of MPA per week over the course of a year is associated with a 7% lower odds of having BP in the hypertensive range, we estimate that adding seven additional sessions of MPA per week (ie, 1 per day) would reduce the probability of hypertensive range BP by 3.5%.[33] Given that half of participants with elevated BP in our study engaged in seven or fewer sessions of MPA per week (data not shown), it seems feasible to encourage adolescents to add one more session of MPA each day to their usual practice.

TABLE 2 Proportion of participants with normal, elevated or hypertensive range blood pressure at each level of past-year physical activity intensity and frequency, Nicotine Dependence in Teens study (Canada), (n = 993; n_{obs} = 1753)[a]

Physical activity	Tertile grouping	Number of sessions/week[d] Median (IQR)	n_{obs}	Blood pressure category[b] Normal (n_{obs} = 1509) %	Elevated (n_{obs} = 165) %	Hypertensive range (n_{obs} = 79) %
Intensity[c]						
LPA	1	0.0 (0.0, 0.5)	569	84.2	10.5	5.3
	2	2.0 (1.5, 2.8)	616	87.5	7.6	4.9
	3	6.3 (4.8, 8.3)	568	86.4	10.2	3.4
MPA	1	3.0 (1.8, 4.5)	571	83.5	10.2	6.3
	2	7.0 (6.5, 7.5)	598	86.5	8.9	4.7
	3	10.8 (9.4, 13.5)	584	88.2	9.3	2.6
MVPA	1	6.5 (4.3, 7.8)	590	86.1	8.0	5.9
	2	12.3 (10.5, 14.0)	587	86.4	9.4	4.3
	3	23.7 (19.0, 30.4)	576	85.8	10.9	3.3
VPA	1	1.3 (0.3, 2.3)	599	86.1	8.5	5.3
	2	5.5 (4.3, 7.0)	578	87.7	8.5	3.8
	3	13.8 (10.8, 18.0)	576	84.4	11.3	4.3
Frequency[e]	1	3.0 (2.3, 3.8)	583	86.5	8.2	5.3
	2	5.3 (4.8, 5.5)	543	87.0	9.4	3.7
	3	6.5 (6.3, 7.0)	627	85.0	10.5	4.5

Note: Row proportions may not sum to 100% because of rounding.

[a]Data were pooled over cycles 12 and 19.

[b]Blood pressure categories: normal (<120/<80 mm Hg); elevated (120-129/<80 mm Hg); hypertensive range (≥130/≥ 80 mm Hg).

[c]Physical activity intensity levels in metabolic equivalent of task (MET) units: light (1.5-3.9 METs); moderate (4-5.9 METs); moderate-to-vigorous (≥4 METs); vigorous (≥6 METs).

[d]Mean number of sessions/week of at least five minutes of duration at each intensity level in the past year, in groupings defined by tertile. Range of sessions/week: LPA = 0-14; MPA = 0-38.5; MVPA = 0-95.8; VPA = 0-62.

[e]Mean number of days/week in the past year on which the participant engaged in at least one physical activity session at any level of intensity (except walking), in groupings defined by tertile. Range of days/week = 0-7.

In our study, PA had a stronger association with BP at higher BP levels (ie, PA was more protective in the transition from normal or elevated BP to the hypertensive range than in the transition from normal BP to elevated BP or the hypertensive range). This parallels findings from a large cross-sectional study of youth ages 8-17 that, although there was only a modest inverse correlation between PA (measured over 7 days) and BP, increasing frequency of both total PA and MVPA was associated with a curvilinear decrease in the odds of being hypertensive (defined as BP ≥ 90th percentile for age, height, and sex). Relative to no PA, increasing total PA by 30, 60, 90, or 120 minutes per week reduced the likelihood of hypertension by 20%, 39%, 46%, and 60%, respectively, and increasing MVPA by 30 or 60 minutes per week reduced the odds of hypertension by 50% and 62%, respectively.[17] Also concordant with our findings, a narrative review of nine prospective trials of PA in normotensive and two in hypertensive adolescents (ages 6-18 at baseline) found no relationship between PA and BP in the normotensive population, but evidence that endurance and resistance training reduced SBP significantly in the hypertensive population.[34] Moreover, we found a strong and consistent relationship between baseline BP and the odds of having BP in the hypertensive range, in contrast to Kelley et al,[20] whose meta-analysis of prospective studies of short-term trials of PA found no relationship between initial resting BP and changes in BP.

Mechanisms underlying the PA-BP association remain unclear,[35] although reductions in vascular resistance produced by the sympathetic nervous system and the renin-angiotensin systems may play a role.[36] Studies in overweight or obese youth report that PA participation normalized endothelial-dependent dilatation, contributing to reductions in SBP.[37,38] The durability of the reduction in vascular resistance is unknown, ranging from under eight weeks in one study[39] to more than 2 years in another; the longer duration was observed in obese youth who sustained their PA participation.[40]

In our study, regardless of BMI status, individuals who self-reported engaging in at least moderate PA were less likely to have BP in the hypertensive range. Our results parallel those of Maggio et al[40] in highlighting the importance of sustaining PA behavior, since abnormal vascular function was detected in at-risk individuals when PA was discontinued. Moreover, findings from the prospective Young Finns study and its follow-ups demonstrate that elevated BP

TABLE 3 Odds ratios (ORs) and 95% confidence intervals (CIs) for blood pressure as a function of intensity and frequency of physical activity, Nicotine Dependence in Teens study (Canada), 1999-2005 (n = 993)

Physical activity	Estimates for…	OR (95% CI) Unadjusted (n_{obs} = 1753)	Adjusted[a] (n_{obs} = 1746)
Intensity[c,d]			
LPA	BP > normal	0.99 (0.94, 1.04)	1.01 (0.96, 1.06)
MPA[b]	BP > normal	0.97 (0.94, 1.01)	0.99 (0.96, 1.02)
	BP > elevated	**0.91 (0.87, 0.96)***	**0.93 (0.88, 0.97)**
MVPA[b]	BP > normal	1.00 (0.99, 1.02)	1.00 (0.98, 1.01)
	BP > elevated	**0.97 (0.95, 0.99)***	**0.97 (0.94, 0.99)**
VPA[b]	BP > normal	1.02 (1.00, 1.04)	1.00 (0.98, 1.02)
	BP > elevated	0.98 (0.95, 1.01)	**0.96 (0.93, 0.99)***
Frequency[e]	BP > normal	1.04 (0.94, 1.14)	0.95 (0.86, 1.05)

Note: Estimates in bold type are statistically significant: *$P < .05$; **$P \le .01$; ***$P \le .001$.

[a]Includes adjustment for age, sex, mother's education, past-year monthly cigarette consumption, and past-year drinking frequency. Models which also adjust for BMI and baseline SBP (ie, sensitivity analyses) are reported in Table S2. Data were pooled over cycles 12 and 19.

[b]The proportional odds assumption was met only for LPA and frequency of PA. Analyses of MPA, MVPA, and VPA incorporated non-proportional odds. Because the outcome (BP) had three categories (ie, normal, elevated, or hypertensive range), the model simultaneously describes two relationships: the association between the exposure (PA) and the odds that BP > normal (ie, is either elevated or hypertensive range vs normal) and that BP > elevated (ie, is hypertensive range vs normal or elevated), and two estimates are generated for each PA intensity.

[c]PA intensity levels in metabolic equivalent of task (MET) units: light (1.5-3.9 METs); moderate (4-5.9 METs); moderate-to-vigorous (≥4 METs); vigorous (≥6 METs).

[d]Estimates for PA intensity represent one session/week of PA ≥5 min in duration over the past year.

[e]Estimates for PA frequency represent engaging in PA of any intensity (except walking) for ≥5 min on 1 d per week over the past year.

observed at age 9 years or later in childhood predicts subclinical atherosclerosis in adulthood and that childhood BP levels had a more permanent influence on later cardiovascular risk factors than did childhood obesity.[41]

Study strengths include the longitudinal study design, use of objectively measured BP, use of both PA intensity and frequency as exposures and control of confounding using data on covariates collected before the exposure data. Possible limitations include that the relatively small sample size may have limited our ability to detect associations. However, use of confidence intervals (rather than *P*-values exclusively) allows assessment of the precision of the estimates. Loss to follow-up may have resulted in selection bias. Residual confounding is possible because we did not assess pubertal growth, which relates to increases in SBP.[42] However, our BP classifications were adjusted for age and sex, which should have mitigated this bias. Our PA and BP measures may have introduced misclassification bias, which, if non-differential, would attenuate the estimates to the null. Because longitudinal tracking of PA behavior with accelerometers in epidemiological studies continues to be very challenging and costly,[43] we used a self-report PA checklist despite its imprecision regarding the duration of each session and the fact that self-report could contribute to misclassification bias. However, a previous version of our PA checklist was validated against accelerometer in a study of youth.[25] In addition, the frequent measurements in NDIT remain a considerable strength of this study that would not have been achieved had PA been monitored with accelerometers. Although BP was measured up to five times in each of cycles 1, 12, and 19, measurements were taken at one sitting only, precluding investigation of fluctuating BP over the short-term and making a definitive diagnosis of hypertension. Additionally, the device used to measure BP has not been clinically validated for use in adolescents, so that our BP readings may differ from what would have been attained by auscultation. Finally, use of a purposive sample could limit generalizability of the findings, although the similarity of the NDIT sample to a provincially representative sample suggests that such limitation may be minimal.[24]

5 | CONCLUSION

This study adds longitudinal evidence that past-year PA during adolescence is inversely associated with having BP in the hypertensive range. While additional investigations are needed, perhaps focused on youth with high BP,[20] our findings support recommendations that adolescents engage in at least moderate PA on a regular basis to prevent development of BP in the hypertensive range.

CONFLICT OF INTEREST

None to declare.

AUTHOR CONTRIBUTIONS

RJW analyzed the data and wrote the first and subsequent drafts of the manuscript. PAN and MM analyzed the data, reviewed, edited, and contributed to the development of the manuscript. MPS, AC, ED, and GT reviewed, edited, and contributed to the development of the manuscript. JOL oversaw all aspects of the NDIT study and reviewed, edited, and contributed to the development of the manuscript. All authors approved the final version.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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