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Abbreviations: BMI, body mass index; MVPA, Moderate-to-Vigorous Physical Activity; NDIT Study, Nicotine Dependence in Teens Study; %BF, percent body fat; VPA, Vigorous Physical Activity

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ABSTRACT

We describe physical activity trajectories during secondary school and examine the association with change in adiposity in youth aged 12-13 years at baseline. Physical activity was measured in 20 survey-cycles over 5 years; anthropometrics were measured in survey-cycles 1, 12 and 19. Complete data on 840 and 760 adolescents followed from survey-cycles 1-12, and survey-cycles 12-19, respectively, were available. Individual growth curves modeling moderate-to-vigorous physical activity (MVPA), and vigorous physical activity (VPA), were estimated. Estimates of initial level and rate of decline in each of MVPA and VPA bouts/week were included as potential predictors of body fat % and BMI in sex-specific linear regression models. Among girls, a yearly decline of 1 MVPA bout/week during earlier adolescence was associated with an increase of 0.19 (95% CI: 0.02, 0.36) units of body fat %, and a yearly decline of 1 VPA bout/week was associated with an increase of 0.47 (95% CI: 0.015, 0.92) units of body fat %. In boys, a yearly decline of 1 MVPA bout/week during later adolescence was associated with an increase of 0.38 (95% CI: 0.05, 0.70) units of body fat %. Initiation and adherence to moderate and vigorous intensity activity should be promoted during secondary school.

Keywords: adiposity; adolescent; body composition; exercise; longitudinal studies; moderate and vigorous physical activity; obesity

The obesity epidemic is expected to reverse the steady increases in life expectancy that have characterized the human experience in the past several millennia (1, 2). The relatively recent and steep increase in obesity suggests aetiological origins that are environmental and lifestyle-related, rather than genetically based (3, 4). An estimated 1 in 3 North American adults are obese, defined as having a body mass index (BMI) $\geq$ 30 kg/m^2 (5, 6); whereas 1 in 6 youth aged 6-19 years are obese, defined as having a BMI $\geq$ 95th percentile based on age- and sex-specific growth charts (7). Although obesity may have plateaued in North America (8, 9), the prevalence remains much too high, and most overweight or obese youth will retain excess weight into adulthood (10). Effective and early prevention strategies are essential to reduce the economic, social and health burden of obesity (11). However, our ability to develop effective public health and clinical interventions is impeded by the fact that our understanding of the natural course and determinants of pediatric overweight and obesity remains limited (12, 13).

Generally speaking, excess energy intake (e.g., high caloric diet) combined with low energy expenditure (e.g., sedentary lifestyle) will lead to increased adiposity over time (14-16). However, findings on the association between physical activity in adiposity from prospective observational studies of youth are inconsistent (17-21). A number of possible explanations related to design and measurement are likely. First, few longitudinal studies compare the influence of different intensities of activity on adiposity, with most examining all intensities combined or focusing on moderate-to-vigorous physical activity (MVPA) only (17, 22-25). Since vigorous physical activity (VPA) is more consistently and strongly associated with adiposity than moderate, moderate-to-vigorous, or total (i.e., light, moderate and vigorous) physical activity (26-32), failure to distinguish between activity intensities may mitigate the possibility of detecting associations.

Second, the choice of anthropometric indicator may contribute to inconsistencies across studies. Because it is relatively simple to obtain, BMI is often used in large studies (18-20). There is some support for a negative, albeit weak, effect of physical activity on BMI in youth (17, 19-21, 24, 33), but there are many reports of null findings (17, 26, 33-36). BMI quantifies excess weight for height but does not distinguish between lean (i.e., bone, muscle) and fat mass, and therefore presents the potential for misclassifying muscular individuals as overweight or obese (37). Thus, its validity as an indicator of adiposity in youth is questionable. Skinfold thickness which can be used to compute body fat % provides a more accurate estimate of adiposity (38). Several studies that have used multiple indicators of adiposity have observed an inverse relation between physical activity and body fat % with no concomitant effect on BMI (26, 33, 35, 36, 39).

Third, most studies investigating the relationship between physical activity and adiposity are cross-sectional, and thus, insight regarding the temporality of this relationship is limited. Although it is plausible that excess weight gain inhibits physical activity, findings from prospective studies support a weak protective effect of physical activity on adiposity (e.g., see reviews (18-21)). However, existing longitudinal studies are limited by small sample sizes, potentially important unmeasured confounders, and/or short (i.e., less than 1 year) follow-up durations. Moreover, many use sub-optimal statistical approaches (18, 19, 40), typically examining physical activity change scores only (18, 22, 23, 35, 36, 41).

In the current study, we use growth curve modelling to estimate individual trajectories of both MVPA and VPA during secondary school, and then relate these trajectories to change in adiposity in boys and girls separately. Sex-specific analyses were used because of previously

demonstrated sex-differences in the association between physical activity and body fat changes during adolescence (40, 42, 43). We investigate the role of intensity of physical activity by estimating and comparing individual growth curves for each of MVPA and VPA separately. Moreover, because the association may differ over the adolescent life course, which is characterized by dramatic biologic changes related to growth and puberty, we explore these relationships in earlier and later adolescence.

MATERIALS AND METHODS

Study population

Data were drawn from the Nicotine Dependence in Teens (NDIT) study, a longitudinal cohort investigation of the natural course of nicotine dependence in youth (44). Students were recruited from all grade 7 classes in a convenience sample of 10 secondary schools in or near Montreal, Canada. Schools were selected to include a mix of French and English schools, urban, suburban, and rural schools, and schools located in high, medium, and low socioeconomic neighborhoods. All 13 schools approached agreed to participate; 3 schools were excluded, 2 because of a low return of consent forms, and 1 because school administrators could not guarantee collaboration over the entire study period. All participants provided assent and parents/guardians provided written 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.

Baseline data were collected in fall 1999 (i.e., survey cycle 1) in self-report questionnaires administered in English or French according to the language of instruction of in the school. Participants were followed throughout secondary school, with data collected 4 times per school year (approximately every 2.5 months during the 10-month school year) for a total of 20 survey

cycles. Over half (55.4%) of eligible students participated in the first survey cycle. Approximately 94% of participants eligible for follow-up in each survey cycle completed questionnaires. Physical activity was assessed in all survey cycles. Height, weight, and triceps and subscapular skinfold thickness were measured in survey cycles 1, 12 and 19. Anthropometric measurements were taken by technicians trained according to a standardized protocol (45). For the analyses reported here, we used data from the first 19 survey cycles, which covered 57 months of follow-up.

The relationship between physical activity and adiposity is likely confounded by pubertal maturation (43). In addition to controlling for age, we stratified the analyses by sex in order to mitigate confounding by pubertal maturation, since puberty begins and ends earlier in girls than in boys (43) and almost all girls are post pubescent by age 15 years (46). We also divided the follow-up time into 2 periods, corresponding to *earlier* adolescence (mean age, 12.8–15.1 years) and *later* adolescence (mean age, 15.2–17.0 years), to ensure that findings from earlier adolescence in boys, and those from later adolescence in girls would be less confounded by puberty. The analysis pertaining to earlier adolescence used anthropometric data collected in survey cycles 1 and 12, and on repeated assessments of physical activity from the first 12 waves of data collected during this time. The analysis pertaining to later adolescence used anthropometric data collected in survey cycles 12 and 19, and on repeated assessments of physical activity from survey cycles 12 through 19. A more detailed description of the NDIT study design and data collection methods is available (44).

Study variables

Socio-demographic data included age, sex, family status (2-parent Vs. other) and parental education (at least one parent with a university degree Vs. neither).

Two measures of height to the nearest 0.1 cm, weight to the nearest 0.2 kg, and triceps and subscapular skinfold thicknesses to the nearest 0.5mm were obtained for each participant. If discrepancies greater than 0.5 cm for height, 0.2 kg for weight, or 1.0 mm for each skinfold thickness were observed between the 2 measures, a third measure was obtained. The average of the 2 closest measures was recorded. To assess inter-rater reliability, we obtained repeat measures for a systematic 1 in 10 sub-sample of students. Inter-rater reliabilities (split-half coefficients) of 0.99, 0.99, 0.97 and 0.97 were observed for height, weight, triceps and subscapular skinfold thickness, respectively. BMI was computed as weight in kilograms divided by height in meters squared.

Body fat % was computed according to sex-specific Slaughter's equations (38): when the sum of the 2 skinfolds (Sum2SF) was 35 mm or less, %BF = 1.21 (Sum2SF) - 0.008 $(Sum2SF)^2$ - 1.7 in boys, and 1.33 (Sum2SF) - 0.013 $(Sum2SF)^2$ - 2.5 in girls. When the sum of the 2 skinfolds exceeded 35 mm, then %BF = 0.783 (Sum2SF) - 1.7 in boys, and 0.546 (Sum2SF) + 9.7 in girls. Scores obtained using Slaughter's equations have shown excellent reliability and very high validity in criterion validation studies (47) and are recommended for use in clinical settings (48).

Physical activity was measured in each survey cycle using a 7-day recall based on the Weekly Activity Checklist (49), adapted to reflect physical activities engaged in by Montreal youth. Specifically, participants reported the number of days during the preceding week on which they participated in each of 29 different physical activities for at least 5 continuous minutes (50).

Scores on the original instrument correlated with accelerometer data at r=0.34, and the 2-week test-retest reliability of the scores on adapted checklist was 0.73 (51). Scores on the adapted checklist also showed evidence of convergent-construct validity with energy intake (52). For the current analysis, only moderate and vigorous intensity activities were retained, defined as activities with an estimated energy cost of 3 to 6, or more than 6, metabolic equivalent values, respectively (53). Seventeen activities were classified as moderate intensity, and nine activities were classified as vigorous intensity according to these criteria; 26 of the 29 activities listed were retained. The number of sessions per week for each of the 26 activities was summed to create an indicator of weekly bouts of MVPA. Similarly, the number of sessions per week for each of the 9 vigorous activities was summed to create the indicator of weekly bouts of VPA. Weekly bouts of each of MVPA and VPA measured in survey cycles 1 through 12 and 12 through 19 were used to estimate longitudinal patterns of physical activity in earlier and later adolescence, respectively.

Statistical analysis

Repeated assessments of MVPA and VPA bouts for each participant were analyzed using individual growth modeling with the student's age representing time. To represent each participant's individual pattern of MVPA and VPA over time during earlier and later 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 of these variables for each period of adolescence. Age was ''centered'' on 12 years for the earlier adolescence models and on 15 years for the later adolescence models to facilitate interpretation of the intercept (54). Because the two study periods differ in duration, rate of change was expressed in units per year. An indicator variable representing season of data collection was included in the growth models to adjust for seasonal variation in the number of MVPA and VPA bouts (55). The estimates of each

participant's intercept and slope for the number of MVPA and VPA bouts per week were then used as predictors of body fat % and BMI at the end of earlier (i.e., survey cycle 12) and later adolescence (i.e., survey cycle 19). The associations were examined using sex-specific linear regression models for each of the two study periods, and for each indicator of adiposity separately in order to address previously described differences in growth and maturation between boys and girls. All models were adjusted for age and for adiposity at the beginning of follow-up time, thus implicitly adjusting for pre-baseline factors that might influence adiposity. All analyses were carried out in Stata Version 11, College Station, TX, USA.

RESULTS

Of 1293 participants in the NDIT Study, anthropometric data were available for 92.4% of participants in survey cycle 1 (577 boys and 618 girls), 73.5% of participants in survey cycle 12 (462 boys and 489 girls), and 61.9% of participants in survey cycle 19 (389 boys and 412 girls). The final samples for analyses during each of earlier and later adolescence were 840 (65.0% of 1293) and 760 (58.8% of 1293), respectively. At baseline, 81% of participants belonged to two-parent families and 52% had at least one parent with a university degree. Detailed descriptions of participant characteristics have been published previously (44).

The means number of MVPA and VPA bouts per week were stable during earlier adolescence and declined during later adolescence (Table 1). Mean BMI increased slightly from survey cycle 1 to 12, and again from survey cycle 12 to 19. Body fat % increased substantially from survey cycle 1 to 12 in girls, and from survey cycle 12 to 19 in boys (Table 1).

Tables 2 and 3 show the multivariate associations between physical activity patterns and change in body fat % and BMI, respectively, during each study period. Initial levels of both MVPA and VPA were generally negatively associated with body fat %. In contrast, initial levels of MVPA and VPA were generally weakly but positively associated with BMI, with coefficients ranging from 0.02 to 0.04.

Change in physical activity

In earlier adolescence, a yearly decline of one bout of VPA was associated with an increase of 0.47 units of body fat % in girls, but was not statistically significantly related to change in body fat % in boys. Similarly, a yearly decline of one bout of MVPA was associated with an increase of 0.19 units of body fat % in girls, but not in boys. In later adolescence, rates of VPA or MVPA decline were not associated with body fat % among girls. Among boys, a yearly decline of one bout of MVPA per year was associated with an increase of 0.38 units of body fat %, while no association was observed for VPA. Rates of decline in VPA were associated with declines in BMI in earlier adolescence in boys and in later adolescence in girls; rates of decline in MVPA were also associated with declines in BMI, but only in later adolescence in girls.

DISCUSSION

Despite substantial heterogeneity in sample characteristics, measurement of relevant variables and timing, researchers have generally documented a weak negative relationship between physical activity and adiposity in youth (18, 20, 21, 56); however, a number of aspects remained unclear. Hence, the purpose of the current analysis was to investigate the association between physical activity intensity and adiposity in boys and girls during earlier and later adolescence using a large sample with several months of follow-up. Overall, we found that boys and girls

differed substantially with respect to the association not only according to the intensity of physical activity, but also to the timing of the association. While declines in activity were more pronounced in later adolescence among all participants, their effect on adiposity was observed in earlier adolescence among girls, and in later adolescence among boys. These findings point to the existence of critical windows for intervention that differ by sex.

Our findings with respect to body fat % are consistent with the majority of observational studies on physical activity and adiposity in youth, which report a protective, albeit weak relationship (18-20, 57, 58). Moreover, like others (33, 39, 59), we observed stronger and more consistent relationships when using body fat % rather than BMI as the indicator of adiposity. Our results on BMI may exemplify that this indicator is a poor marker of change in adiposity in adolescent populations. Although BMI is strongly associated with body fat, children and adolescents in particular can have a wide range of body fat % for a given BMI value (37), and variations in BMI within general pediatric populations are largely due to differences in lean mass (60). Thus, the counterintuitive positive association between physical activity and BMI observed in this study may reflect loss of muscle mass subsequent to dropping high intensity activities. This is possible since participation in each specific sports decline in this population over time, and vigorous intensity sports are the least likely to be sustained (61).

Researchers generally report a stronger and more favorable effect of VPA than of lower intensity physical activity on adiposity (39, 57, 62). This is consistent with our findings for girls. More specifically, although both MVPA and VPA influenced change in adiposity, the effect of VPA on girls' body fat % was approximately 2.5 times greater than that of MVPA (0.47 Vs. 0.19). On the other hand, declines in MVPA in boys predicted increases in body fat %, but declines in VPA

alone were not associated with changes in adiposity. Although contrary to expectations, other investigators have also described lower adiposity with increasing participation in MVPA, but not with increased VPA per se (63). These somewhat unexpected findings may be attributable in part to the nature of the adipose deposit. More specifically, VPA has been shown to be linked more with abdominal fat (64, 65), but our measure of body fat % may not have been sensitive enough to capture small, localized increases in adipose tissue (29, 58). Alternatively, because intensity was not directly measured, it is possible that thresholds (66) regarding the 'usual' intensity of specific physical activities led to misclassification, with most of the contribution of physical activities engaged in being captured by the MVPA indicator.

Notable strengths of this analysis include the multiple assessments of physical activity with short time intervals between measurements, and the use of growth curve modelling to characterize change in physical activity over time; the use of trained technicians to measure anthropometric indicators; and the availability of baseline anthropometric assessments which allowed us to control for, and therefore minimize, potential confounding by intra-individual determinants of adiposity.

Limitations include the lack of direct measures of puberty. Use of age to control for puberty is imperfect, but findings for earlier adolescence in boys and later adolescence in girls are much less likely to be confounded by puberty. Use of self-reports to assess physical activity is susceptible to recall bias and social desirability, but data collection at up to 19 time points across all seasons, would not have been feasible using accelerometers. Finally, the baseline response proportion was modest, possibly limiting external generalizability. However, this is unlikely to have affected the

reported estimates because non-participation was related to issues extraneous to those of interest in this analysis.

In conclusion, we have illustrated that physical activity involvement declines substantially during secondary school. Given the known public health burden related to physical inactivity (67, 68), and the increasing trends toward sedentary lifestyles, there is an urgent need for population-level strategies aimed at preventing declines in physical activity across the adolescent period. Based on our age-, sex- and intensity- specific associations, carefully crafted public health guidelines promoting a variety of both moderate and vigorous intensity physical activities should be developed for boys and girls throughout secondary school, which incorporate strategies that encourage the initiation and maintenance of physical activities. Clearly, the promotion of a physically active lifestyle is needed throughout the life course, but secondary school based obesity prevention programs may be most effective, particularly if they target girls in earlier adolescence and boys in later adolescence.

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Table 1. Selected Characteristics of Study Participants at Survey Cycle 1, 12 and 19 Stratified by Sex, Nicotine Dependence in Teens Study, Montreal, 1999-2005

	Survey Cycle 1		Survey Cycle 12		Survey Cycle 19	
	Boys (n=577)	Girls (n=618)	Boys (n=462)	Girls (n=489)	Boys (n=389)	Girls (n=412)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	12.8 (0.6)	12.7 (0.6)	15.2 (0.4)	15.1 (0.4)	17.0 (0.4)	16.9 (0.4)
MVPA/week	20.8 (16.8)	17.0 (13.0)	20.8 (17.6)	18.0 (13.2)	16.5 (13.0)	14.3 (9.2)
VPA/week	5.4 (5.9)	2.6 (3.9)	5.3 (6.2)	3.0 (4.1)	3.9 (4.6)	1.9 (3.1)
BMI (kg/m^2)	20.1 (3.8)	20.0 (3.9)	21.6 (3.6)	21.6 (3.8)	22.6 (3.7)	22.2 (3.7)
Body fat (%)	20.3 (8.3)	22.3 (6.9)	21.0 (7.1)	27.5 (6.9)	24.1 (9.1)	30.9 (7.4)

Abbreviations: BMI, body mass index; MVPA, moderate-to-vigorous physical activity; SD, standard deviation; VPA, vigorous physical activity

Table 2. Change in Percent Body Fat Between Ages 12-15 Years (Earlier Adolescence) and 15-18 Years (Later Adolescence) According to Vigorous Physical Activity and Total Physical Activity, Nicotine Dependence in Teens Study, Montreal, 1999-2005 [a]

	Earlier adolescence				Later adolescence			
	Boys (n=406)		Girls (n=432)		Boys (n=369)		Girls (n=390)	
	β	95% CI	β	95% CI	B	95% CI	β	95% CI
VPA								
Baseline Percent body fat	0.695	0.656, 0.734****	0.763	0.720, 0.807****	0.964	0.907, 1.021****	0.792	0.735, 0.849****
Initial level of VPA	-0.009	-0.081, 0.063	-0.107	-0.210, -0.005**	-0.107	-0.221, 0.007*	0.087	-0.071, 0.246
Rate of VPA decline	-0.050	-0.357, 0.258	0.468	0.015, 0.921**	0.271	-0.162, 0.703	0.154	-0.537, 0.846
MVPA								
Baseline Percent body fat	0.693	0.654, 0.732****	0.765	0.722, 0.809****	0.961	0.904, 1.018****	0.786	0.730, 0.843****
Initial level of MVPA	-0.011	-0.039, 0.016	-0.046	-0.080, -0.012***	-0.061	-0.111, -0.012**	-0.011	-0.077, 0.054
Rate of MVPA decline	0.056	-0.069, 0.180	0.189	0.021, 0.357**	0.376	0.050, 0.702**	0.213	-0.217, 0.642

Abbreviations: CI, confidence interval; MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity

* $P < 0.1$; ** $P < 0.05$; *** $P < 0.01$; **** $P \leq 0.001$ (chi-square)

[a] β (95% CI) obtained from multiple linear regression models refer to the change in percent body fat for every unit increase in explanatory variables after controlling for age.

Table 3. Change in Body Mass Index Between Ages 12-15 Years (Earlier Adolescence) and 15-18 Years (Later Adolescence) According to Vigorous Physical Activity and Total Physical Activity, Nicotine Dependence in Teens Study, Montreal, 1999-2005 [a]

	Earlier adolescence				Later adolescence			
	Boys (n=407)		Girls (n=433)		Boys (n=369)		Girls (n=391)	
	β	95% CI	β	95% CI	β	95% CI	β	95% CI
VPA								
Baseline body mass index	0.885	0.851, 0.920****	0.877	0.851, 0.904****	0.934	0.900, 0.969****	0.947	0.915, 0.979****
Initial level of VPA	0.041	0.013, 0.068***	0.039	0.004, 0.075**	0.014	-0.020, 0.048	0.064	0.016, 0.112***
Rate of VPA decline	-0.119	-0.237, -0.002**	-0.067	-0.223, 0.089	0.008	-0.120, 0.136	-0.181	-0.392, 0.029*
MVPA								
Baseline body mass index	0.886	0.852, 0.921****	0.877	0.851, 0.904****	0.935	0.900, 0.969****	0.947	0.915, 0.979****
Initial level of MVPA	0.017	0.006, 0.027***	0.008	-0.004, 0.020	0.006	-0.009, 0.020	0.017	-0.003, 0.037*
Rate of MVPA decline	-0.036	-0.084, 0.011	0.0001	-0.058, 0.058	-0.019	-0.036, 0.057	-0.111	-0.241, 0.020*

Abbreviations: CI, confidence interval; MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity

* $P < 0.1$; ** $P < 0.05$; *** $P < 0.01$; **** $P \leq 0.001$ (chi-square)

[a] β (95% CI) obtained from multiple linear regression models refer to the change in units of body mass index for every unit increase in explanatory variables after controlling for age.