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ORIGINAL RESEARCH

Associations Between Moderate to Vigorous Physical Activity, Sedentary Behavior, and Depressive Symptomatology in Adolescents: A Prospective Observational Cohort Study

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Background: More moderate to vigorous physical activity (MVPA) and less time in sedentary behavior (SB) may protect against poor mental health in adolescence. Depressive symptomatology may also influence adolescents' own MVPA and SB. The aim of this study was to examine the bidirectional relationship between adolescent MVPA, SB, and depressive symptomatology using a longitudinal approach. ***Methods:*** Adolescents (10–16 y) were recruited for a prospective observational cohort. Depressive symptomatology was measured using the Short Mood and Feelings Questionnaire. Accelerometry was used to measure MVPA and SB. Adolescents were classified by meeting the MVPA guideline (≥60 min/d) and quartiles of SB time, with the lowest amount of time in SB compared to others. Bidirectional associations between MVPA, SB, and depressive symptomatology were assessed using mixed-effects regression models. ***Results:*** At baseline, adolescents (n = 205) were 12.5 (2.0) years, 54.6% women, 59.1% White, and 34.6% African American. In unadjusted models, adolescents with less baseline time in SB had lower follow-up Short Mood and Feelings Questionnaire scores, and fewer were classified as depressed at follow-up compared to others. After adjustment, adolescents with less baseline time in SB had lower depressive symptomatology at follow-up. ***Conclusions:*** Limiting time spent in SB in adolescence may improve future mental health.

Keywords: adolescence, accelerometry, mental health, longitudinal

Physical activity in adolescence is associated with long-term health benefits, including a lower risk for obesity and cardiovascular disease, along with improved mental well-being.[1,2] Yet, there are notable declines in physical activity[3] and an increased risk for the development of mental disorders, including depression,[4] within this critical period. Accordingly, few (<9%) adolescents (aged 9–13 y) in the United States meet the World Health Organization recommended guidelines for physical activity,[5] including ≥60 minutes per day of moderate to vigorous physical activity (MVPA).[6] Though the World Health Organization does not quantify a sedentary behavior (SB) threshold for adolescents,[5] the recently created 24-hour movement guidelines stipulate ≤2 hours per day of recreational screen time,[7] one of the main forms of SB. Few youth (33%) meet the screen time guidelines as found in 49,606 youth (aged 6–17 y) in the United States.[8] This finding is concerning, as longitudinal studies report that decreased physical activity and increased SB are associated with increased depressive symptomatology.[9,10] Maintaining adequate physical activity and less time spent sedentary may protect against the development of depressive symptomatology.[11]

Along with changes in activity patterns, the rise in depression among adolescents is a public health concern. As of 2015, 1 in 8 (13%) of adolescents (aged 12–17 y) in the United States was classified as having depression.[12] Adolescents with depression may be less inclined to make healthy lifestyle choices, including participating in physical activity, as they often report having decreased energy, pleasure, and motivation compared with adolescents without depression.[13] Longitudinal studies report depressive symptomatology was associated with lower levels of physical activity and increased SB (eg, screen time) in adolescents.[14,15] Promoting adolescent mental health may help facilitate adequate physical activity and less time spent sedentary.

Considering both relationships, the association between adolescent activity patterns and depression appears to be bidirectional. On the one hand, decreased physical activity and increased SB predict adolescent depression.[9,10] Yet, adolescent depression may also lead to decreased physical activity and increased SB.[14,15] Current longitudinal studies examining this bidirectional association report inconsistent findings,[9,16,17] possibly due to these studies using self-report rather than a device-based measure (eg, accelerometer). Device-based measures can improve upon self-report measures by accurately capturing the frequency, intensity, and duration of activity, and minimizing reporting biases.[10,11,18] Device-based measurement of SB may also help inform future public health guidance on guidelines for adolescents.

Given the importance of promoting both mental health and physical health in adolescence, the aim of this study was to evaluate the bidirectional association among adolescent physical activity, SB, and depressive symptomatology. It was hypothesized that adolescents who meet the MVPA guideline and those with less time spent sedentary at baseline will have lower depressive symptomatology over a 2-year period, relative to their comparison groups. It was also hypothesized that adolescents with depression at baseline will have a decrease in MVPA and an increase in time spent sedentary over a 2-year period, relative to their comparison groups.

Methods

Adolescents (aged 10–16 y) were recruited from a metropolitan city in a southeastern state of the United States between 2016 and 2018 to participate in a prospective observational cohort, the Translational Investigation of Growth and Everyday Routines in

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Kids (TIGER Kids), study (NCT02784509). Eligibility criteria at baseline were weighing <500 pounds, not pregnant, not on a restrictive diet due to illness, no significant physical and mental disabilities that interfered with the ability to walk or wear an accelerometer, and able to comprehend and complete all study procedures. Based on previous literature,[19] the target enrollment for the TIGER Kids main study was ≥334 participants to detect a 24-minute difference change in SB between adolescents with and without obesity ($\alpha = .05$, 80% power), and allowing for a dropout rate of 25% (n = 250). The study team aimed to recruit 340 adolescents at baseline to assess their primary research question. The present report is an ancillary report of the TIGER Kids study and follows the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Supplementary Table S1 [available online]).

Recruitment efforts included flyers and outreach at local schools, email Listservs, Facebook advertisements, local news media, health fairs, and other community events. Follow-up measures occurred approximately 2 years after baseline measurements (range: 18–30 mo). Adolescents were retained by communicating with the guardian biannually.

Procedure

Pennington Biomedical Research Center's institutional review board approved the study protocol (Protocol: 2016-028). Adolescent informed assent and parental informed consent were obtained at the 1-day orientation visit at baseline prior to any measures. At this visit, adolescents were instructed to wear an accelerometer for at least 7 days and return for a clinic visit. At least 7 days after the orientation visit, participants attended the clinic visit and returned the accelerometer. If the accelerometer was not worn, the adolescent was asked to wear the accelerometer for an additional week. At the clinic visit, the parent completed a demographic survey, which included adolescent age, sex, race, parental marital status, and household income. Adolescents also completed the Short Mood and Feelings Questionnaire (SMFQ) with a trained researcher present to ensure that the SMFQ was completed without parental influence. All questionnaires were completed using a secure data capture software.[20,21] Height and weight were objectively measured twice and averaged, with a third measurement taken if the measurements differed by ≥0.5 units. Body mass index (BMI) was calculated by dividing the weight (in kilograms) by squared height (in meters) and compared with age- and sex-adjusted percentiles using the CDC SAS Macro program (Centers for Disease Control and Prevention).[22]

At the follow-up visit, adolescents were mailed the materials ahead of the clinic visit and asked to wear the accelerometer for 7 days prior to the visit. Adolescents and parents were also emailed the questionnaires ahead of the visit for completion. All clinical procedures from the initial clinic visit were repeated during the follow-up clinic visit.

Physical Activity and Sedentary Behavior

Physical activity and SB were measured using an ActiGraph GT3X+ (ActiGraph Corp) accelerometer worn on an elastic belt around the left midaxillary line. Adolescents were instructed to always wear the accelerometer, except for water-based activities, and for at least 7 days (including 2 weekend days). Minimal wear time was ≥10 hours for ≥4 days, including at least 1 weekend day, similar to other studies.[23] An algorithm was used to differentiate wear time, nonwear time, and sleep time.[24] Wear time was classified using age-specific cut points for SB (<25 counts/15 s) and MVPA (≥574 counts/15 s).[25] Adolescents who averaged ≥60 minutes per day of MVPA were classified as meeting the MVPA guideline.[6] SB was represented in hours per day, and adolescents were divided into quartiles as represented in other studies of accelerometer-measured SB.[26,27] Adolescents with the lowest amount of SB (1 quartile) were then compared with all others (remaining 3 quartiles combined).

Depressive Symptomatology

Depressive symptomatology was assessed using the SMFQ, which is a 13-item self-report questionnaire assessing the moods and feelings over the preceding 2 weeks. This questionnaire has been validated against the clinical diagnosis of depression in the adolescent population (aged 6–17 y).[28] Items included "I cried a lot" and "I hated myself." Responses included a 3-point Likert scale, with the possible choices ranging from 0 = "Not True," 1 = "Sometimes," to 2 = "Always True." Question answers were summed, with a possible depressive symptom score of 0 to 26 and a higher score indicating more depressive symptomatology. Adolescents with a SMFQ score ≥8 units were classified as having depression similar to previous literature.[28]

Statistical Analysis

Only adolescents with complete data for both time points were included in the analysis. SMFQ score, MVPA (in minutes per day), and SB (in hours per day) were nonnormally distributed at both time points. Central tendencies were calculated including means and standard deviations (normally distributed variables) and median and interquartile range (IQR; nonnormally distributed variables). Comparisons between those included and not included in analyses were conducted using independent *t* tests and chi-square analyses. The main relationships assessed were (1) baseline MVPA and SB with follow-up depressive symptomatology, (2) baseline depressive symptomatology with follow-up MVPA, and (3) baseline symptomatology with follow-up SB. MVPA and SB were included together in the model due to the interrelationship between MVPA and SB. Paired *t* tests and Wilcoxon signed-rank tests were used to compare values between baseline and follow-up for normally and nonnormally distributed variables, respectively. Crude analyses among variables included Spearman rank correlation coefficients and Kruskal–Wallis tests for categorical representations of baseline variables (MVPA guideline attainment, SB category [lowest quartile vs all others], and depression classification). Two separate cross-lagged linear models were fit to examine bidirectional associations between MVPA and depressive symptomatology, and SB and depressive symptomatology.

As for adjusted analysis, independent multilevel regression models were used to assess the association between baseline independent variables and change in dependent variables with adjustment for clustering of adolescents in the same household. Each model was checked for assumptions of normality. Covariates for adjustment were baseline adolescent age, sex, race, household income, BMI, wear time (not including sleep), and months between time points, in/out-of-school status, and baseline values of dependent variables. Logistic regression was conducted to examine the relationship between categorical independent variables and dependent variables with adjustment for the same covariates as the linear regression models. A consideration for the study is that the COVID-19 pandemic (began in March 2020) occurred during the follow-up visits. Adolescents with a follow-up visit after March

2020 (n = 33) engaged in less MVPA (20.2 [14.7] min/d) compared with adolescents who had their visit prior to March 2020 (n = 172, 27.7 [17.0] min/d, $P = .01$). A covariate (ie, follow-up visit occurred prior vs after March 2020) was added to models where MVPA was the dependent variable. A sensitivity analysis for MVPA and depressive symptomatology was conducted removing those who had their follow-up visit during the COVID-19 pandemic (n = 172). All analyses were conducted in SAS (version 9.4), and significance was set at $P < .05$.

Results

As shown in Figure 1, 342 adolescents completed baseline measures with 320 providing complete measures, and 250 adolescents completed follow-up with 205 adolescents providing complete measures for the present analysis. Those included in analysis had a lower BMI percentile at baseline (69.2 [31.1]), more MVPA (median [IQR]: 22.9 [14.5, 35.1] min/d), longer wear time (14.3 [1.2] h/d), and less time in SB (median [IQR] 73.0 [68.0, 77.6]) at follow-up compared with those not included in analysis (baseline BMI percentile: 76.9 [26.5], $P = .01$; follow-up MVPA: median [IQR] 16.9 [11.5, 25.5] min/d, $P = .03$; follow-up wear time: 13.4 [1.2] h/d, $P = .04$; and follow-up SB: median [IQR] 79.4 [74.7, 80.3], $P = .02$). No other differences were found between those included and not included in analysis (see Supplementary Table S2 [available online]).

Analytic Sample

Approximately half of the sample was women (54.6%) and White (59.1%). On average, adolescents were 12.5 (2.0) years of age at baseline, and the follow-up visit occurred around 2 years after the baseline visit (23.6 [2.6] mo; Table 1). Adolescents reported few depressive symptoms at both time points and engaged in about half the amount of recommended MVPA in minutes per day. The lowest SB category spent 8.2 hours per day (range: 6.5–9.0) in SB, whereas all others had a median of 10.4 hours per day (range: 9.0–13.2). Individual SB quartile estimates at baseline were 9.5 hours per day (range: 9.0–10.0), 10.3 hours per day (range: 10.0–10.6), and 11.2 hours per day (range: 10.8–13.2). At follow-up, the lowest SB category included those who spent 8.9 hours per day (range: 7.0–9.6) in SB, and all others spent 10.8 hours per day (range: 9.6–13.5) in SB. Quartile estimates for time in SB at follow-up were 10.0 hours per day (range: 9.6–10.4), 10.8 hours per day (range: 10.4–11.1), and 11.8 hours per day (range: 11.2–13.5). At follow-up, adolescents had higher depressive symptomatology, lower MVPA, more SB, and more percent time in SB compared with baseline ($P < .001$ for all).

Depressive Symptomatology, Physical Activity, and Sedentary Behavior

In unadjusted models, baseline MVPA minutes ($r = -.18$, $P = .008$) and percent time in SB ($r = .26$, $P = .001$) were associated with follow-up depressive symptomatology. These results were confirmed in cross-lagged linear models (Supplementary Figure S1 [available online]). Adolescents who met the MVPA guideline and those in lowest SB category at baseline reported significantly lower SMFQ scores at follow-up relative to their comparison groups (Ps < .05 for both; Figure 2A and 2B). Fewer adolescents in the lowest SB category at baseline were classified as having depression at follow-up (9.8%, n = 5) compared with all others (23.4%, n = 36, $\chi 2 = 4.41$, $P = .04$). There were no significant associations between baseline depressive symptomatology or depression and follow-up activity patterns (Ps > .05).

As shown in Table 2, those with additional time in SB at baseline increased their SMFQ score (indicating higher levels of depressive symptoms) by 1.70 units (SE = –0.82, $P = .03$) relative to those in the lowest category for SB. Being in the lowest SB category at baseline was not related to lower risk of depression at follow-up ($P = .13$). Meeting the MVPA guideline was not associated with change in depressive symptomatology at follow-up, though baseline depressive symptomatology and male sex (Ps < .05) were significant factors. Depressive symptomatology and being classified as depressed on at baseline were not associated with MVPA or SB at follow-up. Baseline values were associated with their follow-up MVPA and SB measures (Ps < .05).

In sensitivity analysis, there was no longer a difference in depressive symptomatology between those who did (n = 21, median [IQR]: 2.57 [0, 4.0]) and did not (n = 151, median [IQR]: 4.35 [1.0, 7.0]) achieve the MVPA guideline at baseline ($P = .07$). All other results related to MVPA and depressive symptomatology were sustained.

Discussion

This study investigated the bidirectional association between physical activity, SB, and depressive symptomatology within a prospective observational cohort of adolescents using device-based measures. Adolescents who spent less time sedentary had less depressive symptomatology that develop over 2 years relative to their peers, even when accounting for other factors. MVPA was not related to change in depressive symptomatology over 2 years in adjusted models. Adolescents with depression at baseline did not differ in their activity patterns at follow-up compared with adolescents without depression. Overall, this study found that SB was related to subsequent depression but not vice versa; therefore, there was not a bidirectional relationship.

Consistent with previous literature, this study found additional sedentary time was associated with a higher risk of future depressive symptomatology.[9,10] The current sample spent more time sedentary at baseline (median [IQR]: 69.1 [64.0, 73.8]) compared with another longitudinal sample of adolescents (55.3%).[16] About a third of the current sample had obesity (32.7%) at baseline and may already be engaging in additional sedentary time relative to normal weight counterparts. The exact activities during SB were not identified in this study, but a common sedentary activity is recreational screen time. This additional screen time may limit in-person peer interactions and may elicit feelings of isolation and loneliness and thereby increase depressive symptomatology in adolescents.[29]

As for MVPA, meeting the MVPA guideline at baseline was associated with less depressive symptomatology at follow-up in unadjusted models but attenuated to nonsignificance following adjustment for covariates, including sex. The lack of association between MVPA and depression conflicts with studies that used self-report data for physical activity[9,15] but is in concurrence with those that used device-based measures.[30] The inconsistency may be that adolescents often overestimate physical activity. The current study observed a decline in MVPA across timepoints similar other adolescent samples.[6,14,16] This is concerning as only 10.7% met the MVPA guideline at baseline, which is comparable to an international adolescent sample using device-based measures (~9%).[6] Men engaged in more MVPA and less SB at follow-up compared with to women, similar to other reports.[10] Opportunities to promote MVPA across adolescence, especially among women, are encouraged to confer

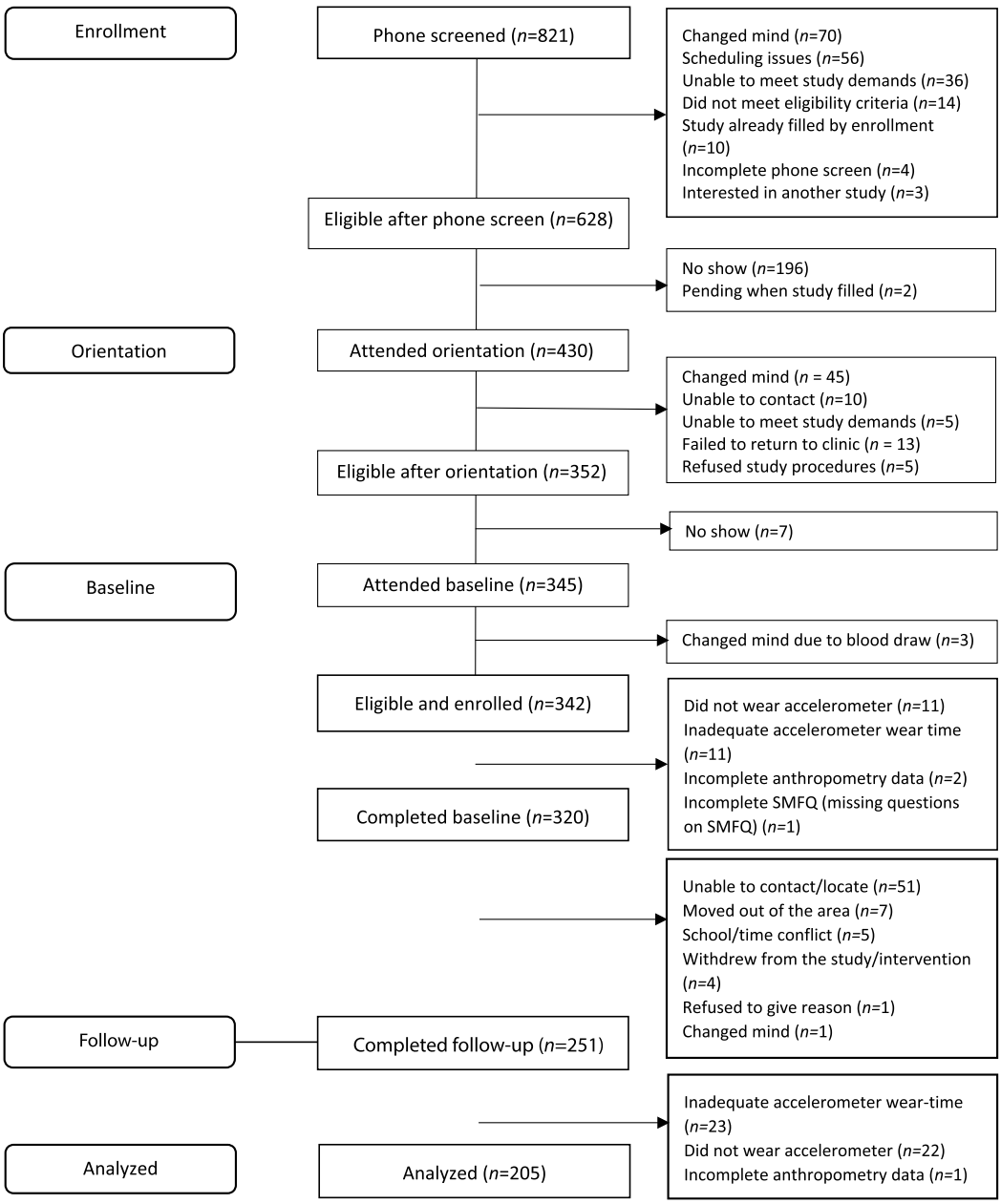

Figure 1 — Flow diagram for study participants. SMFQ indicates Short Mood and Feelings Questionnaire.

other long-term benefits of physical activity despite the lack of association with mental health in this study.

This study did not find an association between baseline depression and activity patterns at follow-up. Few (11.7%) adolescents in the current sample were classified as depressed at baseline, which is half the amount compared with another adolescent sample with identical SMFQ cutoffs (21.6%) but was slightly older (grades 8 and 10 students).[11] Other longitudinal studies report that having depression was related to a decline in physical activity and increase in SB, though these studies relied on self-report measures (ie, screen time).[14,15] Another explanation is that the influence of depressive mood on activity patterns may be short-lasting and vary day to day, making it difficult to capture these associations among longer time periods without using within-day observations.

Several strengths of the current study include a diverse sample (41% non-White) and the use of device-based measures for activity patterns. Another strength is the longitudinal design over 2 years, which allowed for assessment of changes over a crucial time in development. This study utilized a self-report questionnaire (ie, SMFQ), which demonstrates reasonable accuracy and can serve as a lower burden alternative to clinical interviews. A limitation of this study is an analytical sample that was predominately middle income and had higher rates of obesity, lower rates of depression, and more sedentary time relative to other samples.[11,16] These properties may limit generalizability, including adolescents from low-income households, who are at risk for low amounts of physical activity and higher depressive symptoms.[31] This study may be subject to social desirability biases, as the questions in the SMFQ concern sensitive topics, such as self-hatred and loneliness. Another limitation is that the context of physical activity and SB was not assessed, so the results cannot be attributed to a certain activity (eg, recreational screen time). The World Health Organization guidelines for adolescents specify

Table 1 Characteristics of Adolescents (n = 205)[a]

	Baseline			Follow-up			Difference	
	Mean (SD)	Median (IQR)	%	Mean (SD)	Median (IQR)	%	Mean (SD)	*P*
Child and household characteristics								
Age	12.5 (2.0)			15.0 (2.0)				
Boys			45.4					
Ethnicity								
White			59.0					
African American			34.6					
Other			6.3					
Married parents			60.5					
Household income (USD)								
Less than $29,999			8.8					
$30,000–$69,999			24.9					
$70,000–$139,000			34.6					
Greater than $140,000			24.9					
Prefer not to answer			6.8					
BMI	23.9 (7.8)			26.0 (8.6)				
BMI percentile	69.2 (31.2)			71.8 (29.2)			2.6 (14.2)	<.001*
Weight status								
Underweight			3.4			2.4		<.001*
Normal			50.7			49.8		
Overweight			13.2			14.2		
Obese			32.7			33.7		
In school during measurements			66.8			44.9		
Child physical activity, SB, and depressive symptoms								
MVPA, min/d		29.8 (20.6, 42.8)			22.9 (14.5, 35.1)		−7.8 (18.3)	<.001*
SB, h/d	10.0 (1.2)			10.5 (1.2)			0.5 (1.4)	<.001*
Wear time, h/d	14.4 (0.9)			14.3 (1.2)			−0.07 (1.4)	.47
Met MVPA guideline, ≥60 min/d			10.7			6.3		<.001*
Percent time spent in SB, %		69.1 (64.0, 73.8)			73.0 (68.0, 77.6)		0.04 (0.07)	<.001*
Total SMFQ		2.0 (1.0, 4.0)			3.0 (1.0, 6.0)		1.2 (4.5)	<.001*
Depression, SMFQ ≥ 8			11.7			20.0	1.2 (4.5)	<.001*

Abbreviations: BMI, body mass index; IQR, interquartile range; MVPA, moderate to vigorous physical activity; SB, sedentary behavior; SMFQ, Short Mood and Feelings Questionnaire (score range 0–26 possible).

[a]Assessed using Wilcoxon signed-rank and paired *t* tests; median and interquartile ranges are shown for nonnormally distributed variables; "Other" ethnicity included those who identified as mixed race, Asian, or other ethnicity.

*$P < .05$.

reducing time spent sitting, specific to recreational screen time,[5] and accelerometer-measured SB time incorporates additional activities beyond screen time. Finally, despite obtaining the main study's planned analytical sample (75% of baseline sample, n = 250), only 60% of the baseline sample was included in analyses due to low accelerometer wear time. Differing standards exist for accelerometer wear time,[6] and compliance is a commonly reported problem in this age range and requires additional focus.

Future research in this field should consider additional mental health constructs that may interrelate with movement, as well as explore the specific context of physical activity and SB as it relates to mental health in adolescents. Physical activity was inversely associated with incidence of anxiety in cross-sectional and longitudinal results among 1160 adolescents.[14] Further examination into other mental health outcomes, like anxiety, may better illuminate the protective effect of physical activity on adolescent mental health. Another consideration for future research is context, as social physical activities, such as team sports, can serve a protective role against depressive symptomatology in adolescents.[32] In contrast, screen-based SBs, such as television viewing, are associated with the development of depression in adolescents.[10] Additional investigation into the type, amount, and daily or seasonal fluctuations in SB, for example, differences when sitting time is spent engaged in homework, social media, and passive versus interactive screen time, may better elucidate the mechanism between SB and future depressive symptomatology found in this study.[33,34] The incorporation of both physical activity and mental health components into future interventions may facilitate improvements in overall adolescent health.

Conclusions

Adolescents who were less sedentary had fewer depressive symptoms 2 years later, relative to others. These findings support

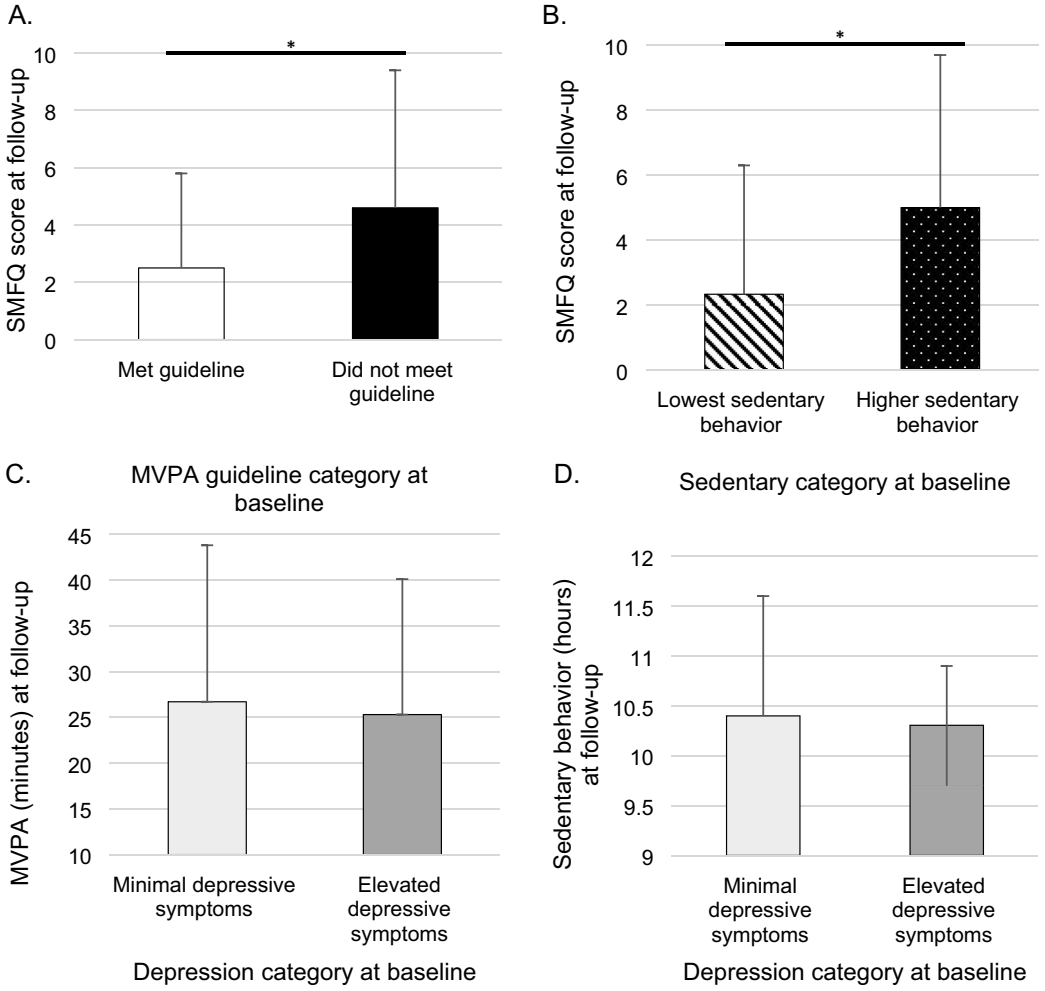

Figure 2 — MVPA, SB, and depressive symptomatology in adolescents. Assessed using Kruskal–Wallis 1-way analysis of variance; means and standard deviations shown. MVPA indicates moderate to vigorous physical activity; SB, sedentary behavior; SMFQ, Short Mood and Feelings Questionnaire. *$P < .05$.

Table 2 Adjusted Associations Between Baseline and Follow-Up Measures of Physical Activity, SB, and Depressive Symptomatology (n = 205)[a]

	SMFQ score at follow-up			MVPA at follow-up, min			SB at follow-up, h		
Baseline	***β***	**SE**	***P***	***β***	**SE**	***P***	***β***	**SE**	***P***
MVPA, min	0.001	0.02	.96						
SB, h	0.005	0.007	.49						
Meeting MVPA guidelines (≥60 min/d)	−0.53	1.08	.62						
Lowest SB category	−1.70	0.82	.03*						
SMFQ score				−0.10	0.27	.69	0.01	0.02	.50
Depression (SMFQ score ≥ 8 units)				1.17	3.26	.72	0.27	0.25	.28

	Depression at follow-up			Met MVPA guideline at follow-up			Lowest SB category at follow-up		
Baseline	**OR**	**95% CI**	***P***	**OR**	**95% CI**	***P***	**OR**	**95% CI**	***P***
Meeting MVPA guidelines (≥60 min/d)	0.99	0.34–12.9	.41						
Lowest SB category	0.37	0.10–1.3	.13						
Depression (SMFQ score ≥ 8 units)				0.44	0.02–8.7	.59	0.82	0.27–2.52	.82

Abbreviations: CI, confidence interval; MVPA, moderate to vigorous physical activity; OR, odds ratio; SB, sedentary behavior; SMFQ, Short Mood and Feelings Questionnaire (score range 0–26 possible).

[a]Assessed using linear mixed models or logistic regression with adjustment for age, sex, race, income, difference in time points (in months), in-school status, body mass index, baseline wear time for models with MVPA and SB as independent variables, and COVID-19 visit when MVPA as dependent variable.

*$P < .05$.

recommendations to limit the time spent sedentary to prevent later illness. Few adolescents engaged in adequate MVPA, and depressive symptomatology was prevalent. Addressing physical inactivity, limiting sedentary time, and prioritizing mental health in adolescence may help foster long-term health benefits.

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