Original Investigation

Exercise and Depressive Symptoms in Adolescents
A Longitudinal Cohort Study

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IMPORTANCE Physical activity (PA) may have a positive effect on depressed mood. However, whether it can act as a protective factor against developing depressive symptoms in adolescence is largely unknown.

OBJECTIVE To investigate the association between objectively measured PA and depressive symptoms during 3 years of adolescence.

DESIGN, SETTING, AND PARTICIPANTS We performed a longitudinal study between November 1, 2005, and January 31, 2010, of a community-based sample from Cambridgeshire and Suffolk, United Kingdom, that included 736 participants (mean [SD] age, 14.5 years [6 months]). The follow-up period was approximately 3 years after baseline (the ROOTS study). Linear regression models were fitted using physical activity energy expenditure (PAEE) and moderate and vigorous physical activity (MVPA) as the predictors and depressive symptoms as the outcome variable. Binomial logistic regression models were also fitted using PAEE and MVPA as the predictors and clinical depression as the outcome measure.

EXPOSURES Exercise.

MAIN OUTCOMES AND MEASURES Individually calibrated heart rate and movement sensing were used to measure PA at baseline only. Physical activity summary measures included total PAEE and time spent in MVPA. These measures were divided into weekend and weekday activity. All participants also completed the Mood and Feelings Questionnaire, a self-report measure of current depressive symptoms, and took part in a Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version interview at baseline and 3 years later.

RESULTS Depressive symptoms at 3-year follow-up were not significantly predicted by any of the 4 PA measures at baseline: weekend MVPA (unstandardized β = 0.02; 95% CI, −0.15 to 0.20; *P* = .79), weekday MVPA (β = 0.00; 95% CI, −0.17 to 0.17; *P* = .99), weekend PAEE (β = 0.03; 95% CI, −0.14 to 0.20; *P* = .75), and weekday PAEE (β = −0.03; 95% CI, −0.20 to 0.14; *P* = .71). This was also true for major depressive disorder diagnoses at follow-up: weekend MVPA (odds ratio [OR], 1.37; 95% CI, 0.76-2.48; *P* = .30), weekday MVPA (OR, 1.33; 95% CI, 0.74-2.37; *P* = .34), weekend PAEE (OR, 1.19; 95% CI, 0.67-2.10; *P* = .56), and weekday PAEE (OR, 0.92; 95% CI, 0.52-1.63; *P* = .78).

CONCLUSIONS AND RELEVANCE No longitudinal association between objectively measured PA and the development of depressive symptoms was observed in this large population-based sample. These results do not support the hypothesis that PA protects against developing depressive symptoms in adolescence.

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Depression is a major contributor to the global burden of disease.[1-3] A reduction in the associated personal and financial costs would benefit society. The onset of depression is thought to be in adolescence or earlier,[4-9] and so preventive measures during this vulnerable stage in life would be beneficial. Physical activity (PA) has been cited in numerous reports as a potential moderator in reducing the risk of clinical depression; however, the evidence for such an effect is less than clear-cut. Psychosocial explanations for why PA may help with depressed mood include increased opportunity of social interaction, leading to increased social support[10]; distraction from symptoms that induce stress[11]; and the feeling of accomplishment, which may promote a more positive outlook.[12]

Cross-sectional research has found that overall PA levels are associated with depressive symptoms during adolescence,[13] but there is no independent effect of moderate and vigorous physical activity (MVPA).[13,14] The longitudinal evidence is equivocal, with some evidence that low levels of PA in early adolescence do not predict the onset of depression or depressive symptoms in later adolescence,[15-18] whereas other studies[19-22] report a significant effect. Randomized clinical trials have been equally inconclusive because of constraints such as poor methodological design and small observed effect size.[23-25] One randomized clinical trial found that aerobic exercise reduced depression in the first 5 weeks but not thereafter.[26]

The aforementioned studies and others[16,27-31] used self-report measures of depressive symptoms in community samples. Self-report measures of depressive symptoms, such as the Mood and Feelings Questionnaire (MFQ), are widely used in mental health research and have been found to have high criterion validity.[32] Contrary to this, self-report measures of PA are known to have considerable error, and a tendency to overreport the intensity of PA when compared with measures taken objectively has been noted in adolescents.[33] All the longitudinal research that investigates the prospective association between PA and depressive symptoms has relied on self-report measures of PA.[15-22] The cross-sectional research that has used objective measures of PA in adolescents used heart rate monitoring or accelerometry alone.[13,14,34]

Even though these measures are objective and may be preferred to self-report methods, they have limitations. For example, because accelerometers are usually worn at the hip, they are not able to accurately measure activities, such as cycling, which predominantly requires lower body movements, or certain household chores that only require upper body movement. Similarly, heart rate can change as a result of stress or other factors that are unrelated to PA. We are not aware of any studies that have used combined heart rate monitoring and accelerometry when investigating adolescent mental health, although these measures have been used in older patients with unipolar and bipolar depression.[35] We believe that this combined measurement of PA provides a more accurate representation of the PA undertaken by adolescents.

To our knowledge, to date, the research that has examined the association between depressive symptoms and objectively measured PA has used a cross-sectional design, and those studies that have used a longitudinal design have used self-report measures of PA. We therefore investigated the association between objectively measured PA and depressive symptoms in a longitudinal study. It was hypothesized that those participants with higher levels of PA in early adolescence would have lower levels of depressive symptoms at the 2.5-year follow-up.

Methods

Participants

This longitudinal study was performed between November 1, 2005, and January 31, 2010. All 1238 participants in the ROOTS study cohort,[36] a community sample of adolescents attending schools in Cambridgeshire and Suffolk, were invited to take part in the PA substudy and 909 (73.4%) participated. The ROOTS study was approved by the Cambridge University Research Ethics Committee. Written parental and participant consent was obtained at all data collection points. Of these 909 participants, 173 (19.0%) provided insufficient valid PA data and were excluded (see below). Physical activity data from 736 participants (418 girls and 318 boys) were available at baseline. The Acorn index (http://acorn.caci.co.uk) was used as a proxy for socioeconomic status (SES) . Categories were combined to represent high (wealthy achievers and urban prosperity), middle (financially comfortable), and low (moderate means and financially strained) SESs.

Design

Physical activity data were collected at time 1 (mean [SD] age, 15.0 years [3.6 months]). Approximately 6 months before this, participants had completed psychosocial measures as part of the wider ROOTS study (time 0) (mean [SD] age, 14.5 years [6 months]). These data collection points are collectively referred to as baseline in the present analyses. The ROOTS study cohort was followed up approximately 3 years after time 0, and psychosocial measures were taken; we call this follow-up visit time 2 (mean [SD] age, 17.5 years [3.6 months]).

PA Measurement

At baseline, PA was assessed using combined heart rate and movement sensing (Actiheart, CamNtech Ltd).[37-39] The monitor clips onto 2 electrocardiographic electrodes and is positioned in the midline just below the xiphisternum and attached via a 70- to 100-mm wire to a smaller clip horizontally to the left chest wall. Both parts were secured to the skin via standard electrocardiographic electrode pads. Participants performed an 8-minute step test,[40] after which the monitor was set up to record data in 30-second epochs. Participants were asked to wear the monitor continuously for the remainder of the testing day and then for 4 consecutive days, including 2 weekend days (mean [SD] weekday wear time, 60.75 [12.41] hours; and mean [SD] weekend wear time, 43.10 [6.47] hours). Participants were encouraged not to remove the monitor at any point during the measurement period, except for changing of electrocardiographic pads, which were provided. Heart rate data were preprocessed,[41] calibrated individually using the step

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test response,[40] and combined with acceleration in a branched equation framework[42] for estimating activity intensity time-series data. This was summarized into PA energy expenditure (PAEE) and MVPA as intensity of 4 metabolic equivalents or more, while minimizing diurnal bias caused by any imbalance of wear or nonwear using the 2-sine regression method.[43] Data were split by weekend and weekday PA. Four PA variables were generated: weekend MVPA, weekday MVPA, weekend PAEE, and weekday PAEE. Each of the 4 PA variables was positively skewed and therefore split into tertiles.

Valid PA data were defined as 32 hours or more of data for weekdays and 16 hours or more for weekends. In addition, the day was divided into quadrants (3 AM to 9 AM, 9 AM to 3 PM, 3 PM to 9 PM, and 9 PM to 3 AM), and each quadrant was required to have 4 hours or more of valid activity data for the estimate to be included.

Psychological Outcomes

At baseline and follow-up, participants were asked to complete the 33-item MFQ,[44] a self-report measure of depressed mood during the prior 2 weeks, which has validity as a screen for adolescents with unipolar depression.[32] The MFQ includes symptoms such as low mood, loss of appetite, anhedonia, irritability, and restlessness (see http://devepi.duhs.duke.edu/mfq.htmlfor full details). Higher summed MFQ scores indicate increased risk for subsequent unipolar depression.[45-47] The internal consistency in this sample was high (Cronbach α = 0.96). Of the sample of 736 participants who provided PA data at baseline, 690 (93.8%) provided MFQ data at baseline and 614 (83.4%) at follow-up. At baseline and follow-up, all adolescents were assessed face-to-face for current episodes of major depressive disorder (MDD) using sections of the Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version, a clinical interview, to generate *Diagnostic and Statistical Manual of Mental Disorders* (Fourth Edition) Axis I diagnoses.[48] Interviews were conducted by fully trained research assistants, and diagnoses were reached at consensus meetings with senior staff, including adolescent psychiatrists. The Schedule for Affective Disorders and Schizophrenia for School-Age Children–Present and Lifetime Version data were available for 718 participants (97.6%) at baseline and 671 (91.2%) at follow-up.

Other Measurements

At baseline, height (Leicester height measures; Chasmors Ltd) and weight (TBF-300A body composition analyzer; Tanita) were measured. Body mass index was then calculated. The International Obesity Task Force body mass index cutoff points[49] were used to classify participants as normal weight and overweight or obese. Also at baseline, participants completed the Tanner Scale[50,51] and provided salivary samples (pubertal status was determined using previously published methods[52]). Information regarding participants' medication use was obtained from parents at baseline.

Statistical Analyses

Analyses were conducted in STATA statistical software, version 12.0 (Stata Corp). In all analyses, the PA variables were divided into tertiles. Sex, SES, medications, pubertal status, and weight class were included in separate models as covariates.

The main effects of PA and sex were tested in separate models to the interaction effects between PA and sex. To investigate the baseline effect of PA on depressive symptoms, we used 4 linear regression models (1 for each PA variable). Because the MFQ scores were not normally distributed, they were transformed using the square root function and were entered as the outcome variable and PA and sex as the predictors. To investigate the longitudinal effects, the analyses were then performed again, and the MFQ at baseline was replaced with an MFQ at follow-up. Baseline and follow-up analyses were performed again, and all covariates were included.

To investigate the baseline effect of PA on diagnoses of MDD at baseline, we used 4 binomial logistic regression analyses (separately for each of the PA variables). The outcome variable was entered as diagnosis (yes or high clinical index vs no), and the predictors were sex and PA. To investigate longitudinal effects, we performed the analyses again using MDD at follow-up instead of baseline. At baseline and follow-up, analyses were performed again, and all covariates were included.

Results

Descriptive Statistics

The MFQ data for both time points were transformed using the square root function to improve the alignment to a gaussian distribution (original MFQ values are reported in **Table 1**). Descriptive statistics are given in Table 1. Physical activity tertiles were as follows: weekend MVPA (<15.73, ≤15.73-42.05, and ≥42.06 min/d), weekday MVPA (<25.68, ≤25.68-72.79, and ≥72.80 min/d), weekend PAEE (<26.04, ≤26.04-41.91, and ≥41.92 kJ/kg daily), and weekday PAEE (<44.66, ≤44.66-69.75, and ≥69.76 kJ/kg daily). No significant effect of SES was found on any of the 4 PA measures (weekend MVPA, $P = .73$; weekday MVPA, $P = .46$; weekend PAEE, $P = .36$; and weekday PAEE, $P = .65$). The MFQ scores at baseline were higher in the moderate means and financially strained group compared with those who were financially comfortable ($z = 3.05$, $P = .002$) and compared with the wealthy ($z = 3.22$, $P = .001$) group; however, these did not differ from each other. The MFQ at follow-up did not differ by SES. On a weekend day, normal-weight adolescents took part in more MVPA compared with overweight and obese participants ($z = 2.04$, $P = .04$). This was also true for weekday MVPA ($z = 2.23$, $P = .03$). These differences were not present for weekend PAEE ($P = .16$), weekday PAEE ($P = .09$), or MFQ scores at baseline ($P = .08$) or follow-up ($P = .48$). Boys were more active than girls in all 4 PA measures: weekend MVPA ($z = -11.05$, $P < .01$), weekday MVPA ($z = -11.04$, $P < .01$), weekend PAEE ($z = -9.34$, $P < .01$), and weekday PAEE ($z = -9.92$, $P < .01$). At baseline, participants who were using medications had higher MFQ scores than those who were not ($t_{678} = 2.51$, $P = .01$). The MFQ scores at follow-up did not differ by medications ($P = .28$). Physical activity lev-

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Table 1. Characteristics of Patients by MFQ Scores at Baseline, MFQ Scores at Follow-up, and All Physical Activity Variables[a]

Characteristic	MFQ Score		Weekend MVPA		Weekday MVPA		PAEE, kJ/kg Daily		MDD, %	
	Baseline (n = 690)	Follow-up (n = 614)	MVPA, min/d (n = 736)	MVPA ≥60 min/d, % (n = 736)	MVPA, min/d (n = 736)	MVPA ≥60 min/d, % (n = 736)	Weekend (n = 736)	Weekday (n = 736)	Baseline (n = 718)	Follow-up (n = 671)
Overall	14.55 (9.78)	13.72 (10.58)	31.69 (21.60)	9.92 (73)	53.43 (36.64)	33.70 (248)	35.10 (12.72)	58.82 (20.57)	2.37 (17)	4.17 (28)
Sex										
Male	12.30 (8.13)	10.96 (8.94)	41.33 (23.40)	17.30 (55)	69.46 (38.88)	54.09 (172)	40.02 (13.47)	66.92 (21.16)	1.29 (4)	2.80 (8)
Female	16.27 (10.55)	15.75 (11.23)	24.36 (16.78)	4.30 (18)	41.23 (29.53)	18.18 (76)	31.37 (10.72)	52.66 (17.81)	3.18 (13)	5.18 (20)
Socioeconomic status										
Moderate and financially strained	17.55 (11.00)	16.37 (11.22)	31.94 (22.08)	10.91 (12)	57.36 (38.70)	39.09 (43)	33.51 (13.34)	59.65 (21.42)	4.59 (5)	4.08 (4)
Financially comfortable	13.80 (9.22)	13.65 (10.83)	30.67 (19.08)	10.32 (16)	52.44 (33.92)	35.09 (60)	34.90 (11.07)	59.72 (19.32)	2.92 (5)	4.94 (8)
Wealthy	14.13 (9.57)	13.12 (10.26)	32.07 (22.57)	10.05 (44)	52.79 (37.41)	31.28 (137)	35.60 (13.31)	58.24 (21.05)	1.60 (7)	3.89 (16)
Weight group										
Normal	14.23 (9.51)	13.35 (10.30)	32.27 (21.65)	9.09 (11)	54.64 (37.07)	35.45 (217)	35.32 (12.68)	59.34 (20.72)	2.51 (15)	3.74 (21)
Overweight or obese	16.17 (10.91)	15.65 (11.81)	28.75 (21.23)	10.08 (62)	47.27 (33.86)	25.62 (31)	34.06 (12.92)	56.18 (19.65)	1.65 (2)	6.36 (7)
Medications										
No	14.07 (9.51)	13.38 (10.27)	31.99 (21.11)	9.95 (59)	54.04 (36.15)	34.90 (207)	35.26 (12.60)	59.19 (26.61)	2.03 (12)	3.71 (21)
Yes	16.58 (10.72)	15.07 (11.61)	30.70 (24.66)	10.43 (12)	50.69 (39.74)	26.96 (31)	34.60 (14.08)	57.13 (21.41)	4.35 (5)	5.66 (6)
Pubertal status										
Prepubertal	13.52 (8.94)	9.03 (7.89)	43.18 (23.90)	23.08 (15)	71.79 (38.24)	58.46 (38)	40.58 (14.49)	67.29 (21.16)	1.54 (1)	4.53 (27)
Pubertal	14.81 (9.91)	14.27 (10.60)	30.31 (21.00)	8.45 (54)	51.11 (35.65)	30.67 (196)	34.32 (12.35)	57.60 (20.25)	2.31 (16)	1.67 (1)

Abbreviations: MDD, major depressive disorder: MFQ, Mood and Feelings Questionnaire; MVPA, moderate and vigorous physical activity; PAEE, physical activity energy expenditure.

[a] Values reported are mean (SD) except for MDD at baseline and MDD at follow-up, which are reported as the percentage of participants diagnosed as having MDD (actual MDD values). In the Weekend MVPA ≥60 min/d and Weekday MVPA ≥60 min/d columns, values are reported as percentage of patients who accumulated at least 60 min/d of MVPA (actual MPVA numbers). The MFQ scores are original untransformed values.

els were higher for prepubertal than pubertal adolescents in all 4 domains: weekend MPVA ($z = 4.58$, $P < .001$), weekday MVPA ($z = 4.57$, $P < .001$), weekend PAEE ($z = 4.57$, $P < .001$), and weekday PAEE ($z = 3.79$, $P < .001$). The MFQ score at follow-up was higher in pubertal compared with prepubertal participants ($t_{599} = 4.14$, $P < .001$); however, there was no difference in MFQ scores at baseline ($P = .30$), MDD at baseline ($P = .91$), or MDD at follow-up ($P = .56$). More boys accumulated 60 minutes or more of MVPA on weekend days ($z = 34.11$, $P < .001$) and on weekdays ($z = 104.22$, $P < .001$) compared with girls. The percentage of participants who met the 60-minute guidelines on a weekend day did not differ based on SES ($P = .91$), weight group ($P = .74$), or medications ($P = .87$). For weekdays, a higher percentage of normal-weight participants met the guidelines compared with the overweight or obese group ($z = 4.23$, $P = .04$), but no differences were found in SES ($P = .26$) and medication use ($P = .10$). For weekend ($z = 14.28$, $P < .001$) and weekday MVPA ($z = 20.53$, $P < .001$), a higher percentage of prepubertal adolescents met the MVPA guidelines. No significant differences were found between the participants who provided valid PA data and those who did not in terms of MFQ score at baseline ($P = .43$), MFQ score at follow-up ($P = .39$), sex ($P = .76$), weight group ($P = .52$), medications ($P = .55$), pubertal status ($P = .39$), and SES ($P = .30$).

Participants undertook more MVPA ($z = 23.40$, $P < .01$) and PAEE ($z = 23.40$, $P < .01$) on weekdays than they did on weekend days. The MVPA and PAEE were highly correlated for weekend ($r = 0.87$, $P < .01$) and weekdays ($r = 0.88$, $P < .01$). Therefore, those participants who engaged in more MVPA were more physically active overall. In line with previous work,[53] girls had higher MFQ scores than boys at baseline ($t_{688} = 5.17$, $P < .01$) and follow-up ($t_{612} = 5.97$, $P < .01$). There was also a significant overall correlation between MFQ scores at baseline and follow-up ($r = 0.51$, $P < .01$).

PA and Depressive Symptoms

For baseline and longitudinal analyses, no main effects of PA variables and no interactions between sex and PA were observed. These findings are given in **Table 2**.

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Table 2. Linear Regression Models for Baseline and Longitudinal Analyses of MFQ Scores[a]

Linear Regression Model	Unstandardized β (95% CI)	*P* Value
Baseline (No Covariates)		
MVPA		
Weekend	−0.05 (−0.20 to 0.10)	.51
Weekday	−0.02 (−0.16 to 0.13)	.83
PAEE		
Weekend	−0.08 (−0.22 to 0.06)	.24
Weekday	−0.05 (−0.19 to 0.09)	.50
MVPA × sex interaction		
Weekend	0.08 (−0.21 to 0.38)	.58
Weekday	−0.03 (−0.33 to 0.26)	.81
PAEE × sex interaction		
Weekend	−0.19 (−0.47 to 0.10)	.20
Weekday	0.02 (−0.26 to 0.31)	.87
Baseline (Weight Group, Pubertal Status, Socioeconomic Status, Sex, and Medications as Covariates)		
MVPA		
Weekend	−0.03 (−0.18 to 0.11)	.65
Weekday	−0.04 (−0.18 to 0.11)	.63
PAEE		
Weekend	−0.04 (−0.18 to 0.10)	.58
Weekday	−0.05 (−0.20 to 0.09)	.49
MVPA × sex interaction		
Weekend	0.08 (−0.22 to 0.38)	.61
Weekday	−0.12 (−0.42 to 0.18)	.42
PAEE × sex interaction		
Weekend	−0.17 (−0.47 to 0.12)	.24
Weekday	−0.01 (−0.30 to 0.28)	.96
Longitudinal (No Covariates)		
MVPA		
Weekend	0.02 (−0.15 to 0.20)	.79
Weekday	0.00 (−0.17 to 0.17)	.99
PAEE		
Weekend	0.03 (−0.14 to 0.20)	.75
Weekday	−0.03 (−0.20 to 0.14)	.71
MVPA × sex interaction		
Weekend	−0.24 (−0.59 to 0.11)	.18
Weekday	−0.23 (−0.58 to 0.12)	.19
PAEE × sex interaction		
Weekend	−0.11 (−0.45 to 0.23)	.52
Weekday	0.08 (−0.27 to 0.42)	.67
Longitudinal (MFQ at Baseline, Weight Group, Pubertal Status, Socioeconomic Status, Sex, and Medications as Covariates)		
MVPA		
Weekend	0.06 (−0.09 to 0.21)	.45
Weekday	0.00 (0.00 to 0.00)	.91
PAEE		
Weekend	0.08 (−0.07 to 0.23)	.29
Weekday	−0.01 (−0.15 to 0.14)	.95
MVPA × sex interaction		
Weekend	−0.21 (−0.51 to 0.10)	.19
Weekday	0.00 (−0.01 to 0.01)	.88
PAEE × sex interaction		
Weekend	0.02 (−0.28 to 0.32)	.89
Weekday	0.05 (−0.26 to 0.35)	.77

Abbreviations: MFQ, Mood and Feelings Questionnaire; MVPA, moderate and vigorous physical activity; PAEE, physical activity energy expenditure.

[a] Physical activity variables are tertiles as discussed in the Descriptive Statistics subsection in the Results section. The square root transformed MFQ score was used in the models reported here.

PA and MDD

No significant main effects of PA or interactions between sex and PA in the baseline or the longitudinal analyses of MDD were found (**Table 3**).

Discussion

Summary of Main Findings

In this longitudinal study of adolescents, we found that individual differences in objectively measured PA in early adolescence did not predict depressive symptoms or diagnoses of MDD in later adolescence. These findings are concurrent with previous longitudinal studies[15-18] using self-report measures of PA. We are only aware of 4 research studies[19-22] that found an effect of PA on depressive symptoms during adolescence in a longitudinal design, all of which used a self-report method of assessing PA. We believe that these results may have been driven by measurement error in the self-report measure of PA because of potential overreporting of PA,[33] smaller sample sizes,[20,21] samples limited to females,[20,21] and short (approximately 1 year) follow-up duration.[22] There may also be sample-specific variation due to other factors not included here. A review[54] of longitudinal studies concluded that PA reduced the risk of developing depression; however, this review focused on all age groups rather than just adolescence. Our findings do not eliminate the possibility that PA positively affects depressed mood in the general population; rather, we suggest that this effect may be small or nonexistent during the period of adolescence.

Strengths, Limitations, and Future Directions

A major strength of the research reported here is the use of a reliable, objective measure of PA used in the form of individually calibrated combined heart rate and movement information. The research design was strengthened further with the longitudinal aspect, which allowed us to examine the prognostic role of PA in determining depressive outcomes. We also included MDD diagnoses in the analyses, which strengthened the design further because, although self-report measures of depressive symptoms are widely used, interviews are arguably more rigorous. With the use of a diagnostic interview, this potential bias, which may have been increased by self-report, is reduced. Although the design

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Table 3. Binomial Logistic Regression Models for Baseline and Longitudinal Analyses of MDD Diagnosis[a]

Binomial Logistic Regression Model	Odds Ratios (95% CI)	*P* Value
Baseline (No Covariates)		
MVPA		
Weekend	1.15 (0.54-2.45)	.71
Weekday	1.34 (0.62-2.71)	.49
PAEE		
Weekend	1.25 (0.61-2.59)	.54
Weekday	0.96 (0.46-1.98)	.91
MVPA × sex interaction		
Weekend	0.33 (0.06-1.73)	.19
Weekday	0.31 (0.06-1.64)	.17
PAEE × sex interaction		
Weekend	0.74 (0.14-3.92)	.73
Weekday	0.50 (0.10-2.57)	.40
Baseline (Weight Group, Pubertal Status, Socioeconomic Status, and Medications as Covariates)		
MVPA		
Weekend	1.24 (0.57-2.68)	.58
Weekday	1.33 (0.62-2.83)	.47
PAEE		
Weekend	1.34 (0.65-2.78)	.43
Weekday	0.97 (0.12-1.47)	.17
MVPA × sex interaction		
Weekend	0.31 (0.06-1.67)	.17
Weekday	0.24 (0.04-1.39)	.11
PAEE × sex interaction		
Weekend	0.71 (0.13-3.98)	.70
Weekday	0.47 (0.09-2.40)	.36
Longitudinal (No Covariates)		
MVPA		
Weekend	1.37 (0.76-2.48)	.30
Weekday	1.33 (0.74-2.37)	.34
PAEE		
Weekend	1.19 (0.67-2.10)	.56
Weekday	0.92 (0.52-1.63)	.78
MVPA × sex interaction		
Weekend	0.78 (0.22-2.82)	.71
Weekday	0.92 (0.25-3.40)	.91
PAEE × sex interaction		
Weekend	1.20 (0.33-4.28)	.78
Weekday	1.63 (0.45-5.94)	.46
Longitudinal (MDD at Baseline, Weight Group, Pubertal Status, Socioeconomic Status, and Medications as Covariates)		
MVPA		
Weekend	1.37 (0.74-2.54)	.32
Weekday	1.09 (0.28-4.27)	.90
PAEE		
Weekend	1.19 (0.62-2.16)	.58
Weekday	1.01 (0.56-1.83)	.97
MVPA × sex interaction		
Weekend	0.94 (0.25-2.50)	.92
Weekday	1.32 (0.71-2.43)	.38
PAEE × sex interaction		
Weekend	1.39 (0.38-5.17)	.62
Weekday	1.63 (0.43-6.19)	.71

Abbreviations: MDD, major depressive disorder; MVPA, moderate and vigorous physical activity; PAEE, physical activity energy expenditure.

[a] Physical activity variables are tertiles as discussed in the Descriptive Statistics subsection of the Results section.

and data collection methods are strengths of the work reported here, there are also limitations that should be considered. The baseline MFQ and PA data were collected approximately 6 months apart. Although we have treated these as cross-sectional, the findings should be interpreted with this in mind. Furthermore, the timing of follow-up was valid because the participants had entered the risk period for developing depression; however, we only identified 17 cases of MDD at baseline and 28 at follow-up, which could have contributed to the absence of an effect. In addition, because data on follow-up depressive measures were collected approximately 30 months after baseline PA, it was not possible to investigate the short-term effects of exercise. Physical activity measures were not repeated at follow-up; therefore we cannot eliminate the possibility that an effect may have been obscured because of a change in the level of PA between baseline and follow-up.

In addition, some literature differentiates between types and context of PA (eg, lone and group PA).[19,55] It may be that team PA provides social support that may be lacking in those with depressed mood. We did not collect data on the context of PA so we were unable to investigate this theory. We did, however, differentiate between weekend and weekday PA. Adolescents who took part in our study were still in compulsory education and so were required to take part in physical education at school; weekend PA was assumed to be a more accurate representation of their voluntary PA levels. Although weekend and weekday PA differed, they did not have a differential effect on depressive symptoms. Finally, the males who responded to the invitation to take part in the PA study had a lower MFQ score compared with those who did not take part. It is not possible to rule this out as a reason why a significant effect was not found. This finding has wider implications in PA research with reference to the profile of participants who volunteer their time.

Our findings carry important public policy implications because they help to clarify the effect of PA on depressive symptoms in the general population. Although PA has numerous benefits to physical health in later life, such positive effects may not be expected on depressive outcomes during adolescence. These findings would be valuable in future meta-analyses of such effects. Well-designed randomized clinical trials should be commissioned to investigate the short- and long-term effects of PA on depressive symptoms. This will allow an accu-

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rate measurement of the short- and long-term treatment effects of PA in depressive symptoms.

Conclusions

In this sample of adolescents, no association was found between the levels of PA at 14 years of age and depressive outcomes at 17 years of age. That is, those participants who were more physically active in early adolescence did not subsequently have significantly lower (or higher) depressive symptoms or significantly altered odds of depressive disorders in later adolescence. Although it is important to promote PA because of its well-documented effect on physical health, during adolescence, PA may not serve as a strong protective factor of developing depressive symptoms or disorders.

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Study concept and design: Brage, Corder, Dunn, Jones, Owens, Goodyer.
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