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Original article

Sedentary behavior and physical activity predicting depressive symptoms in adolescents beyond attributes of health-related physical fitness

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Abstract

Background: Sedentary behavior (SB), physical activity (PA), and attributes of physical fitness have been shown to be related to depressive symptoms in adolescents. The purpose of the present study was to investigate whether SB and fitness-producing activity predicted depression in active adolescents over and above gender and fitness attributes.
Methods: Participants were 249 adolescents (age: 12.85 ± 0.89 years, mean $\pm$ SD) from 3 public middle schools who wore Actical accelerometers to assess their SB and PA. Participants also completed the FITNESSGRAM health-related fitness assessment and a brief depression questionnaire. A 3-step hierarchical regression analysis was conducted with gender and fitness attributes (i.e., body mass index (BMI), maximal volume oxygen uptake (VO_{2max}), curlups, and pushups), moderate- and vigorous-intensity activity, and SB entered in respective steps.
Results: Regression analysis indicated activity variables (i.e., moderate- and vigorous-intensity activity) significantly predicted depression ($\Delta R^2 = 0.12$, $p < 0.01$) beyond gender and fitness attributes. Overall, gender, fitness attributes, activity variables, SB explained 31% of the variance in depression. Structure coefficients revealed VO_{2max} ($r_s = -0.77$), moderate-intensity activity ($r_s = -0.67$), vigorous-intensity activity ($r_s = -0.81$), and SB ($r_s = 0.57$) were substantially correlated with the criterion variable; thus, they were the strongest predictors of depression.
Conclusion: The findings of the current study indicated SB and PA were both significant predictors of depression; however, sufficient fitness-producing activity and adequate cardiorespiratory fitness may nullify the negative influence of SB on depressive symptoms in active adolescents.
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Keywords: Accelerometers; Adolescent health; Cardiorespiratory fitness; FITNESSGRAM; Mental health; Moderate-to-vigorous-intensity activity

1. Introduction

The relations between physical activity (PA) and attributes of health-related physical fitness (HRF) are well-established. HRF is often inferred from PA in health research.[1] Though they are often used interchangeably in large studies,[2] PA is bodily movement produced by the skeletal muscles that results in substantial increases in energy expenditure. Thus, PA is a process, while HRF is a set of attributes (i.e., body composition, cardiorespiratory fitness, muscular strength and endurance, and flexibility), which are mainly, although not entirely, determined by or the product of effective PA.[3,4] Literature also indicates PA and HRF may individually impact health outcomes such as depressive symptoms.[2,5–7] For instance, Dunn et al.[5] found greater amounts of PA were associated with reduced depressive symptoms, and Ruggero et al.[7] found higher levels of cardiorespiratory fitness were associated with a reduced chance of developing depression. Given that recent research reveals approximately 11% of youth will experience depression[8] and that depressive episodes during adolescence are highly associated with negative consequences throughout life,[9,10] adolescent depression has become a major public health concern. Though research indicates both PA and HRF are strong predictors of health outcomes, it is not clear whether profiles of PA, the process, or attributes HRF, the product, are more highly related to health outcomes such as depression.[3]

While it is generally accepted that any amount of PA is considered health beneficial, the extent to which it benefits health can greatly vary depending on the type, intensity, and amount of PA.[6] Hagströmer[11] claimed for PA to positively affect HRF, thereby health, it should be moderate- or vigorous-intensity. Thus, moderate-to-vigorous-intensity PA (MVPA) is often referred to as fitness-producing activity. The 2008 Physical Activity Guidelines for Americans were established in light of the vast amount of evidence relating fitness-producing activity

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and HRF to rising health concerns, such as obesity and depression in youth.[4,6] While HRF is often inferred with PA, research suggests the impact of each on health outcomes may entail independent and supplementary effects.[3,12] Lindwall et al.[12] suggested the act of engaging in PA may have stronger relations with mental health than cardiorespiratory fitness, whereas Blair et al.[3] claimed it is not clear whether being physically active yields additional benefits beyond achieved HRF.

Over the past few decades sedentary behavior (SB) has become a critical concern.[1] Activity trend research indicates PA is declining, whereas SB is rising, especially among adolescents.[13,14] Though PA and SB superficially appear to be inversely related, research indicates SB may not significantly displace fitness-producing activity.[15] Research has also revealed fitness-producing activity and SB are independently associated with HRF,[16] and SB may not significantly vary between those meeting and not meeting PA guidelines.[17] In addition, Liu et al.[18] found excessive SB was associated with an increased risk of depression, and limited SB was associated with a decreased risk of depression in children and adolescents.

Given that, research has directly and indirectly linked current negative health trends (e.g., obesity and depression) with increased sedentariness and decreased PA and HRF,[19] which gives a better understanding of how SB affects the efficacy of fitness-producing activity and attributes of HRF to reverse these trends.[20] As such, research has found that adequate levels of fitness-producing activity might effectively buffer the negative influence of SB on certain attributes of HRF,[21] and a higher HRF might effectively buffer the negative influence of SB on health outcomes such as obesity and depression.[7] However, it has not been established whether or not SB can nullify the collective efficacy of fitness-producing activity and HRF on depression in youth.[20,22] In fact, Liu et al.[18] found most studies examining the relationship between SB and depression did not adjust for PA, let alone measure HRF. In addition, though Asare and Danquah[23] found a significant negative relationship between PA and depression independent of SB in adolescents, they again did not assess HRF. Further, Esmaeilzadeh[24] found lower depressive symptoms were associated with increased levels of fitness-producing activity and cardiorespiratory fitness in children and early adolescents, but they did not assess SB. Collectively, these findings suggest SB might independently predict depressive symptoms in adolescents.

However, as previously mentioned, it is not known whether SB affects health outcomes such as depression beyond the influences related to being physically active and achieved HRF, signifying a gap in the literature regarding the collective influence of PA, HRF, and SB on depression. Thus, the purpose of the present study was to examine the relations among activity behaviors (i.e., SB and light-, moderate-, and vigorous-intensity activity), HRF attributes, and depression in adolescents, and then to determine the predictive strengths of activity behaviors and HRF attributes on depression. Specifically, the aim of this study was to investigate whether SB and fitness-producing activity predicted depression in adolescents beyond gender and attributes of HRF. Gender was included in this investigation due to previous research indicating significant gender differences in SB, PA, HRF, and depression in adolescents.[7,22,25] In addition, given the questionable objectivity of self-reported activity and HRF measures,[26] this study used objective measures to assess activity and HRF components.

Based on the literature, it was first hypothesized SB would be negatively related to light-, moderate-, and vigorous-intensity activity in adolescents with the strongest relationship existing between SB and light-intensity activity. Second, it was hypothesized SB would be positively related to body composition and depression, and negatively related to cardiorespiratory fitness. Lastly, it was hypothesized SB and fitness-producing activity would explain additional variance in depression beyond gender and HRF attributes.

2. Methods

2.1. Participants

Participants were 249 adolescents (54% female) who were aged 12.85 ± 0.89 years and enrolled in physical education, sampled from 3 public middle schools from a metropolitan county in North Texas. Participants' respective schools provided demographic information including age, gender, ethnicity, and grade. Participants were predominately Caucasian (64.9%) or Hispanic (14.6%). Approximately half were in the sixth grade (50.2%), one-third in the seventh grade (29.4%), and one-fifth in the eighth grade (20.4%).

2.2. Measures

2.2.1. SB and PA

Wrist-mounted Actical accelerometers (Koninklijke Philips Electronics N.V., Amsterdam, The Netherlands) were used to objectively assess SB and PA. These units have been found to be a reliable and valid measure of SB and PA in adolescents.[27] Participants were instructed to wear units for 5 consecutive days and to press the marker button to signify the start and end of sleep time or unavoidable non-wear time (e.g., water-based activities). Accelerometers were prepared with 1 min epochs and with participants' age, gender, height, and weight uploaded. SB was defined as activity energy expenditure (AEE) < 0.01 kcal/kg/min, light-intensity activity as $0.01 \leq \text{AEE} < 0.04$ kcal/kg/min; moderate-intensity activity as $0.04 \leq \text{AEE} < 0.10$ kcal/kg/min; and vigorous-intensity activity as $\text{AEE} \geq 0.10$ kcal/kg/min.[28] Accelerometer data were examined using Actical software (Koninklijke Philips Electronics N.V.) so that daily custom intervals (i.e., waking time minus the marked time) could be created before being imported to the data management software. Data for each participant was then examined to ensure wear-time included a minimum of 4 valid week days with a minimum of 13 h per valid day.[29,30]

2.2.2. HRF

FITNESSGRAM test items were used to assess HRF attributes.[31] Specifically, body composition was assessed by participants' body mass index (BMI) computed by the measured height and weight using Health-o-meter 500KL digital physician height and weight scale. Cardiorespiratory fitness was assessed by an estimate of maximal oxygen uptake (VO_{2max}) derived from performance on the progressive aerobic cardiovascular endurance run.[32] Abdominal strength and endurance were assessed by performance on the 4.5-inch curlups test. Upper body strength and endurance were assessed by performance on the 90° pushups test, and flexibility was assessed by the average performance between left and right leg on the back-saver sit-reach test.[31]

2.2.3. Depression

Depression was assessed using the 20-item Center for Epidemiologic Studies Depression Scale for Children (CES-DC).[33] Participants were asked to indicate the way they might have felt or acted during the past week, on a 4-point scale ranging from *not at all* (0) to *a lot* (3). Though the total scale can range from 0 to 60, developers of the CES-DC indicate scores at or above 15 are suggestive of depression. However, in the current study depression was primarily analyzed as a continuous variable. The CES-DC has demonstrated good reliability and validity among adolescents.[7,33] In the present study, scores for the CES-DC items had good internal consistency ($\alpha = 0.89$).

2.3. Procedure

A cross-sectional research design was used, and data were collected in fall 2015. In accordance with school district's physical education curriculum, FITNESSGRAM testing was conducted at each middle school. All HRF data were collected during the regular physical education class time, and collection was completed within 1 week per school. In an effort to confirm accurate FITNESSGRAM administration, HRF testing for the 3 schools were scheduled in sequential weeks so that researchers and their trained assistants could support the physical education instructors for the entire data collection process. After HRF data collection were completed, researchers returned to each school to distribute accelerometers and administer a brief survey containing the CES-DC. Accelerometers were worn on the non-dominate wrist using a Velcro wrist strap (Respironics Inc., Murrysville, PA, USA) according to manufacturer's instructions.[34] Researchers demonstrated proper unit wear and gave physical education instructors take-home instruction sheets that reiterated proper wear and marker button use and included researchers' contact information if questions arose regarding the units. Lastly, participants were explicitly instructed to continue their normal daily activity routine. Approval for this study was given by the University of North Texas Institutional Review Board and the schools' district administrative offices, principals, and physical education instructors. Parents or guardians signed informed consent and students signed child assent forms.

2.4. Data analyses

Statistical analyses were conducted using SPSS Version 22.0 (IBM Corp., Armonk, NY, USA) for Windows or Apple Mac, and statistical significance was set at $\alpha < 0.05$. G*Power Version 3.1.9.2[35] (Heinrich-Heine-Universität, Düsseldorf, Germany) was used to perform a *post hoc* power analysis. Given the inclusion criteria (i.e., adequate wear-time), data were first analyzed for insufficient values. Participants whose accelerometer wear-time did meet minimum days or hours were excluded from analyses. Attrition analysis revealed mean HRF and depression scores for those excluded ($n = 38$) were not significantly different than those included ($n = 211$). Missing values and distributions were explored using expectation-maximization and Shapiro-Wilks W tests. Missing data analysis revealed less than 0.01% of data were missing. A non-significant Little's MCAR test, $\chi^2(7) = 3.230$, $p = 0.86$, revealed data were missing at random; therefore, missing data were imputed using expectation-maximization in SPSS.[36] Box-Cox transformation was performed to correct skewness of depression variable.[37] Descriptive statistics were computed, and independent-samples t tests and χ^2 tests were conducted to determine mean differences and associations between variables. Correlation analyses were conducted to examine the relationships among activity and HRF variables, as well as depression scores. Lastly, a 3-step hierarchical regression analysis was conducted to investigate the ability of SB (i.e., Step 3) and PA (i.e., Step 2) in predicting depression in adolescents after accounting for HRF attributes and gender (i.e., Step 1).

3. Results

Participants' average accelerometer wear-time was 4.80 ± 0.48 days, with an average of 14.95 ± 1.36 h or 896.82 ± 81.69 min/day, 38 participants were excluded from data analyses due to inadequate amounts of accelerometer wear-time. Accelerometer data revealed participants spent, on average, 26.3% of their waking-time in sedentary, 54.8% in light-intensity activity, 17.0% in moderate-intensity activity, and 2.0% in vigorous-intensity activity. Activity data also indicated only 2 participants did not meet minimal recommendations for aerobic activity (i.e., ≥ 60 min/day).[4] Descriptive statistics for HRF variables revealed mean performances for both genders in all HRF components were considered in the healthy fitness zone (HFZ).[31] Collectively, the PA and HRF data revealed participants were, on average, sufficiently active and fit. The untransformed mean composite score for the CES-DC was 13.30 ± 9.81, and approximately 32% of the participants had scores at or above 15. Independent-samples t tests indicated participants with CES-DC scores at or above 15 were statistically, on average, more sedentary; engaged in less fitness-producing activity; had a higher BMI and lower VO_{2max}; and did fewer curlups and pushups (Table 1). χ^2 tests revealed significant associations between HRF performance scores, HFZ status, and whether or not CES-DC scores were less than 15 (Table 2). Based on the odds ratios, the odds of participants having depression scores less than 15 were 2.31, 3.66, 3.16, and 2.43 times higher, respectively, if they had a BMI, VO_{2max}, curlups, and pushups performance score classified as HFZ.[37]

3.1. Correlation analysis

A correlation matrix including means and standard deviations is presented in Table 3. Analyses revealed the strongest bivariate relationship between activity variables was SB with moderate-intensity activity ($r = -0.72$, $p < 0.01$). Strongest bivariate

Table 1
Summary of the independent-samples *t* tests.

	No ($n = 144$)[a]		Yes ($n = 67$)[b]		*t*	*df*
	Mean	SD	Mean	SD		
SB (min)	213.93	84.41	282.41	100.62	−4.84**	110.82
Moderate-intensity (min)	166.08	50.91	120.71	43.57	6.30**	209
Vigorous-intensity (min)	22.79	16.47	8.40	5.98	9.26**	200.66
BMI (kg/m^2)	19.82	3.18	21.65	4.38	3.07**	99.49
VO_{2max} (mL/kg/min)	47.31	6.02	42.42	6.10	5.47**	209
Curlups (reps)	40.69	19.12	33.45	21.49	2.46*	209
Pushups (reps)	18.24	9.22	13.91	5.95	4.09**	187.68

* $p < 0.05$; ** $p < 0.01$.
[a] CES-DC scores < 15. [b] CES-DC scores ≥ 15.
Abbreviations: BMI = body mass index; CES-DC = Center for Epidemiologic Studies Depression Scale for Children; SB = sedentary behavior; VO_{2max} = maximal volume oxygen uptake.

Table 2
Summary of the independent-samples χ^2 tests (n(%)).

	No ($n = 144$)[a]	Yes ($n = 67$)[b]	χ^2	*df*
BMI (kg/m^2)			6.92**	1
NIZ	31(21.5)	26(38.8)		
HFZ	113(78.5)	41(61.2)		
VO_{2max} (mL/kg/min)			13.92**	1
NIZ	18(12.5)	23(34.3)		
HFZ	126(87.5)	44(65.7)		
Curlups (reps)			8.94**	1
NIZ	14(9.7)	17(25.4)		
HFZ	130(90.3)	50(74.6)		
Pushups (reps)			4.56*	1
NIZ	13(9.0)	13(19.4)		
HFZ	131(91.0)	54(80.6)		

* $p < 0.05$; ** $p < 0.01$.
[a] CES-DC scores < 15. [b] CES-DC scores ≥ 15.
Abbreviations: BMI = body mass index; CES-DC = Center for Epidemiologic Studies Depression Scale for Children; HFZ = healthy fitness zone; NIZ = needs improvement zone; VO_{2max} = maximal volume oxygen uptake.

relationship between HRF variables was VO_{2max} with BMI ($r = -0.65$, $p < 0.01$). All predictor variables except light-intensity activity and sit-reach correlated significantly with depression. Thus, for parsimony, light-intensity activity and sit-reach were excluded from the hierarchical regression analysis.

3.2. Hierarchical regression analyses

Table 4 presents a summary of the 3-step hierarchical regression analyses including structure coefficients. Results of Step 1 were statistically significant, $R^2 = 0.19$, $F(5, 205) = 9.36$, $p < 0.01$; $\Delta R^2 = 0.19$, $p < 0.01$; which indicated gender (0 for girls and 1 for boys) and HRF attributes accounted for approximately 18.6% of the variance in depression. However, due to multicollinearity among the HRF variables, only the regression coefficient for VO_{2max} ($\beta = -0.36$, $p < 0.01$) was statistically significant, confirming the correlative findings in Table 3.[38] Step 2 was also statistically significant, $R^2 = 0.30$, $F(7, 203) = 12.60$, $p < 0.01$; $\Delta R^2 = 0.12$, $p < 0.01$; which meant adding fitness-producing activity to the model further increased the variance explained in depression beyond gender and HRF attributes by 11.7%. Regression coefficients revealed both moderate-intensity activity ($\beta = -0.23$, $p < 0.01$) and vigorous-intensity activity ($\beta = -0.22$, $p < 0.01$) were statistically significant. In addition, the regression coefficient for VO_{2max} ($\beta = -0.27$, $p = 0.04$) remained statistically significant in Step 2. The f^2 reported by Cohen et al.,[37] which measured the effect size of adding fitness-producing activity, was 0.17. *Post hoc* power estimation yielded ($1 - \beta = 0.99$).[35] Lastly, Step 3 indicated the full model was statistically significant, $R^2 = 0.31$, $F(8, 202) = 11.50$, $p < 0.01$, which indicated gender, HRF, fitness-producing activity, and SB accounted for 31.3% of the variance in depression. However, the change in variance explained by adding SB was not statistically significant ($\Delta R^2 = 0.01$, $p = 0.09$, Cohen's $f^2 = 0.015$, ($1 - \beta = 0.41$). On the other hand, the regression coefficients for VO_{2max} ($\beta = -0.28$, $p = 0.03$) and vigorous-intensity activity ($\beta = -0.20$, $p = 0.01$) remained statistically significant in Step 3. Conversely, due to multicollinearity, the regression

Table 3
Correlation matrix including means ± SD for activity, fitness, and depression[a] variables.

Variables	SB	Light	Moderate	Vigorous	BMI	VO_{2max}	Curlups	Pushups	Sit-reach	Depression
SB	–									
Light	−0.62**	–								
Moderate	−0.72**	0.34**	–							
Vigorous	−0.36**	−0.05	0.45**	–						
BMI	0.08	0.13	−0.16*	−0.26**	–					
VO_{2max}	−0.04	−0.24**	0.19**	0.51**	−0.65**	–				
Curlups	−0.06	−0.00	0.14*	0.19**	−0.14*	0.34**	–			
Pushups	0.04	−0.17*	0.06	0.23**	−0.25**	0.49**	0.49**	–		
Sit-reach	0.01	0.07	−0.04	−0.14*	0.11	−0.16*	0.02	−0.06	–	
Depression	0.32**	0.04	−0.37**	−0.45**	0.29**	−0.43**	−0.15*	−0.24**	0.02	–
Gender[b]	0.00	−0.24**	0.12	0.44**	−0.06	0.57**	0.09	0.18**	−0.35**	−0.25**
Mean	235.67	491.30	151.67	18.22	20.40	45.76	38.39	16.86	12.59	13.30
SD	95.16	104.31	53.00	15.52	3.69	6.45	20.14	8.55	3.05	9.81

* $p < 0.05$; ** $p < 0.01$.
[a] Outcome variable, depression, was box-cox transformed for the analysis. Depression′ (M = 4.82, SD = 9.81). [b] Gender = 0 for girls and 1 for boys.
Abbreviations: BMI = body mass index; Depression = Center for Epidemiologic Studies Depression Scale for Children depression score; SB = sedentary behavior; Sit-reach = back saver sit and reach flexibility score; VO_{2max} = maximal volume oxygen uptake.

Table 4
Summary of the 3-step hierarchical regression analysis predicting depression.[#]

	B	SE	β	p	R^2	ΔR^2	r_s
Step 1					0.19**	0.19**	
(Constant)	11.14	3.33					
Gender[†]	−0.19	0.47	−0.04	0.69			
BMI	0.03	0.07	0.04	0.67			
VO_{2max}	−0.15	0.05	−0.36	<0.01**			
Curlups	0.00	0.01	0.01	0.93			
Pushups	−0.02	0.02	−0.05	0.53			
Step 2					0.30**	0.12**	
(Constant)	11.95	3.17					
Gender[†]	0.17	0.45	0.03	0.70			
BMI	0.01	0.06	0.01	0.88			
VO_{2max}	−0.11	0.05	−0.27	0.04*			
Curlups	0.01	0.01	0.05	0.48			
Pushups	−0.02	0.02	−0.07	0.35			
Moderate-intensity	−0.01	0.00	−0.23	<0.01**			
Vigorous-intensity	−0.04	0.01	−0.22	<0.01**			
Step 3					0.31**	0.01	
(Constant)	10.54	3.26					
Gender[†]	0.10	0.45	0.02	0.82			−0.45**
BMI	0.01	0.06	0.01	0.90			0.52**
VO_{2max}	−0.11	0.05	−0.28	0.03*			−0.77**
Curlups	0.01	0.01	0.05	0.48			−0.27**
Pushups	−0.02	0.02	−0.08	0.29			−0.43**
Moderate-intensity	−0.01	0.00	−0.13	0.15			−0.67**
Vigorous-intensity	−0.03	0.01	−0.20	0.01**			−0.81**
SB	0.00	0.00	0.15	0.09			0.57**

* $p < 0.05$; ** $p < 0.01$.
[#] Outcome variable, depression, was box-cox transformed for this analysis.
[†] Gender = 0 for girls and 1 for boys.
Abbreviations: B = unstandardized regression coefficients; BMI = body mass index; β = standardized regression coefficients; R^2 = total variance explained; ΔR^2 = the change in variance explained per step; r_s = structure coefficients; SB = sedentary behavior; SE = standard error; VO_{2max} = maximal oxygen uptake.

coefficient for moderate-intensity activity was not statistically significant beyond the other variables in the full model. Courville and Thompson[38] suggested structure coefficients need to be examined to determine true predictive power of the highly correlated factors. Structure coefficients revealed BMI ($r_s = 0.52$), VO_{2max} ($r_s = -0.77$), moderate-intensity activity ($r_s = -0.67$), vigorous-intensity activity ($r_s = -0.81$), and SB ($r_s = 0.57$) were substantially correlated to the criterion variable, confirming regression coefficients were reduced due to multicollinearity. Shapiro-Wilks W test ($S\text{-}W = 0.99$, $df = 211$, $p = 0.90$) was used to test normality and revealed the distribution of residuals was normal.

4. Discussion

The present study investigated the relations among SB, fitness-producing activity, HRF attributes, and depression, as well as examining whether SB and fitness-producing activity predicted depression after accounting for gender and HRF attributes in adolescents. Compared to a previous study measuring similar variables, participants in the current study, on average, were less sedentary, had greater amounts fitness-producing activity, were more physically fit, and had lower depression scores.[22] Variable associations in the current study were congruent with previous research in that adolescents with less SB,[18] greater amounts fitness-producing activity, especially vigorous-intensity activity[39] and enhanced physical fitness[40] were more likely to have favorable depression scores. Further, χ^2 tests results were consistent with previous research evidence that indicated having HRF performance scores classified as HFZ were more likely to have favorable depression scores.[41]

Consistent with previous literature,[15] SB was significantly negatively correlated with light-, moderate-, and vigorous-intensity activity. Although a *post hoc* Fisher's r-to-z' test (http://vassarstats.net/rdiff.html)[42] indicated the relationship between SB and moderate-intensity activity was not significantly stronger than the relationship between SB and light-intensity activity,[37] this result opposed the first hypothesis. While previous literature indicates SB may only significantly displace light-intensity activity,[15,43] the current study found SB also significantly displaced minutes spent in moderate-intensity activity. However, given that the participants in the current sample, on average, were sufficiently active, this conflicting result might suggest activity displacement patterns are different between those meeting and not meeting minimal PA recommendations. That is, in those sufficiently active, fitness-producing activity may have a greater propensity to displace SB, whereas in those physically inactive (i.e., not meeting recommendations), SB may have a greater propensity to displace light-intensity activity. Similar to previous research, which found that MVPA increased when physical behavior was substituted for SB,[44] this finding could, therefore, suggest that in order to meet PA recommendations, fitness-producing activity rather than light-intensity activity needs to displace SB. However, further research in needed to test this hypothesis.

Consistent with prior studies,[18,23] correlation analyses revealed SB was significantly positively related to depression. Conversely, SB was not significantly positively related to body composition nor was it significantly negatively related to VO_{2max}, which partially opposed the second hypothesis. However, considering this sample were sufficiently active and 73% had body compositions and VO_{2max} scores classified as HFZ,[31] these findings were supported by previous literature that controlled for fitness-producing activity.[21,25] In addition, these findings could suggest sufficient PA might nullify the negative influence of SB on body composition and cardiorespiratory fitness in adolescents, but further research is needed to verify this.

Step 1 of the regression analyses revealed HRF attributes significantly predicted depression scores, which was consistence with previous literature.[7,40] Moreover, regression coefficients indicated VO_{2max} was statistically significant beyond the other HRF attributes and gender, which further supported previous research findings.[7] Step 2 of the regression supported the third hypothesis in that fitness-producing activity significantly predicted depression beyond gender and HRF attributes. Specifically, the regression coefficients for moderate- and vigorous-intensity activity and the computed medium effect (i.e., Cohen's f^2)[37] indicated fitness-producing activity significantly predicted depressive symptoms in adolescents beyond gender and HRF attributes. While previous research has shown PA, especially vigorous-intensity, to be a significant predictor of troubling mental health complaints such as depression,[39,45] the present study found greater amounts of fitness-producing activity may provide protective effect against depressive symptoms beyond achieved HRF.

The regression analysis revealed SB was not a statistically significant predictor of depression beyond gender, HRF attributes, and fitness-producing activity, which partially conflicted with the third hypotheses. However, structure coefficients for this analysis indicated only VO_{2max} and fitness-producing activity shared more variance with depression than SB. Overall, the 3-step hierarchical regression analyses indicated both fitness-producing activity and SB were significantly related to depressive symptoms in adolescents. The findings also indicated sufficient fitness-producing activity and higher achieved HRF, particularly cardiorespiratory fitness, may decrease the influence of SB on mental health outcomes such as depression in adolescents.

The present study had some limitations to consider when interpreting the results. First, accelerometers are unable to distinguish between productive (e.g., reading, studying, or eating) and unproductive (e.g., watching television or playing video games) SB, nor were they able to determine when participants engaged in strength training activity. Given that, previous research found different types of SB often demonstrate opposing relations[46] and that strength training has also suppressed depression,[47] and controlling for these may have varied the results found. Second, PA was not assessed during the weekend. Though previous research has shown PA during weekend days and week days can vary, Fairclough et al.[48] found most active children's SB and PA levels remain stable across all days. However, not measuring PA during the weekend is still a limitation. Third, the depression measure was self-reported, thus, subject to social desirability biases (e.g., wanted to not be depressed or have others think you are depressed). Fourth, given that participants, on average, were sufficiently active and fit, the generalizability of the findings may be limited. However, considering health trend research indicates approximately 40% of adolescents aged 9−12 are sufficiently active,[13] gaining a better understanding in how these variables associate with depression within this population is warranted. Additionally, it should be noted that participants attended physical education daily, which is above the national average (i.e., 3.9 days)[49] and likely, in part, accounted for their activity and HRF levels. Lastly, it is impossible to posit cause-effect inferences from the data collected due to the cross-sectional nature of data collection. Future researchers should use an experimental research design so that cause-effect relations can be examined.

Despite the above limitations, the present study had several strengths worth noting. First, the use of objective-assessments for measuring behavioral variables (i.e., SB, PA, and HRF) likely improved the validity of our findings; thus, providing a significant contribution to the literature.[15] Previous studies involving both PA and HRF often relied on self-reported assessments for at least one of these variable sets.[3] Second, while there has been an abundance of research investigating the relations among SB, PA, HRF, and depression, to our knowledge this was the first study to investigate whether SB and PA predicted depression in adolescents over and above attributes of HRF. Thus, this study, in part, filled a gap in the literature. Finally, while this study cannot infer causality, it is important to understand the relationship between PA and depression is reciprocal in that depressive symptoms can foster lower energy levels, which are associated with reduced PA.[10] Thus, while increased SB, decreased PA, and a poorer HRF profile may foster depression, depression may also foster increased SB, decreased PA, and a poorer HRF profile.[24]

5. Conclusion

The present study revealed SB, fitness-producing activity, and attributes of HRF were all significant predictors of depression in active adolescents. Moreover, fitness-producing activity significantly predicted depression in active adolescents beyond gender and achieved HRF; thus, actively promoting fitness-producing activity while discouraging SB is likely an efficient way to combat depressive symptoms in adolescents. While the causal nature of this relationship was not determined, the results of the current study did add important information about the significance of these relationships in that SB, fitness-producing activity, and cardiorespiratory fitness were revealed to have a stronger relationship with depression than light-intensity activity; body composition; muscular strength and endurance; and flexibility in adolescents. Therefore, interventions designed to specifically impact SB, fitness-producing activity, and cardiorespiratory fitness might produce results effectively combating depression in adolescents.

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Authors' contributions

GLF collected the data, participated in the coordination of the study, performed the statistical analysis, and drafted the manuscript; TZ participated in the study's design and coordination and helped to draft the manuscript; XG conceived of and designed the study, participated in data collection and coordination, and helped draft the manuscript; KTT helped conceived of the study and participated in its design and coordination. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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