



Longitudinal bidirectional associations of physical activity and depressive symptoms: The CARDIA study

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ARTICLE INFO

Keywords:

Physical activity
Depressive symptom
Bidirectional
Self-reported
Accelerometer estimated

ABSTRACT

Depression affects many aspects of health and may be attenuated through increases in physical activity. While bidirectional associations between physical activity (PA) and depressive symptoms have been examined, few studies have examined these associations using both self-reported and accelerometer-estimated measures. Using data from Years 20 (2005–06, age 38–50) and 30 of the Coronary Artery Risk Development in Young Adults (CARDIA) study (N = 2,871), the bidirectional associations between moderate to vigorous intensity physical activity (MVPA) and depressive symptoms were examined using a cross-lagged panel model. Differences in the observed associations by physical activity assessment method were also examined. An inverse bidirectional association between self-reported MVPA and depressive symptoms was found. In subsequent analyses stratified by intensity category, higher levels of vigorous intensity physical activity at baseline, but not moderate intensity physical activity were associated with lower levels of depressive symptoms at the 10-year follow-up ($\phi = -0.04$, $p < 0.01$; $\phi = -0.03$, $p = 0.15$, respectively). A 10-year increase in self-reported MVPA was associated with a 10-year decrease in depressive symptoms. No associations were observed between accelerometer MVPA estimates and depressive symptoms. These findings may support the notion that each assessment method captures related, but also unique, aspects of physical activity behavior. When possible, future studies should explore measures of association by each physical activity assessment method to gain a better understanding of the complex relationship between physical activity and health.

1. Introduction

Depression has an estimated annual prevalence of 6% in most countries and thus represents an important public health concern and the second leading cause of global burden of illness (Ferrari et al., 2013; Vos et al., 2016). It has been defined as a chronic and recurring condition associated with increased risk of morbidity, declines in psychosocial health, and premature mortality (Blazer, 2003; Vancampfort et al., 2016; Walker et al., 2015; Wilson et al., 2015). Physical activity has received much attention in the past decade as one potentially modifiable risk factor for depression, with cohort studies and clinical trials reporting higher levels of physical activity are associated with lower risk of

depression and depressive symptoms (Gordon et al., 2018; Hallgren et al., 2017; Knox et al., 2006; Mammen and Faulkner, 2013; Schuch et al., 2018).

Associations between physical activity across a range of intensity levels with depressive symptoms have been found over a variety of age groups. For example, studies have reported inverse associations between MVPA and depressive symptoms in young adults, middle-aged adults, and older adults (Brunet et al., 2013). Studies on LPA and depression are more mixed, with some finding inverse associations (Brunet et al., 2013), and others reporting no association (Morres et al., 2019). Sedentary behavior has also been associated with higher risk of depressive symptoms in adolescents (Kandola et al., 2020) and adults

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<https://doi.org/10.1016/j.pmedr.2021.101489>

Received 1 July 2021; Accepted 3 July 2021

Available online 12 July 2021

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(Teychenne et al., 2010).

The association between physical activity and depressive symptoms is complex and limited studies have examined the bidirectional associations between physical activity and depressive symptoms. Gunnell and colleagues examined data from the Research on Eating and Adolescent Lifestyles study among participants in grades 7 and 9 between 2006 and 2010 at baseline and at three additional time points covering the ages from 10 to 21 years. Findings suggested that higher initial depressive symptoms predicted a greater decline in self-reported physical activity over 11 years, but not the other way around (Gunnell et al., 2016). In a 2-sample mendelian randomization study using genetic instruments from large-scale genome-wide association studies, findings from Choi et al. suggested higher levels of accelerometer-estimated physical activity, but not self-reported physical activity, were associated with reduced odds of major depression among a combined sample size of 611,583 adult participants from nonoverlapping genome-wide association studies (Choi et al., 2019).

Results across these earlier studies have found inconsistent associations between physical activity and depressive symptoms by physical activity assessment method. This is likely because self-report and accelerometer assessments are measuring different constructs of physical activity (behavior vs. movement, respectively) and each have unique strengths and limitations. For this reason, it is recommended that both measures be used concurrently to better capture the physical activity phenotype (Gabriel et al., 2012; Troiano et al., 2012); however, few studies have used both self-report and accelerometer estimates to examine the associations of physical activity with depressive symptoms. Further, use of both methods also provides the necessary bridge to synthesize information obtained from historical epidemiological studies using questionnaire data to more contemporary studies that include accelerometer-based assessments only. This will be of important value to the next iteration of the Physical Activity Guidelines for Americans.

The goals of the current study were to examine the bidirectional associations between MVPA and depressive symptoms using a cross-lagged panel model (CLPM) and to examine associations between changes in MVPA and changes in depressive symptoms over a 10-year period. In addition, we explored differences in the observed measures of association by measurement method. We hypothesized that higher levels of self-reported and accelerometer MVPA estimates at baseline would be associated with lower levels of depressive symptoms at follow-up, and higher levels of depressive symptoms at baseline would be associated with lower levels of self-reported and accelerometer MVPA estimates at follow-up. We also hypothesized that increasing levels of self-reported and accelerometer MVPA estimates over 10 years are associated with decreasing depressive symptoms.

2. Methods

2.1. Study population

The CARDIA study is an ongoing longitudinal cohort of 5,114 Black and White men and women aged 18–30 years who completed an in-person clinical exam in 1985–86 (year 0) at one of four field centers: Birmingham, AL; Minneapolis, MN; Chicago, IL; or Oakland, CA. Additional in-person clinic examinations were held approximately every 2–5 years. The current study includes individuals who took part in the year 20 (N = 3,549, 2005–06, henceforth referred to as baseline) and year 30 (2015–16, henceforth referred as 10-year follow-up) exams. The retention rates of the surviving participants for these two years were 72% and 71%, respectively. Details on eligibility criteria, methods of participant selection, and follow-up procedures have been reported previously (Friedman et al., 1988).

Fig. 1 shows how samples were derived for each stage of our analyses. Participants were included in bidirectional analysis if they had no missing data on any of the covariates (n = 2,817). Of the 2,817 participants, 1,951 also had accelerometer MVPA estimates. For the change

analysis, only individuals with self-reported MVPA data and depressive symptoms data at both baseline and the 10-year follow-up were included (N = 2,278), among which, 804 had valid accelerometer MVPA estimates and depressive symptoms at both time points. The institutional review board at each field center approved all study protocols for the primary CARDIA exam, as well as the ancillary CARDIA Fitness and Activity Studies. Written informed consent was obtained at each exam and completed separately for the primary and ancillary studies.

2.2. Self-reported MVPA

Self-reported physical activity was measured using the validated CARDIA Physical Activity History questionnaire at each examination (Gabriel et al., 2014; Jacobs et al., 1993, 1989). The questionnaire asks about participation in 13 moderate physical activity (MPA, 5 out of the 13 activity types, including nonstrenuous sports, walking and hiking, golfing and bowling, home exercises or calisthenics, and home maintenance or gardening) and vigorous-intensity physical activity (VPA, 8 out of the 13 activity types, including running or jogging; racquet sports; biking; swimming; exercise or dance class; job lifting, carrying, or digging; shoveling or lifting during leisure; and strenuous sports) types over the previous year. Each activity type was assigned an intensity score (ranging from 3 to 8 metabolic equivalents) and a duration threshold (ranging from 2 to 5 h/week), above which participation was considered to be frequent. A score for each activity type was calculated using a computer algorithm based on the intensity of the activity, months of participation, and a weighting factor representing months with a minimum weekly duration. The total activity score was the sum of scores for all activities, expressed in exercise units, which represents the usual level of activity over the previous 12 months.

2.3. Accelerometer MVPA

The ActiGraph 7164 uni-axial accelerometer (baseline) and wGT3X-BT accelerometer (10-year follow-up) were used to collect device-based physical activity estimates (both ActiGraph LLC; Pensacola, FL). Accelerometers were initialized to begin data collection at 12:00am on the day of the in-person CARDIA examination. Accelerometers were worn at the right hip on an elastic belt during all waking hours for seven consecutive days following the in-person examination. Data from both monitors were processed using ActiLife6 software through a digitally matched filter; a calibration factor was applied to the GT3X data to enhance comparability with the 7164 estimates (Whitaker et al., 2018). Vertical axis data from both devices were screened for wear time using the validated Troiano algorithm (National Cancer Institute, 2016; Troiano et al., 2008). Total and average accelerometer counts per day were calculated using summed counts detected over wear periods and time (i.e., minutes) spent in different intensity levels using standardized and validated Freedson cut-point threshold values, with MVPA defined as ≥ 1952 counts/minute (Freedson et al., 1998), as previously described in CARDIA (Petee Gabriel et al., 2018; Whitaker et al., 2019). Both MVPA (every minute ≥ 1952 ct·min⁻¹) and MVPA bouts (estimate only includes ≥ 8 of 10 consecutive minutes ≥ 1952 ct·min⁻¹) were examined (Troiano et al., 2008).

2.4. Depressive symptoms

Depressive symptoms were measured using the 20-item Center for Epidemiologic Studies Depression (CES-D) scale at baseline and 10-year follow-up. The CES-D asks about the severity of symptoms (Likert scale from 0 to 3) an individual has experienced over the past two weeks, for a total possible score between 0 and 60, where scores ≥ 16 are indicative of elevated depressive symptoms (Radloff, 1977). In the current sample, the Cronbach's alpha for the CES-D at years 20 and 30 were 0.67 and 0.64, respectively.

2.5. Covariates

Covariates from the CARDIA baseline exam included center (Birmingham, AL; Minneapolis, MN; Chicago, IL; or Oakland, CA), age, sex (male or female), race (black or white), years of education completed, self-reported antidepressant medication use, self-reported unemployment status (unemployed or employed), health insurance status (health insurance over the last two years or not), overall diet quality score (Sijtsma et al., 2012), smoking status (current, former, never), alcohol consumption (milliliters/day), BMI, self-reported sleep duration during last month (hours/day), physical quality of life using the physical component score from the Medical Outcomes Study Short Form (SF-12) (Ware et al., 1996), and baseline MVPA (self-reported or accelerometer-estimated measures based on model). Body mass index (BMI) was calculated using measured height in meters and weight in kilograms (kg/m²).

2.6. Statistical analyses

Correlations were calculated for all variables of interest and covariates for baseline and 10-year follow-up as shown in Supplemental Tables 1 and 2. To better understand the bidirectional association between MVPA and depressive symptoms between baseline and 10-year follow-up, a cross-lagged panel model (CLPM) was used to examine the associations between both self-reported MVPA (exercise units) and accelerometer MVPA (minutes/day) in separate models, and depressive symptoms (raw score).

In exploratory analyses, we also tested accelerometer MVPA estimates accumulated in 10-minute bouts and depressive symptoms as a dichotomous outcome with scores ≥ 16 indicating clinical depression symptoms in separate models. Notably, of the self-reported VPA activity

types assessed, racquet sports, biking, swimming, job and leisure lifting were likely not fully captured by accelerometer-estimated measures. As few individuals achieved VPA by accelerometer, similar analyses were not conducted with the accelerometer-estimated measures. Self-reported MPA and VPA estimates were also tested separately to examine potential differences by intensity category in the associations with depressive symptoms. For all analyses in Mplus, the full information maximum likelihood estimation (FIML) method was used for missing values on physical activity and depressive symptoms at both baseline and follow-up to fully utilize our available data, and standardized coefficients were reported (standardized on both PA and depressive symptoms). Because of the large sample size in our study and sensitivity of χ^2 , model fit for CLPM was assessed using the comparative fit index (CFI) and the root mean square error of approximation (RMSEA) as the primary guidelines. Missing data were dealt with using FIML in Mplus. In sensitivity analyses, we only included those with complete data on MVPA and depressive symptoms at baseline and 10-year follow-up. Mplus 7.4 was used for all CLPM analyses.

To examine the associations between changes in MVPA (self-report and accelerometer) and changes in depressive symptoms, generalized linear models were used. Changes of MVPA were examined using raw data (exercise units and minutes/day) and standardized coefficients. In our model examining changes in self-reported MVPA estimates and changes in depressive symptoms, our first model is our base model where we adjusted for age, sex, race, center, and education. In our second model, we additionally adjusted for potential confounders at baseline including self-reported antidepressants medication use, unemployment status, health insurance status, diet quality, smoking status, alcohol consumption, BMI, sleep duration, and physical quality of life. In our third, final model, we further adjusted for baseline MVPA to account for participants baseline physical activity level. A similar approach was

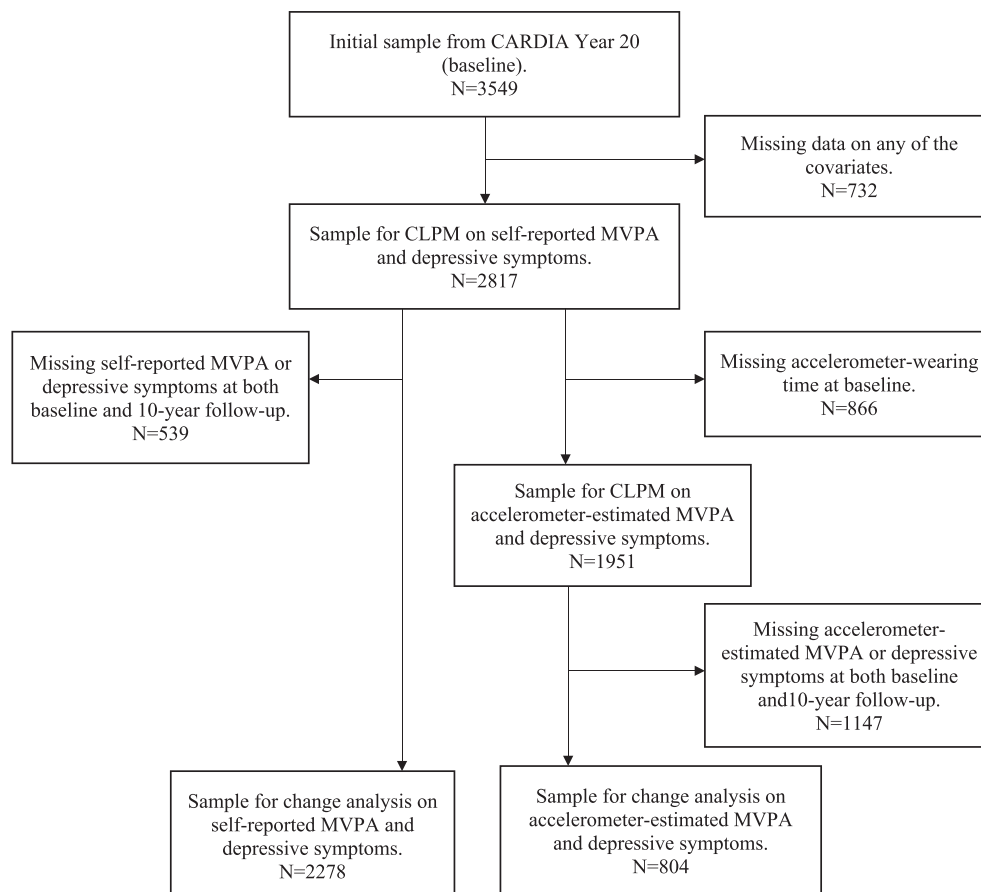


Fig. 1. Flow chart of study sample sizes.

conducted when examining the associations of accelerometer MVPA estimates and depressive symptoms except that we additionally adjusted for change in total wear time between baseline and the 10-year follow-up in all change models, as reported previously (Whitaker et al., 2019). Furthermore, subgroup analyses were also conducted to examine in-teractions between sex, race, age and education groups. SAS version 9.4 was used for all generalized linear model analyses.

3. Results

3.1. Descriptive data

Descriptive characteristics of participants included and excluded at baseline from the study were presented in Supplemental Table 3. Compared to those who were excluded, participants included in the study were more likely to be female and White with more years of education, lower unemployment rate, and with health insurance coverage. Participants included were less likely to be a current smoker, had less alcohol consumption and fewer depressive symptoms compared to those who were excluded. Descriptive data for the variables used in the study at baseline and 10-year follow-up were shown in Table 1. Median self-reported MVPA exercise units decreased from 273 at baseline to 264 at 10-year follow-up, while median accelerometer MVPA minutes per day decreased from 29.67 to 22.69. Median score of depressive symptoms decreased from 7 to 6.

3.2. Cross-lagged panel models

3.2.1. Self-reported MVPA

Standardized coefficients (represented as ϕ) were shown on the paths in Fig. 2. Higher levels of MVPA at baseline were associated with lower levels of depressive symptoms at 10-year follow-up ($\phi = -0.04$, $p < 0.05$), and higher levels of depressive symptoms at baseline were

Table 1
Participant characteristics at baseline and follow-up, N = 2,871 (2005–2016), the CARDIA Study.

Participant Characteristics	Baseline	10-year follow-up
Female, n(%)	1,643 (57.2)	
White, n(%)	1,576 (54.9)	
Age, mean years \pm SD	45.20 \pm 3.6	55.20 \pm 3.6
Education, mean years \pm SD	15.11 \pm 2.6	15.37 \pm 2.6
Unemployed, n(%)	339 (11.8)	210 (8.8)
Health insurance, n(%)	2,524 (87.9)	2,189 (91.8)
Smoking Status, n(%)		
Current	522 (18.2)	271 (11.4)
Former	567 (19.8)	542 (22.8)
Never	1,782 (62.1)	1,582 (65.8)
Alcohol consumption, ml/day, median \pm IQR	2.43 \pm 14.3	2.73 \pm 14.9
Body Mass Index, kg/m ² \pm SD	29.36 \pm 7.2	30.26 \pm 7.0
Diet quality ^a \pm SD	62.56 \pm 13.0	
Self-reported sleep duration, mean hours \pm SD	6.80 \pm 3.0	
Antidepressants medication n(%)	279 (9.8)	315 (13.2)
Self-reported MVPA, median exercise units \pm IQR	273.00 \pm 362.0	264.00 \pm 340.5
Accelerometer MVPA ^b , median minutes/day \pm IQR	29.67 \pm 30.4	22.69 \pm 28.9
Depressive symptoms ^c , median score \pm IQR	7.00 \pm 9.0	6.00 \pm 9.0
Depression ^d , n(%)	471 (16.8)	368 (15.6)

Abbreviations: IQR = interquartile range; MVPA = moderate-to-vigorous intensity physical activity; SD = standard deviation.

^a Diet Quality score range from 0 to 132, higher score indicates diet quality.
^b Freedson cut point thresholds defined MVPA time in counts/minute at \geq 1952.
^c Depressive symptoms measured using the 20-item Center for Epidemiologic Studies Depression (CES-D) scale with possible score range of 0–60, higher score indicates higher levels of depressive symptoms.
^d CES-D score \geq 16.

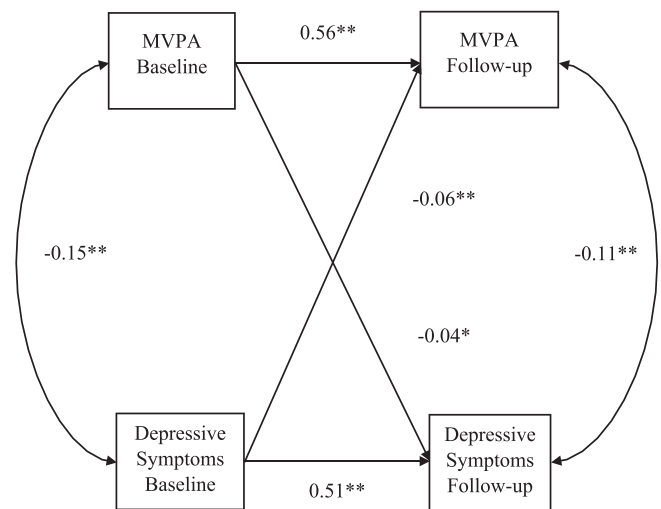


Fig. 2. Structural equation model of the cross-lagged panel model examining the bidirectional association between self-reported MVPA and depressive symptoms (N = 2871), 2005–2016, the CARDIA Study All estimates reported are standardized regression estimates. Full information maximum likelihood (FIML) were used for missing. Abbreviation: MVPA = moderate-to-vigorous intensity physical activity. * $p < 0.05$, ** $p < 0.01$.

associated with lower levels of MVPA at 10-year follow-up ($\phi = -0.06$, $p < 0.01$). Higher levels of MVPA at baseline were associated with higher levels of MVPA at 10-year follow-up ($\phi = 0.56$, $p < 0.01$), and higher levels of depressive symptoms at baseline were associated with higher levels of depressive symptoms at 10-year follow-up ($\phi = 0.51$, $p < 0.01$).

3.2.2. Accelerometer MVPA

MVPA at baseline was not associated with depressive symptoms at 10-year follow-up ($\phi = 0.03$, $p = 0.17$) as shown in Fig. 3. Similarly, depressive symptoms at baseline were not associated with MVPA at 10-year follow-up ($\phi = -0.03$, $p = 0.33$). Higher levels of MVPA at baseline were associated with higher levels of MVPA at 10-year follow-up ($\phi = 0.19$, $p < 0.01$), and higher levels of depressive symptoms at baseline were associated with higher levels of depressive symptoms at 10-year

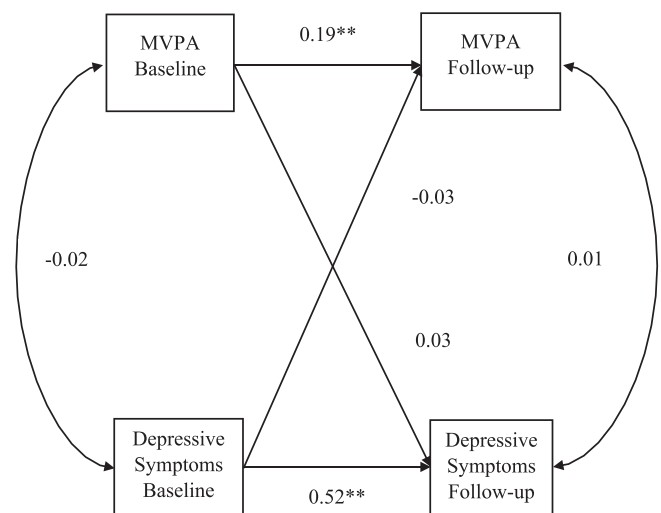


Fig. 3. Structural equation model of the cross-lagged panel model examining the bidirectional association between accelerometer MVPA and depressive symptoms (N = 1951), 2005–2016, the CARDIA Study All estimates reported are standardized regression estimates. Full information maximum likelihood (FIML) were used for missing. Abbreviation: MVPA = moderate-to-vigorous intensity physical activity. * $p < 0.05$, ** $p < 0.01$.

follow-up ($\phi = 0.52, p < 0.01$).

3.2.3. Changes in physical activity & depressive symptoms

Negative associations were found between changes in self-reported MVPA estimates and depressive symptoms, and the association remained after adjustment (Table 2). For example, a one standard deviation increase in self-reported MVPA estimates (241 exercise units) from baseline to 10-year follow-up resulted in a 0.071 standardized deviation decrease in depressive symptoms (0.95 units) over the same time period. However, no associations were found between changes in accelerometer MVPA estimates and changes in depressive symptoms (Table 3). In subgroup analysis, no significant interactions were found between sex, race, age and education groups.

3.3. Exploratory analyses: Self-reported and accelerometer MVPA estimates

In exploratory analysis, consistent results were found in models including participants with complete data only for both self-report and accelerometer MVPA estimates (Supplemental Figs. 2 & 3), as well as models examining accelerometer MVPA in 10-minute bouts (data not shown). Models examining depressive symptoms as a dichotomous outcome failed to converge, likely due to the limited number of individuals with elevated depressive symptoms at either time points (16.5%). Associations for self-reported MPA and VPA estimates with depressive symptoms were shown in Supplemental Fig. 3. Two differences were found between the two models. First, higher levels of depressive symptoms at baseline were associated with lower levels of MPA at 10-year follow-up ($\phi = -0.09, p < 0.01$) but not for VPA ($\phi = -0.04, p = 0.06$). Secondly, higher levels of VPA at baseline, but not MPA ($\phi = -0.03, p = 0.15$), were associated with lower levels of depressive symptoms at 10-year follow-up ($\phi = -0.04, p < 0.01$). To further explore the observed differences between self-report and accelerometer MVPA measurements, we examined self-report activities that may not be assessed accurately by accelerometry in post hoc analysis (results not shown). As a result of the location of accelerometer and lack of waterproof function, a portion of self-reported VPA were not well documented by the accelerometer, including activities such as biking, swimming, and leisure lifting.

4. Discussion

This study examined the bidirectional associations of self-reported and accelerometer MVPA estimates with depressive symptoms in a

Table 2
Associations between 10-year change in self-reported MVPA and changes in depressive symptoms.

Change in MVPA	Raw estimate B^a	95% CI	Standardized estimate β^b	95% CI
Model 1	-0.002	(-0.003, -0.001)	-0.051	(-0.092, -0.010)
Model 2	-0.001	(-0.003, -0.001)	-0.048	(-0.088, -0.007)
Model 3	-0.002	(-0.004, -0.001)	-0.071	(-0.118, -0.024)

Abbreviations: CI = confidence interval; MVPA = moderate-to-vigorous intensity physical activity.

Model 1 adjusted for age, sex, race, center, and education. Model 2 additionally adjusted for self-reported antidepressants medication use at baseline, unemployment status, health insurance, diet quality, smoking status, alcohol usage, BMI, sleep duration and physical quality of life; Model 3 additionally adjusted for baseline self-reported MVPA.

^a Raw estimates show changes on depressive symptoms when there is one-unit change in raw self-reported MVPA score.

^b Standardized estimates show changes on depressive symptoms when there is one standardized deviation change in self-reported MVPA score.

Table 3

Associations between 10-year change in accelerometer-estimated MVPA and changes in depressive symptoms.

Change in MVPA	Raw estimate B^a	95% CI	Standardized estimate β^b	95% CI
Model 1	0.003	(-0.006, 0.012)	0.024	(-0.042, 0.090)
Model 2	0.004	(-0.006, 0.012)	0.025	(-0.041, 0.092)
Model 3	0.004	(-0.018, 0.027)	0.017	(-0.071, 0.106)

Abbreviations: CI = confidence interval; MVPA = moderate-to-vigorous intensity physical activity.

Model 1 adjusted for age, sex, race, center, and education. Model 2 additionally adjusted for self-reported antidepressants medication use at baseline, unemployment status, health insurance, diet quality, smoking status, alcohol usage, BMI, sleep duration and physical quality of life; Model 3 additionally adjusted for baseline accelerometer-estimated MVPA.

^a Raw estimates show changes on depressive symptoms when there is one-unit change in raw self-reported MVPA score.

^b Standardized estimates show changes on depressive symptoms when there is one standardized deviation change in self-reported MVPA score.

longitudinal cohort of black and white men and women. CLPM results showed significant cross-lagged associations in analyses of self-reported MVPA estimates but not analyses of accelerometer MVPA estimates. Specifically, a significant negative association was observed between baseline MVPA and depressive symptoms at the 10-year follow-up, and a significant negative association was also shown between baseline depressive symptoms and MVPA at the 10-year follow-up. Additionally, an increase in self-reported MVPA estimates was associated with a decrease in depressive symptoms over 10-years but no significant associations were observed in accelerometer MVPA estimates and depressive symptoms.

Our findings contribute to the current literature in several notable ways. Results of CLPM showed significant negative cross-sectional associations between self-reported MVPA and depressive symptoms at both baseline and follow-up, which provides additional support to earlier studies examining cross-sectional links between physical activity and depressive symptoms (Harvey et al., 2010; Lindwall et al., 2007). Further, the association between higher self-reported MVPA at baseline and lower depressive symptoms at follow-up were also in line with previous studies suggesting a protective role of physical activity against future depressive symptoms (Brown et al., 2005; De Moor et al., 2008; Jerstad et al., 2010; Lindwall et al., 2011; Strawbridge et al., 2002). When exploring the associations between changes in self-reported MVPA and depressive symptoms over time, the negative associations were confirmed as shown by others (Lindwall et al., 2014). But given the nature of our study design, no causal relationship nor directional effect can be drawn. In addition, lack of significant interactions between sex, race, age and education groups suggests the associations between MVPA and depressive symptoms were consistent across different demographic subgroups.

Although earlier studies examining bidirectional associations between MVPA and depressive symptoms showed mixed results (Birkeland et al., 2009; Jerstad et al., 2010), our findings were largely consistent with prior studies in similar aged adult populations using self-reported measurements (Brody et al., 1994; Lindwall et al., 2011; Pereira et al., 2014; Steinmo et al., 2014). Mechanisms by which physical activity may reduce the incidence of depressive symptoms include an increase in monoamines, endorphins, and self-confidence/self-esteem after the completion of physical activity (Dunn and Dishman, 1991; North et al., 1990; Phillips et al., 2001; Stewart et al., 1994; Thoren et al., 1990). Conversely, participants with higher level of depressive symptoms are more likely to have other health related issue such as anxiety (Strohle, 2009), obesity (Stunkard et al., 2003), and low self-esteem (Sowislo and Orth, 2013), which might make them less motivated to engage in

physical activity and is supported by the negative association observed in CLPM.

Of the limited studies to examine both self-reported and accelerometer-estimated physical activity, our findings differ compared to those of Choi and colleagues (Choi et al., 2019). Choi and colleagues found a protective relationship between accelerometer assessed physical activity, but not self-reported physical activity and risk for major depressive disorder (MDD). Our findings suggested significant bidirectional associations with depressive symptoms only existed in self-reported MVPA estimates but not in the accelerometer MVPA estimates. Several differences between the two studies might help explain discrepancies in findings. First, we used self-reported measurements of MVPA and accelerometer MVPA estimates directly while Choi's study used proxy single-nucleotide polymorphisms to examine the associations. Second, CLPM was used to examine the bidirectional association in our study while Choi and colleagues used a 2-sample mendelian randomization approach. In addition, a critical difference is that Choi and colleagues examined MDD, which is a clinical diagnosis for depression, while the current study examined depressive symptoms using the CES-D score, which is a screening measure.

There are several potential explanations for why study findings differed when comparing the associations of self-report vs. accelerometer MVPA estimates with depressive symptoms. First, there are well-recognized distinctions in self-reported and accelerometer MVPA estimates (Dyrstad et al., 2014), with both measures having unique strengths and limitations. Self-reported physical activity has its strength in capturing common activity types that are not detected using hip worn accelerometers (e.g., bicycling, swimming, yoga, resistance training); however, there are important limitations that lead to biases and measurement error, such as recall error, social desirability bias, and incomplete assessment across intensity categories and domains (Troiano et al., 2008). Accelerometer MVPA estimates have been widely used to record and capture (primarily ambulatory) movement; however, certain activities that may relate to depressive symptoms may not be accurately detected depending on the location of device and instructions to remove devices during water-based activities (Pedisic and Bauman, 2015). Second, the self-reported questionnaire used in CARDIA focused primarily on leisure-time MVPA whereas the accelerometer provided total accumulated MVPA in all domains, including leisure, occupational, transportation, and household. Third, there is a difference in the timing of assessment for self-reported MVPA (1 year) and accelerometer MVPA estimates (7 days), thus it is possible that habitual activity has a stronger association with depressive symptoms than activity patterns over a shorter duration. Fourth, those with depressive symptoms might be more likely to perceive themselves as more inactive, hence underestimating their physical activity, which would result in stronger associations between self-reported activity and depressive symptoms. Finally, participants included in this study had lower levels of depressive symptoms and were generally healthier compared to those excluded. As a result, associations between physical activity and health outcomes may be biased towards the null, particularly for accelerometer data given the smaller sample size, and true associations may be of greater magnitude than observed. Moreover, the absence of significant associations between accelerometer MVPA-estimates and depressive symptoms does not discard the association; rather, the null finding might be related to the specific population or other factors, as the absence of significance is not evidence of the absence of effect (Harms and Lakens, 2018). Interestingly, a study by Sternfeld and colleagues also found differences in associations between self-reported and accelerometer MVPA estimates with incident diabetes and hypertension in the CARDIA cohort (Sternfeld et al., 2019). Unlike our study, significant associations were only observed for accelerometer MVPA estimates, not self-reported MVPA with the health outcomes of interest.

Despite the use of a diverse cohort of Black and White adults and CLPM study design examining both self-reported and accelerometer MVPA estimates, there are several limitations to note. First, because we

only have data on self-reported and accelerometer MVPA estimates at two timepoints, we were not able to separate trait-like stability and moment-to-moment stability using an analysis method like random intercept cross-lagged panel model (RI-CLPM), which requires a minimum of three assessments. However, the CARDIA study will continue to assess physical activity and depressive symptoms longitudinally, which will provide opportunities to explore these associations as the cohort ages. Second, although both self-reported and accelerometer physical activity estimates were examined, report and measurement errors may exist in both assessment methods. Third, the CARDIA cohort in the current study were aged 38–50 years at baseline and 48–60 years at follow-up, which may limit the generalizability of our findings to other age groups. In addition, participants included in this study differed in several ways from those excluded from analysis, which also limits generalizability.

In conclusion, this study found an inverse bidirectional association between self-reported MVPA and depressive symptoms but not for accelerometer MVPA estimates. Similarly, changes in self-reported MVPA, but not accelerometer MVPA estimates, were associated with change in depressive symptoms over a 10-year period. In the current study, the discrepancy in results between the two methods of MVPA assessment may be due to the unique limitations of each approach. Additional studies are needed to explore consistency between self-reported and accelerometer estimated MVPA measurements in different populations, and future research should examine physical activity and depressive symptoms with more than two assessments in order to help us better understand bidirectional associations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The Coronary Artery Risk Development in Young Adults Study (CARDIA) is conducted and supported by the National Heart, Lung, and Blood Institute (NHLBI) in collaboration with the University of Alabama at Birmingham (HHSN268201800005I & HHSN268201800007I), Northwestern University (HHSN268201800003I), University of Minnesota (HHSN268201800006I), and Kaiser Foundation Research Institute (HHSN268201800004I). This manuscript has been reviewed by CARDIA for scientific content.

Disclosures

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.pmedr.2021.101489>.

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