NEW RESEARCH

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Symptoms of Depression, Physical Activity, and Sedentary Time: Within-Person Relations From Age 6 to 18 in a Birth Cohort

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Objective: To examine the within-person relations between objectively measured physical activity and clinically assessed symptoms of depressive disorders from childhood to late adolescence.

Method: Seven waves of biennially collected data from a Norwegian birth-cohort (n = 873; 53% girls) followed from age 6 to 18 years were used. Accelerometers were used to assess total physical activity, moderate-to vigorous physical activity, and sedentary time, and symptoms of depression were assessed by semi-structured psychiatric interviews. Mediators (athletic self-esteem, body image, sports participation) were captured by questionnaires. Random intercept cross-lagged panel models were estimated to test the within-person relations and their potential mediators.

Results: From ages 14 to 16 and 16 to 18 years, significant within-person relations were found. Decreased levels of total physical activity (PA) and moderate-to-vigorous physical activity (MVPA) predicted more symptoms of depression (PA: 14-16 years: $\beta = -0.08$; 16-18 years: $\beta = -0.09$; MVPA: 14-16 years: $\beta = -0.10$; 16-18 years: $\beta = -0.07$). These relations were not evident at earlier ages. From ages 10 to 12 and 14 to 16 years, an increased number of depressive symptoms predicted decreased levels of physical activity (PA: 10-12 years: $\beta = -0.10$; 14-16 years: $\beta = -0.14$: MVPA: 10-12 years: $\beta = -0.10$; 14-16 years: $\beta = -0.17$). We found no evidence for within-person relations between sedentary time and depressive symptoms, and no significant sex differences or mediations.

Conclusion: Individuals who increase their physical activity levels from middle to late adolescence are less likely to develop symptoms of depression compared to what they otherwise would. Thus, in this age period, physical activity may protect against depressive symptoms.

Plain language summary: Using data from a Norwegian birth cohort (n = 873), this study found that from ages 14 to 18, decreased physical activity predicted more depressive symptoms, while increased depressive symptoms predicted decreased physical activity from ages 10 to 12 and 14 to 16. No significant correlations were found for sedentary time. These findings suggest that physical activity may protect against depressive symptoms from middle to late adolescence.

Key words: depression; physical activity; sedentary time; children; adolescents; within-person relations

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The prevalence of major depressive disorder episodes and symptoms in youth has increased during the last decade.[1] Preventive efforts and effective treatments are therefore needed more than ever, especially in the transition to adolescence, when depression substantially increases.[2] Increasing physical activity (PA) has been one avenue of intervention, but efforts to prevent depression in children and adolescents through increased PA have a modest effect in the short term, which diminishes with increasing methodological strictness.[3,4] To guide interventions, the demonstration of longer-term effects is preferable; however, no study has followed participants beyond 12 months, and the effects in those with 8- to 12-month follow-ups are equivocal.[3] In the absence of experimental evidence, observational studies may help to shed light on any enduring effects, and reviews and meta-analyses of such studies indicate that PA may protect against depression in childhood and adolescence.[4,5] Observational studies have asked whether a child with a higher level of PA than other children will have less depression than other children (ie, between-person effects); however, other unknown children's PA cannot be involved in a specific child's depression. When planning a treatment or preventive initiative, we need to know whether children who increase their own PA or reduce their sedentary time become less depressed than they otherwise would be (ie, within-person effects, using the individual as his/her own control). Separating between-persons differences in levels from within-person changes is therefore of vital importance,[6] and is thus at the core of the present examination. Importantly, sedentary time (ie, time spent on activities that require little energy, such as sitting) is worthy of attention along with PA, as it predicts health irrespective of the latter,[7] increases from childhood to adolescence,[8] and is associated with depression.[9]

Existing Research and Knowledge Gaps

Observational research shows that associations between PA and depressive symptoms range from null to small,[4] and by increasing methodological requirements, the strength of the associations decreases. For example, a meta-analysis of the relation between PA and depression in childhood and adolescence found that cross-sectional studies (n = 36) had a mean effect size of $r = -0.17$. In contrast, for longitudinal studies (n = 14), the association was $r = -0.07$.[5] However, these studies used approaches that did not fully account for the potential confounding effects of unmeasured, stable, between-person differences (eg, stable effects of common genetics, parenting styles, or personality). Hence, even weak prospective associations may be further attenuated at the within-person level. Importantly, the within-person analyses applied here will, by design, adjust for all time-invariant effects of confounders (ie, factors that are relatively stable over time).[6]

Only 2 studies of youths have separated between- and within-person information, and thus adjusted for time-invariant confounding effects, applying a random intercept cross-lagged panel model (RI-CLPM) approach. One study[10] found that self-reported PA predicted fewer self-reported depressive symptoms in a sample of 12- to 18-year-old individuals. Self-reports of PA do not correspond well with objectively measured PA[11] and are more strongly associated with psychological factors than objective measures of PA,[12] which makes it uncertain to what extent common methods produced the predictions. Another study[13] reported objectively measured sedentary time in 10-year-olds to be unrelated to depressive symptoms 1 year later. However, the sample size was small (n = 167) and considerably below what has been recommended for within-person analyses[14]; thus the null finding may be due to a lack of power.

Furthermore, in 46 of 50 studies included in the above-noted meta-analysis,[5] symptoms of depression were self-reported, which only modestly corresponds with diagnostically defined symptoms captured by gold-standard psychiatric interviews.[15] Studies applying self-reported depression showed stronger associations ($r = -0.15$) than those using interview-based measures of depression ($r = -0.05$).[5] We have identified one study that examined the relationship between objectively measured PA and interview-based assessments of depression among youths.[16] The authors reported that the depression score at age 18 years was associated with lower levels of PA at ages 12, 14, and 16 years, and with higher levels of sedentary time at age 12. However, because depression was measured at one time point only, the findings do not speak to whether changes in objectively measured PA forecast changes in symptoms of depression.

Mechanisms

Provided that a link between increased PA/decreased sedentary time and reduced depression can be established, for preventive and treatment efforts, we need to understand the mechanisms involved. Here, we examine commonly proposed psychosocial and behavioral mediators,[17,18] namely athletic self-esteem, body image, and sports participation. First, physically active adolescents often exhibit high athletic self-esteem,[19] leading to intrinsic satisfaction, enjoyment, fulfillment, and mastery.[20] These positive experiences and emotions may buffer against depressive symptoms. Second, increased PA predicts declined body dissatisfaction in adolescents,[21] which in turn is associated with depressive symptoms.[22] Thus, body image may mediate the relationship between PA and depressive symptoms. Finally, PA is typically conducted with peers in organized sports, which fosters social interactions, belongingness, and peer acceptance, thereby promoting positive moods.[23] Conversely, dropping out of sports is linked to poorer mental health and well-being.[24]

Two reviews examining potential mechanisms linking PA and mental health concluded that self-esteem was the only one found to explain the relation.[17,18] Importantly, however, no longitudinal studies of objectively assessed PA were included in these reviews.

Study Aims

Drawing on 7 waves of biennially collected data from a birth cohort of Norwegian children, we test the hypothesis that increased levels of total PA (ie, all daytime PA) predict a reduced number of *DSM-5*–defined depressive symptoms from age 6 to 18 years. Because moderate-to-vigorous PA (MVPA; ie, activities elevating one's breathing, such as biking) is particularly beneficial for health,[25] and sedentary time predicts reduced health irrespective of PA,[7] we also test the within-person relation between MVPA, sedentary time, and depressive symptoms. Furthermore, boys are generally more physically active and less sedentary than girls[26]; adolescent girls are at higher risk for depression than are boys[2]; and activity levels decline and sedentary time increases in the transition from childhood to adolescence,[26] paralleling an increase in the prevalence of depression.[2] For these reasons, we also examine sex, and age differences in the within-person relations between PA/sedentary time and depressive symptoms. Finally, based on the above theory and research, we test whether the relation is mediated by athletic self-esteem, body image, or sports participation.

METHOD

Participants and Procedures

The present inquiry uses data from the Trondheim Early Secure Study (TESS), a cohort study of children born in

Trondheim, Norway, in 2003 and 2004. Ahead of the mandatory health checkup for 4-year-olds (2007/2008), parents of all children in these cohorts received a letter of invitation and the Norwegian version of the Strengths and Difficulties Questionnaire (SDQ) version 4-16,[27] which is a screening assessment for emotional and behavioral problems. When attending the health care center (97.2%), parents were informed about the study by the health care nurse and handed in the completed SDQ. Of those who were asked to participate (n = 3,016), 82.2% gave written consent. To increase variability and thus statistical power, children with behavioral and emotional problems were oversampled at 4 years of age for participation in a further study by allocating children to 4 strata based on their SDQ scores (cutoffs: 0-4, 5-8, 9-11, and 12-40; drawing probabilities of 0.37, 0.48, 0.70, and 0.89 in the respective strata); this resulted in 1,250 participants being drawn, of whom 1,007 were successfully examined at the first assessment (49.4% girls, mean age = 4.7 years, SD = 0.3). Since then, they have been assessed every second year. Because PA and sedentary time were measured from age 6 years onward, the current study includes data collected at age 6 (mean age = 6.66, SD = 0.17), 8 (mean age = 8.81, SD = 0.24), 10 (mean age = 10.51, SD = 0.17), 12 (mean age = 12.49, SD =0.15), 14 (mean age = 14.35, SD = 0.16), 16 (mean age = 16.98, SD = 0.31) and 18 (mean age = 18.6, SD = 0.24) years. Details of the recruitment procedure and the flow of participants are displayed in the online material (Figure S1, available online). Characteristics of participants are presented in Table 1.

Attrition analyses showed that none of the main study variables (ie, total PA, MVPA, sedentary time, symptoms of depression) predicted dropout from any of the time points included, but attrition was higher in boys compared to girls on several occasions (age 8-10: odds ratio [OR] = 1.33 [95% CI = 1.03, 1.71], p = .029; age 12-14: OR = 1.38 [95% CI = 1.08, 1.76], p = .010; age 14-16: OR = 1.78 [95% CI = 1.39, 2.28], $p \leq .001$; age 16-18: OR = 1.66 [95% CI = 1.30, 2.12], $p \leq .001$).

The Regional Committee for Medical and Health Research Ethics Central Norway approved the study (project number 2019/509).

TABLE 1 Characteristics of the Sample

	%
Sex	
Boys	49.2
Girls	50.1
Sex of parent informant	
Male	15.2
Female	84.8
Ethnic origin of biological mother	
Norwegian	93.0
Western countries	6.8
Other countries	0.3
Ethnic origin of biological father	
Norwegian	93.0
Western countries	6.5
Other countries	0.5
Biological parent's cohabiting status	
Cohabiting	84.6
Not cohabiting	15.4
Parent's highest completed education	
Junior high school not completed	0.0
Junior high school (10th grade)	0.3
Some education after junior high school	3.9
Senior high school (13th grade)	9.4
Some education after senior high school	2.1
Some college or university education	3.8
Bachelor's degree	4.1
College degree (3-4 years study)	21.4
Master's degree or similar	13.7
Doctorate completed or ongoing	3.2
Parent's occupational status	
Manager	7.8
Professional, higher level	26.3
Professional, lower level	40.5
Formally skilled worker	22.2
Farmer/fisherman	0.1
Unskilled worker	3.0

Note: The displayed sample characteristics are based on data for age 6 years, which is the baseline assessment of the present study, although baseline of the overarching Trondheim Early Secure Study (TESS) was age 4 years.

Measures

Symptoms of Depression. Semi-structured clinical interviews were used to assess symptoms of major depression at all ages. When participants were 6 years of age, the parents were interviewed about their children's mental health, using the Preschool Age Psychiatric Assessment (PAPA).[28] The corresponding Child and Adolescent Psychiatric Assessment (CAPA)[29] was used at ages 8, 10, 12, and 14 years. Children and their parents were interviewed separately, and a symptom was considered present if either party reported it to be present. Following a structured protocol with both mandatory and optional follow-up questions, interviewers asked questions until they had acquired enough information to decide whether a symptom was present at predetermined severity thresholds, using a 3-month primary period. This procedure was also applied at ages 16 and 18, for which the Norwegian versions of the Schedule for Affective Disorders and Schizophrenia for

School-Aged Children (K-SADS)[30] and the Structured Clinical Interview for the *DSM-5* (SCID)[31] were used, respectively. In comparison, the PAPA and CAPA are based on *DSM-IV,* but as the criteria for major depression have not changed from *DSM-IV* to *DSM-5,* this difference does not affect the assessment. To assess interrater reliability, raters who were blinded to all information recoded audiotapes of the interviews at age 4 (n = 86; intraclass correlation coefficient [ICC] = 0.91), age 10 (n = 110; ICC = 0.87), age 16 (n = 91; ICC = 0.81), and age 18 (n = 116; ICC = 0.94) years.

Physical Activity and Sedentary Time. At each measurement point, participants were instructed to wear a hip-mounted ActiGraph GT3X accelerometer (Manufacturing Technology Inc, Fort Walton Beach, FL) for 24 hours per day for 7 consecutive days, taking it off only when bathing or showering. Only participants with ≥3 days of recordings with ≥480 minutes of activity per day were included, and nonwear time was defined as sequences of consecutive zero counts lasting ≥20 minutes.[32] Accelerometer measurements typically produce output in activity counts per unit of time.[33] Daytime activity (06:00–23:59) (ie, excluding periods of nightly sleep) was used to calculate total PA (ie, daily counts), whereas sedentary time was defined as minutes per day with ≤100 counts per minute.[34] Moderate-to-vigorous PA (MVPA) was estimated based on the Evenson criteria,[35] applying a cut-off value of ≥2,296 counts per minute.

Sex. Each participant's national ID number was used to code sex assigned at birth.

Athletic Self-Esteem. At ages 8 and 10 years, the subscale Physical Abilities of the self-reported Self-Description Questionnaire (SDQ-I)[36] was used, whereas the corresponding and more developmentally appropriate Athletic Competence subscale of the Revised Self-Perception Profile for Adolescents (SPPA-R)[37] was applied at ages 12 to 18 years. Both subscales extract ability factors,[38] contain 5 items, and are rated on a 5-point Likert scale. To be positioned to examine construct validity, we applied both measures at age 12 years. The correlation between the SDQ-I and the SPPA-R Athletic Competence subscales was $r = .89$ ($p \leq .001$)[39] when attenuation was accounted for.[40] The SDQ-I and the SPPA-R have shown good psychometric properties.[36,37] At ages 8 and 10 years, internal consistency of the SDQI Physical Abilities subscales was $\alpha = 0.83$ and $\alpha = 0.85$, respectively, whereas for the SPPA-R Athletic Competence subscale used at ages 12 to 18 years, it ranged from $\alpha = 0.74$ to $\alpha = 0.86$.

Body Image. A sumscore of the 9 item Body Area Satisfaction Scale (BASS)[41] was used to assess body image. BASS captures the respondent's satisfaction with specific body parts and their weight and height, rated on a 5-point Likert scale. The measure displays good psychometric properties,[41] with internal consistency of the sumscore ranging from $\alpha = 0.66$ (age 8) to $\alpha = 0.74$ (age 16) in the present sample.

Sports Participation. Parents reported how many days per week their participating child took part in organized sports.

Statistical Analysis

Analyses were carried out using Mplus version 8.3, using a robust maximum likelihood estimator (MLR) to account for handling the anticipated right-skewedness of symptoms of depression. A full information maximum likelihood procedure was used to address missing data, and probability weights were used to account for the previously mentioned oversampling (see Methods). Participants with information from at least one data wave composed the analytical sample (n = 873). Two-sided p values <.05 were regarded as statistically significant.

To examine within-person relations between PA, sedentary time, and symptoms of depression, random intercept cross-lagged panel models (RI-CLPM)[6] were estimated, one for each of the activity factors (ie, total PA, MVPA, and sedentary time), respectively. In these models, latent random intercepts were estimated for each study variable with factor loading set to 1, representing the average level of these factors from age 6 to 18 years, thus capturing the between-person differences. The correlations among these random intercepts represent the between-person associations. Furthermore, for every observed variable at every time point, one latent variable was created with the factor loading set to 1 and the error variance in the observed variable set to 0, thereby transferring the variance to its latent counterpart. In effect, these time-specific latent variables capture the change (increase or decrease) from the person's mean during the study period. Finally, in the respective models, the activity variable (ie, total PA, MVPA, and sedentary time) at time point t was regressed on the t-1 value of this variable (ie, autoregressions). The same applied to depressive symptoms; however, because depression often waxes and wanes (eg, evident at one time point, receding at the next, then appearing again),[42] we included autoregressions across all time points (eg, allowing depressive symptoms at age 18 years not only to be regressed on depressive symptoms at age 16, but also at age 14 and earlier).

In a second step, relying on the models described above, multiple group analyses[43] were conducted to examine sex differences. We compared a model in which the cross-lagged paths were allowed to be freely, and thus differently, estimated across sex with a model in which the paths were constrained to be equal between boys and girls. The Satorra–Bentler scaled χ^2 test was used to examine whether constraining led to a statistically significant worsening of model fit. If a model in which the paths are freely estimated fits the data better than the constrained model, sex differences are present. We also examined whether the strength of the cross-lagged paths differed across age, thus comparing a model in which the paths were constrained to be equal between given ages vs a model in which no such constraints were added. If constraining the paths did not significantly deteriorate the model fit, no age effects were demonstrated.

Finally, using the best-fitting model based on the sex- and age-specific analyses, we tested mediation in the cross-lagged paths. To adjust for any direct effects, a path from total PA/MVPA/sedentary time to depression 4 years later was added to the model. As recommended, one mediator was tested at a time.[44] As bootstrapping is not possible with population weights, the Sobel test[45] was applied.

A variety of within-person techniques exist that may yield different results, depending on their initial assumptions about development and relation between variables.[46] Therefore, sensitivity analyses using 3 other common within-person approaches (ie, Dynamic Panel Model [DPM], Autoregressive Latent Trajectory Models with Structural Residuals [ALT-SR] and RI-CLPM without stationarity implied) were conducted to test whether these would yield results similar to those of the RI-CLPM models.

RESULTS

The mean and SD values of the main study variables are displayed in Table 2, and their bivariate correlations are shown in Table S1, available online. As expected, the correlations between PA and MVPA were high, both cross-sectionally and prospectively, whereas the negative associations between PA and sedentary time ranged from small (prospectively) to moderate (cross-sectionally). Depressive symptoms were cross-sectionally unrelated to or weakly associated with PA, MVPA, and sedentary time (r = –0.19 being the strongest estimate).

Within-Person Relations

The freely estimated RI-CLPM model examining the relation between total PA (daily counts) and depressive symptoms yielded good model fit (comparative fit index [CFI] = 0.959; Tucker–Lewis index [TLI] = 0.920; root mean square error of approximation [RMSEA] = 0.031). The results are displayed in Figure 1, showing significant negative within-person relations from total PA to depression symptoms from ages 14 to 16 and 16 to 18 years only, whereas the opposite direction of prediction was evident from ages 10 to 12 and 14 to 16 years. The paths from total PA to depressive symptoms showed a moderate effect size, whereas the 2 estimates capturing the relationship from depressive symptoms to total PA corresponded to moderate and strong effect sizes, respectively.[47] The sensitivity analyses testing the same model using 3 alternative within-person methods yielded comparable estimates for the paths from total PA to symptoms of depression; however, the results for the opposite direction of influence did not fully mirror the main results (Figure S2, available online).

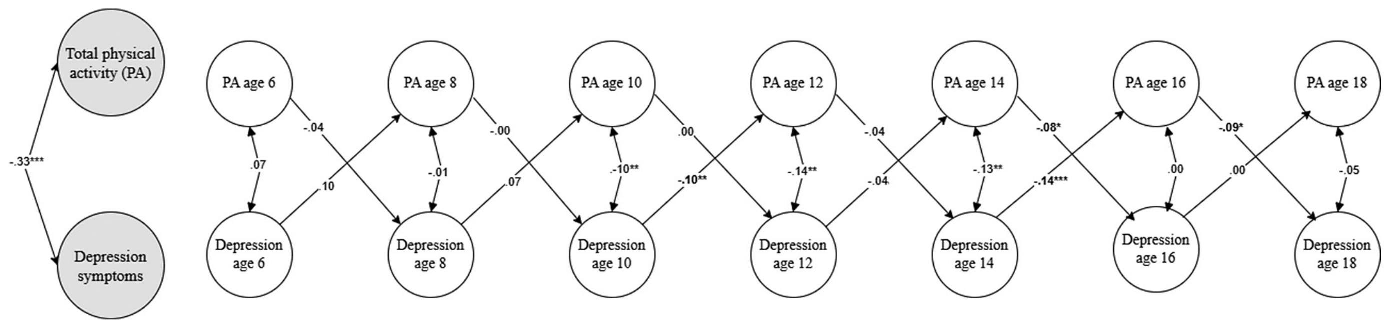
The model estimating the relations between MVPA and depressive symptoms also showed good fit to the data (CFI = 0.961; TLI = 0.924; RMSEA = 0.031), and the same cross-lagged paths identified for total PA were evident for MVPA (Figure 2). The third model, capturing sedentary time, also displayed good fit (CFI = 0.956; TLI = 0.914;

TABLE 2 Means and SDs of the Main Study Variables at Age 6 Years (n = 873)

	Mean	SD
PA age 6	614.28	180.88
PA age 8	589.79	198.41
PA age 10	516.05	178.47
PA age 12	462.44	160.06
PA age 14	401.11	157.14
PA age 16	328.72	148.90
PA age 18	328.17	130.17
MVPA age 6	71.23	23.95
MVPA age 8	70.80	25.89
MVPA age 10	65.69	24.04
MVPA age 12	60.49	23.11
MVPA age 14	54.17	22.35
MVPA age 16	35.99	21.80
MVPA age 18	41.68	19.96
Sedentary time age 6	514.92	54.86
Sedentary time age 8	553.32	63.97
Sedentary time age 10	594.89	66.31
Sedentary time age 12	619.50	71.90
Sedentary time age 14	666.12	81.42
Sedentary time age 16	608.35	104.35
Sedentary time age 18	661.35	99.10
Symptoms of depression age 6	0.53	0.86
Symptoms of depression age 8	0.46	0.79
Symptoms of depression age 10	0.53	0.89
Symptoms of depression age 12	0.62	1.09
Symptoms of depression age 14	0.82	1.37
Symptoms of depression age 16	0.25	0.96
Symptoms of depression age 18	1.58	2.66

Note: MVPA = moderate-to-vigorous physical activity, minutes per day; PA = total physical activity, number of counts per day; Sedentary time = total counts per day.

FIGURE 1 Standardized Random Intercept Cross-Lagged Panel Model (RI-CLPM) Estimates of the Within-Person Relations Between Daily Physical Activity (Total Counts) and Symptoms of Depression From Age 6 to 18 Years



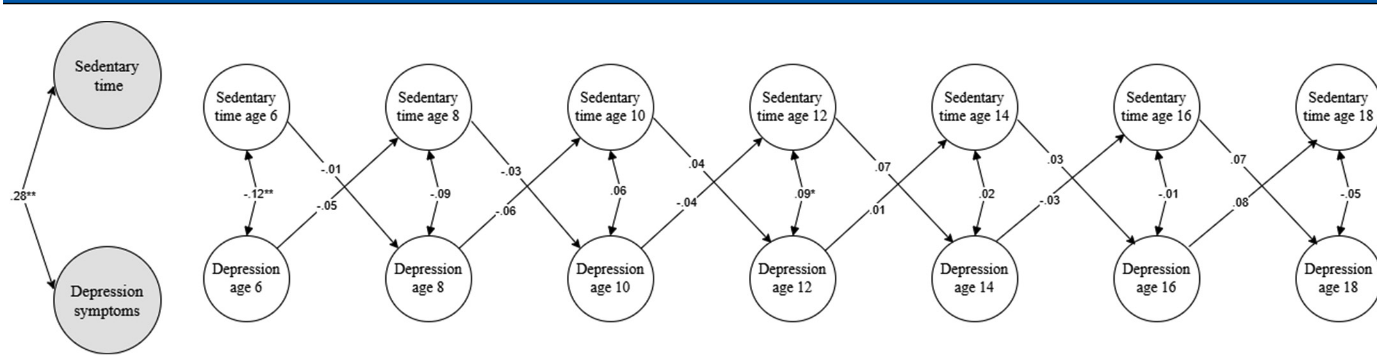
Note: *Larger gray circles represent random intercept estimates; straight lines represent within-person cross-lagged relations between daily physical activity and symptoms of depression (smaller white circles); concave lines represent associations. For illustration purposes, only the latent variables are displayed in the figure (ie, not the observed study variables on which they are based), and estimated autoregressions are not included. PA = total physical activity, daily counts.*

RMSEA = 0.031), but no within-person relations between sedentary time and depressive symptoms were found (Figure 3). All estimates of the models corresponding to Figures 1 to 3 are shown in Tables S2 to S4 (available online).

In a second step, and relying on the above models, we conducted multigroup comparisons, testing whether the strength of the estimated within-person cross-lagged paths from total PA/MVPA/sedentary time to depressive symptoms differed between the sexes (ie, constraining this direction of paths only, not the paths from depression to PA/MVPA/sedentary time). According to the Satorra–Bentler χ^2 tests, models in which these specific paths were constrained to be equal between the sexes did not differ from comparable models in which the paths were freely estimated (total PA: $\Delta df = 6$; $\Delta\chi^2 = 11.47$; $p = .075$; MVPA: $\Delta df = 6$; $\Delta\chi^2 = 8.77$; $p = .187$; sedentary time: $\Delta df = 6$; $\Delta\chi^2 = 9.87$; $p = .131$), which suggests that sex differences do not exist. The same was found for the opposite direction of influence: there were no sex differences in the strengths of the paths from depressive symptoms to total PA/MVPA/sedentary time (ie, one model for each was tested) (total PA: $\Delta df = 6$; $\Delta\chi^2 = 10.99$; $p = .089$; MVPA: $\Delta df = 6$; $\Delta\chi^2 = 6.43$; $p = .377$; sedentary time: $\Delta df = 6$; $\Delta\chi^2 = 8.93$; $p = .178$). Thus, the models including the entire sample, not the sex-specific ones, constitute our main models.

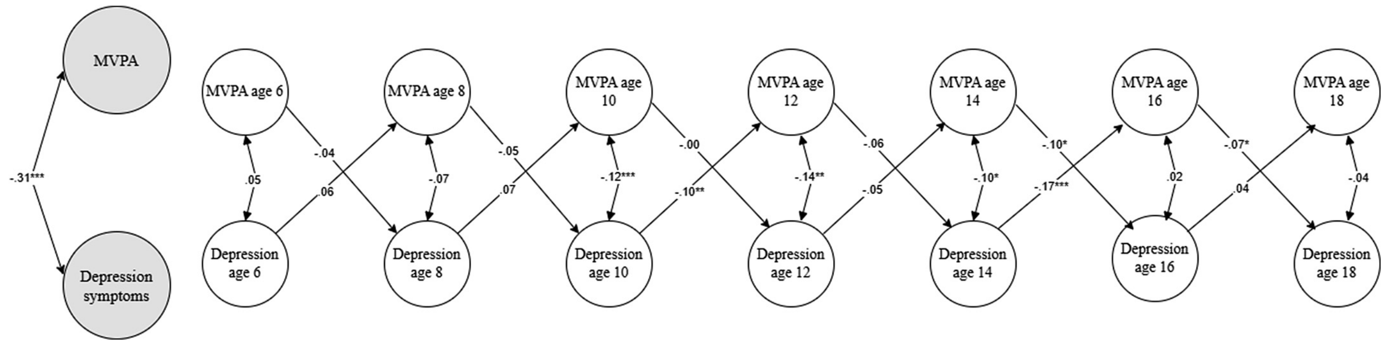
As displayed in Figures 1 and 2, participants who became more physically active from middle to late adolescence showed a decreased number of depressive symptoms 2 years later, whereas from age 6 to 14 years, no such within-person relations were found. To test whether this age difference was significant for each of the 2 PA outcomes respectively, we compared the main models with a model in

FIGURE 2 Standardized Random Intercept Cross-Lagged Panel Model (RI-CLPM) Estimates of the Within-Person Relations Between Moderate-to-Vigorous Physical Activity (MVPA) and Symptoms of Depression From Age 6 to 18 Years



Note: *Larger gray circles represent random intercept estimates; straight lines represent within-person cross-lagged relations between moderate-to-vigorous physical activity (minutes per day) (MVPA) and symptoms of depression (smaller white circles); concave lines represent associations. For illustration purposes, only the latent variables are displayed in the figure (ie, not the observed study variables on which they are based), and estimated autoregressions are not included. MVPA = moderate-to-vigorous physical activity (minutes per day).*

FIGURE 3 Standardized Random-Intercept-Cross-Lagged Panel Model (RI-CLPM) Estimates of the Within-Person Relations Between Sedentary Time (Total Counts) and Symptoms of Depression From Age 6 to 18 Years



Note: Larger gray circles represent random intercept estimates; straight lines represent within-person cross-lagged relations between sedentary time and symptoms of depression (smaller white circles); concaved lines represent associations. For illustration purposes, only the latent variables are displayed in the figure (ie, not the observed study variables on which they are based), and estimated autoregressions are not included.

which the paths from total PA/MVPA to depressive symptoms were constrained to be equal from childhood to middle adolescence (ages 6-8, 8-10, 10-12, and 12-14 years) and different from middle adolescence to late adolescence (constraining paths from ages 14-16 and 16-18 to be equal). Adding these constraints did not deteriorate the fit, either for total PA (Δdf $= 4$; $\Delta\chi^2 = 2.97$; $p = .564$) or for MVPA (Δdf $= 4$; $\Delta\chi^2 = 2.15$; $p = .710$), which indicates that the estimated effects were not significantly stronger from middle to late adolescence as compared to earlier ages.

Between-Person Relations

As shown in Figures 1 and 2, there were medium-sized negative associations between the random intercepts of PA/MVPA and symptoms of depression. Sedentary time was positively associated with depressive symptoms at the between-person level (Figure 3).

Mediation Analyses

Descriptives of the mediators are displayed in Table S5, available online. Since no within-person relations were found for sedentary time and symptoms of depression (Figure 3), mediation was not tested. For total PA and MVPA, one mediator was tested at a time. Thus, 6 models were estimated (Figure S3, available online). The models yielded good fit (Table S6, available online), but none of the assumed mediators mediated the relation between total PA/MVPA and symptoms of depression (Table S7, available online).

DISCUSSION

Using 7 waves of biennially collected data (ages 6-18 years) from a birth cohort of Norwegian children, we aimed to identify within-person relations between objectively measured total PA, MVPA, and sedentary time and symptoms of depression assessed by clinical interviews. The results revealed that in middle to late adolescence, individuals who decreased their levels of total PA were at risk for an increased number of symptoms of depression 2 years later, but no significant age difference was found. We also found no sex differences. The same pattern of relations was found for MVPA, whereas sedentary time was unrelated to depressive symptoms. Regarding the opposite direction of influence, an increased number of depressive symptoms predicted decreased levels of PA from ages 10 to 12 and 14 to 16 years. All within-person relations were of moderate-to-large effect size.[47] Neither athletic self-esteem, body image, nor sports participation mediated the within-person relation between total PA/MVPA and depressive symptoms.

Physical Activity May Protect Against Symptoms of Depression From Middle to Late Adolescence

Our finding that increased PA predicted a decreased number of depressive symptoms from middle to late adolescence at the individual level extends existing research showing a negative association between the PA and depressive symptoms.[5] No previous study of objectively measured PA has separated within-person from between-person effects, but our findings accord with the those of Ames *et al.*,[10] who found negative within-person relations between self-reported PA and depressive symptoms in a sample of 12- to 18-year-old youths. Mendelian randomization studies of adults also suggests that PA protects against depression.[48]

The strengths of the paths from PA/MVPA to depressive symptoms did not significantly differ between the sexes. This accords with meta-analytical evidence indicating that sex does not moderate the association between PA and depression.[5] Thus, although girls show higher increases in depressive symptoms than boys in the transition to adolescence,[2] and although boys tend to be more physically active and less sedentary than girls,[26] the relations between these variables do not seem to differ by sex. Furthermore, the paths from PA to depressive symptoms were evident from ages 14 to 16 and 16 to 18 years only, not at earlier ages. This is in accordance with a meta-analysis of PA interventions that showed greater reductions in depressive symptoms among youths above age 13 years.[3] However, the seeming age difference in our study was nonsignificant. Thus, it does not indicate that PA plays a more important role in protecting against the development of depressive symptoms at some ages than others. Before firm conclusions can be drawn, this null finding should be replicated in larger samples. Furthermore, although no significant within-person effects were found in childhood and early adolescence, shorter-term effects may be evident, which should be examined in future studies. It should also be acknowledged that the revealed estimates were of medium effect size.[47] Our not finding large effects is not surprising, given the multitude of factors explaining why some youths develop depressive symptoms whereas others do not.[2] Furthermore, although within-person effects of PA on depression were moderate at each specific age, they may accumulate over time, making a stronger contribution to depression than is depicted in each coefficient.

No Within-Person Relations Found Between Sedentary Time and Depressive Symptoms

Although previous research reports sedentariness to be positively associated with depression,[9] the one within-person study that we identified did not find that sedentary time predicted depressive symptoms in 10-year-olds assessed 1 year later.[13] A Mendelian randomization study of adults also found PA, but not low sedentariness, to protect against depression.[48] Finding that PA, but not low levels of sedentary time, is linked to mental health at the individual level underscores that sedentariness is not simply the opposite of PA. PA is associated with a sense of accomplishment, self-esteem, neurophysiological effects, social interactions, companionship, and belongingness,[17] among other outcomes, possibly explaining the above findings. However, as discussed below, we did not find athletic self-esteem, body image, or sports participation to mediate the relationship between PA/MVPA and depressive symptoms in this study.

Nonsignificant Mediation Effects

The nonsignificant mediation effects that were found may simply reflect that the examined mediators do not act as mechanisms linking PA and depressive symptoms at the within-person level. However, it is also possible that some or all of these mediators are operative, but that the effect was concealed: the within-person effects may be too small for us to be positioned to identify mediation (that is, the study may be lacking the statistical power to detect mediation effects), and the lags between measurement points may be too long for mediation to be evident (ie, the mediation effects might be more immediate).

Depression Predicting Reduced Physical Activity

Youths who had increased levels of depressive symptoms at age 10 and 14 years compared to their own mean level of depression decreased their PA levels relative to their own mean 2 years later. These findings accord with a recent within-person study of adults[49] and are not very surprising, given that symptoms of depression include loss of interest or pleasure in activities, anhedonia, fatigue or loss of energy, psychomotor retardation, and sleep difficulties, which all may contribute to reduced levels of PA/MVPA.

The strengths of the present study are the longitudinal design, the use of accelerometers and clinical interviews, and the within-person approach. The downside of such time- and resource-demanding data collection is the size of the sample. Although the study included around 800 participants and had low attrition, it is still not optimal for testing sex differences and mediation.[14] The risk for the study being underpowered to detect such effects indicates that the results of these specific analyses should be cautiously interpreted.

Furthermore, although the 2-year time lags of our study are appropriate considering the many data waves and the corresponding burdens placed on the participants, we might miss important changes that take place within these lags. On the other hand, our focus is on how changes in total PA/MVPA/sedentary time are related to changes in depressive symptoms over time and throughout development, which justifies the length of the lags. Nevertheless, our findings may not generalize to shorter time lags. Also, the findings cannot be generalized to clinical samples of adolescents with depression, as the association between PA and depression is stronger in clinical samples.[4] Regarding generalizability, the prevalence of mental health problems is lower in Norway compared to many other countries,[50] and Norwegian children are reportedly more physically active than other European children.[26] On the other hand, there is no immediate reason to believe that this will affect the relation between PA and mental health. Finally, using wearable devices is associated with increased PA and less sedentary behavior[51]; thus, wearing accelerometers may have boosted the participants' PA levels. However, that does not imply that the within-person relation to depression should be altered, as a methods effect would be reflected in the overall level (ie, random intercept) of each person and not in each person's deviation from this mean.

This study of children assessed every second year from ages 6 to 18 years shows that from middle to late adolescence, individuals who increase their PA levels are less likely to develop symptoms of depression compared to what they otherwise would. Thus, in this age period, both total PA and MVPA may protect against depressive symptoms. The findings support the etiological role of PA in the development of depression in this age period, and suggest that interventions aimed at increasing PA may help to prevent the development of depressive symptoms.

CRediT authorship contribution statement

Silje Steinsbekk: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Joakim Skoog:** Methodology, Formal analysis, Data curation. **Lars Wichstrøm:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

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Consent has been provided for descriptions of specific patient information.

Data Sharing: The data cannot be made available because the study is still ongoing and consent restrictions from participants apply.

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