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CROSS-SECTIONAL AND LONGITUDINAL ASSOCIATIONS BETWEEN OBJECTIVELY MEASURED SEDENTARY BEHAVIOUR, LIGHT AND MODERATE TO VIGOROUS PHYSICAL ACTIVITY, AND DEPRESSIVE AND ANXIETY SYMPTOMS: A POPULATION-BASED MULTIWAVE COHORT STUDY

Master's thesis

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Cross-sectional and longitudinal associations between objectively measured sedentary behaviour, light and moderate to vigorous physical activity, and depressive and anxiety symptoms: a population-based multiwave cohort study

Abstract

Physical (in)activity has been cross-sectionally and longitudinally associated with mental health problems, depression and anxiety. So far, physical activity's (PA) objective measures remain underutilized compared to subjective measures. In the current thesis, cross-sectional and longitudinal associations between objectively measured sedentary behaviour (SB), light PA (LPA), moderate to vigorous PA (MVPA), and both depressive and anxiety symptoms were investigated using the data from the younger cohort of the Estonian Children Personality Behaviour and Health Study (ECPBHS). Physical activity and mental health data were measured when participants were 18, 25, and 33 years old. Objective PA was measured by ActiGraph (first and second wave) and GENEActive (third wave) accelerometers. Associations were investigated by cross-lagged panel analysis. Associations between SB and MVPA, but not between LPA and depressive and anxiety symptoms, were found. Both SB and MVPA predicted cross-sectional and longitudinal depressive symptoms, and MVPA predicted cross-sectional anxiety symptoms. According to our findings, to keep anxiety and depressive symptoms low and prevent depression in the future, it is recommended to use interventions that decrease SB levels and increase MVPA levels. Due to inconsistent results, future studies are warranted to investigate the objectively measured PA and mental health associations both cross-sectionally and longitudinally.

Keywords: CLPM, objective PA, anxiety, depression

Läbilõikelised ja prospektiivsed seosed objektiivselt mõõdetud liigistuvaja, madala ja mõõduka kuni kõrge kehalise aktiivsuse ning depressiooni ja ärevuse sümptomite vahel: tavapopulatsioonipõhine mitmelaineline kohortuuring

Kokkuvõte

Kehalist (in)aktiivsust on seostatud depressiooni ja ärevusega nii läbilõikelistes kui propektiivsetes uuringutes. Tänaseni on objektiivsed kehalise aktiivsuse (KA) mõõtevahendid alakasutatud võrreldes subjektiivsete mõõtevahenditega. Käesolevas töös uuriti läbilõikelisi ja prospektiivseid seoseid objektiivselt mõõdetud liigistuvaja, madala KA, mõõduka kuni kõrge KA (MVPA) ning depressiooni ja ärevuse sümptomite vahel. Seoste uurimiseks kasutati Eesti laste isiksuse, käitumise ja tervise uuringu (ELIKTU) esimese kohordi andmeid. Kehalise aktiivsuse ja vaimse tervise andmeid koguti, kui uuritavad oli 18, 25 ja 33 aastat vanad. Objektiivne KA oli mõõdetud ActiGraph aktseleromeetriga esimeses ja teises laines ning GENEActiv aktseleromeetriga kolmandas laines. Kehalise aktiivsuse ja vaimse tervise vahelisi seoseid uuriti *cross lagged panel analysis* meetodi abil. Leiti seosed liigistuvaja ja MVPA, aga mitte madala KA ning depressiooni ja ärevuse vahel. Liigistuvaeg ja MVPA mõlemad ennustasid läbilõikelist ja prospektiivset depressiooni, samuti ennustas MVPA läbilõikelist ärevust. Järeldati, et sekkumised, mis tõstavad MVPA-d ja vähendavad liigistuvaega, aitavad hoida läbilõikelise depressiooni ja ärevuse sümptomite esinemise madalamal ning vähendavad depressiooni esinemise tõenäosust prospektiivselt. Tulenevalt ebajärjekindlatest tulemustest on objektiivselt mõõdetud KA ja vaimse tervise läbilõikelised ja prospektiivsed uuringud jätkuvalt vajalikud.

Märksõnad: CLPM, objektiivne KA, ärevus, depressioon

Research is increasingly supporting the idea that physical activity is important for mental health (Biddle & Asare, 2011; Rebar et al., 2015; Rodriguez-Ayllon et al., 2019; Sampasa-Kanyinga et al., 2020). However, over 25% of adults worldwide (1.4 billion people) are insufficiently active, and globally, around 1 in 3 women and 1 in 4 men do not do enough physical activity to maintain their health (World Health Organization (WHO), 2022); physical inactivity is the biggest public health problem of the 21st century (Blair, 2009). At the same time, according to the Injuries and Risk Factors Study, anxiety and depressive disorders were the two most disabling mental disorders, ranking in the top 25 global causes of burden (Global Burden of Disease, 2020). Thus, the prevention and treatment of depression and anxiety are important in the interest of public health (Cuijpers et al., 2012; Marquez & Saxena, 2016), especially when considering WHO's assessment that the prevalence of anxiety and depressive symptoms are rising globally (World Health Organization, 2020).

Physical activity

Physical activity (PA) is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure", and it includes activities of daily life (sports, household, etc.), exercise (planned, structured, and repetitive PA), and physical fitness ("a set of attributes that are either health- or skill-related") (Caspersen et al., 1985). PA can be classified according to intensity as sedentary behaviour (SB), light (LPA), moderate (MPA), vigorous (VPA), or moderate-vigorous (MVPA) physical activity. This is based on its metabolic equivalents of task (MET), a measure of energy expenditure during PA compared to the body at rest.

Sedentary behaviour is defined as "energy expenditure ≤1.5 METs while in a sitting or reclining posture", whereas it is recommended to use the term "inactive" to describe those who are not meeting specified PA guidelines (e.g., insufficiently performing in amounts of MVPA) (Sedentary Behaviour Research Network, 2012). Light intensity PA energy expenditure is between 1.6 < 3.0 METs and includes domestic or occupational activities such as washing dishes, cooking, working at a computer desk, or performing other office duties (Ainsworth et al., 2000). MVPA includes both moderate intensity PA, whose energy expenditure ranges from 3 < 6 METs and includes activities such as walking (at least up to 10 minutes), gentle swimming, and golf, and vigorous intensity PA that starts with an energy expenditure of 6 METs, including activities such as jogging, cycling, and aerobics (Australian Institute of Health and Welfare, 2003).

Measuring physical activity

There are two main categories of methods for investigating physical activity: subjective methods and objective methods. Self-report questionnaires as subjective measures are the most commonly used methods for investigating physical activity as they are easy to use and low cost (Warren et al., 2010). For investigating PA objectively, wearable monitors such as accelerometers, pedometers, and heart rate monitors can be used. The trend of using objective measures in PA studies increased significantly between 2006 and 2016, but still, these devices remain underutilized compared to subjective measures (Silfee et al., 2018). The use of objective measures can help overcome some of subjective measure pitfalls such as reporting and recall biases, the influence of mood, anxiety, depression, cognition, and disability on responses (Rickli, 2000), and provide a more accurate measure of daily and habitual PA. It has also been found that subjective measures are particularly poor at detecting SB and LPA, such as casual walking and light housework (Matthews et al., 2012).

Hukkanen et al. (2018) found that PA investigation is strongly dependent on the method, and different methods might not be interchangeable. Adamo et al. (2009) reported in a systematic review that 72% of the subjective measures overestimated the objectively measured values. In a sample of 1751 adults, who wore an accelerometer and, in parallel, completed the Physical Activity Questionnaire (IPAQ), both men and women reported less sedentary behaviour and more vigorous PA compared with objective measurements (Dyrstad et al., 2014). Similarly, Atienza et al. (2011) found in a nationally representative sample of U.S. adults that objectively measured PA is more strongly associated with physiological and anthropometric biomarkers than self-reported PA, specifically MVPA. A systematic review also supports previous studies suggesting that the method of measurement may have an important impact on the observed levels of PA (Prince et al., 2008).

Using accelerometer to measure physical activity

An accelerometer is commonly used and evaluated as an objective measure in epidemiological research, and it gives objective measures about frequency, duration, and intensity of overall PA and time spent in activities by measuring acceleration of the body (Chen & Bassett, 2005). Hip-worn and wrist-worn accelerometers are typically used in PA assessments. The ActiGraph accelerometer, usually worn on the hip rather than the wrist, is the most commonly used validated accelerometer in PA studies (Migueles et al., 2017). However, it has been found that wrist-worn accelerometers are more preferred by participants due to their higher comfort, and the wrist-worn accelerometers have fewer days with insufficient data (Scott et al., 2017), which supports conducting the study. For measuring PA intensity, the wrist-worn device GENEActiv can also be used as an accurate assessment measure. Physical activity measures from waist-worn ActiGraph have been reported to be potentially comparable to wrist-worn GENEActiv devices (Rowlands et al., 2014; Scott et al., 2017).

Recordings of body acceleration and deceleration are the main data outcomes from accelerometers (Strath et al., 2013). To convert monitor signals into energy expenditure units (such as kilocalories or METs) or activity intensity categories, accelerometers must be calibrated. Later, accelerometer values can be converted into PA outcomes such as kilocalories per week, METs per minute or hour, or how much time an individual spends in SB, LPA, or MVPA.

Depression

As said above, physical (in)activity has been associated with different mental health conditions and disorders. One of the examples is depression. Depression (also known as major depressive disorder (MDD)) is a common mental disorder that may significantly affect an individual's wellbeing and daily functioning (Kessler, 2012). Depressive symptoms can vary from mild to severe, and during a depressive episode, an individual experiences a depressed mood, decreased enjoyment or interest in activities. An estimated 3.8% of people in the population are suffering from depression, including 5% of adults (4% of males and 6% of women) and 5.7% of individuals over 60 years old (WHO, 2023). Depression shares comorbidity with many mental and physical disorders, for instance cardiovascular diseases (Vaccarino et al., 2020; Berk et al., 2023), diabetes (Arnaud et al., 2022), multiplex sclerosis (Steffen et al., 2020), sleep disorders, any anxiety disorders, and dysthymia (Thaipisuttikul et al., 2014). According to a recent meta-analysis of 49 longitudinal cohort studies involving 1,837,794 person-years reports, people with high levels of PA had 17% reduced risk of depression (OR = 0.83) than people with low PA, and PA had a protective effect against the emergence of depression in youths (adjusted OR=0.90), in adults (adjusted OR=0.78, 95%), and in older people (adjusted OR=0.79, 95%) (Schuch et al., 2018).

Depression and physical activity

Physical activity has been shown to have protective effects on the state of depression, both in subjective (Strawbridge et al., 2002; Janka et al., 2011; Lindwall et al., 2011; Mammen & Faulkner, 2013; Marques et al., 2020) and objective (Vallance et al., 2011; Loprinzi, 2013; Schuch et al., 2017; Jung et al., 2018; Kandola et al., 2019) measurements. People who are physically more active have a reduced risk of being diagnosed with depression (Strawbridge et al., 2002; Lindwall et al., 2011; Vallance et al., 2011; Loprinzi, 2013; Schuch et al., 2017; Schuch et al., 2018). Conversely, sedentary behaviour and physical inactivity have been shown to be a risk factors for higher depression scores (Jacka et al., 2011; Vallance et al., 2011; Schuch et al., 2017; Kandola et al., 2020).

There is a systematic review and meta-analysis based on only objectively measured PA studies, and it showed a potential protective effect of PA on depression (Gianfredi et al., 2020). Different PA intensity levels are investigated in PA and depression studies to explain the more specific effects of PA on depression. A longitudinal cohort study found that SB in adolescence, measured objectively between 12-16 years of age in three study waves, is associated with a higher risk of depressive symptoms at 18 years of age (Kandola et al., 2020). They reported that increasing LPA and decreasing SB, as well as increasing MVPA, may help to reduce the prevalence of depression. An objectively measured PA study on a Swedish longitudinal population-based sample of 1,117,292 males showed that low cardiovascular fitness in males at age 18 is associated with increased risk for serious depression in adulthood (hazard ratios (HR) = 1.96, 95%) (Åberg et al., 2012). In a cross-sectional study in a sample of 2,862 adults where PA was measured objectively, lower odds of depression were associated with increasing MVPA and decreasing sedentary behaviour (Vallance et al., 2011). It has been found that objectively measured PA, such as sedentary behaviour is associated with depression (Vallance et al., 2011; Schuch et al., 2017; Kandola et al., 2020), and therefore, even LPA may have antidepressant effects (Loprinzi, 2013; Ku et al., 2018; Jung et al., 2018; Kandola et al., 2020) and MVPA is also inversely associated with depression (Vallance et al., 2011; Loprinzi, 2013; Schuch et al., 2017) cross-sectionally and longitudinally.

Anxiety

Physical (in)activity has also been associated with anxiety and anxiety disorders. Anxiety is an emotion that everyone can feel sometimes, but anxiety disorders are often experienced as intense and excessive feelings of fear and worry (WHO, 2023). An estimated 4% of people worldwide are currently suffering from anxiety disorder, and by affecting 301 million people worldwide, anxiety disorders are the world's most common mental disorders (GBD Results Tool, 2020). Anxiety disorders have comorbidity with many mental and physical disorders, for instance, chronic physical disorders (i.e., hypertension, arthritis, asthma, ulcers), dysthymia (Kessler et al., 2003), depression (Thaipisuttikul et al., 2014) and attention deficit hyperactivity disorder (ADHD) (Kessler et al., 2006). According to a recent meta-analysis of 13 unique longitudinal cohort studies involving 357,424 person-years, people with higher PA (versus lower PA) were at reduced odds of developing anxiety (adjusted OR = 0.74) (Schuch et al., 2019).

Anxiety and physical activity

Anxiety's relations with different levels of PA are not as well assessed as relations with depression, especially longitudinal associations with objectively measured PA. Still, there are several studies that have shown the protective effects of PA on anxiety. SB, or physical inactivity, has been shown as a risk factor for higher anxiety scores, which are mainly assessed in subjective (De Mello et al., 2013; Teychenne et al., 2015; McDowell et al., 2019; Allen, Walter & Swann, 2019; Silva et al., 2020) and less assessed in objective (Helgadóttir et al., 2015, Kandola et al., 2022) measurement studies. Unfortunately, subjective measures have been reported to be particularly poor at detecting SB and LPA (Matthews et al., 2012), so study results investigating these PA levels may be in doubt. However, it has been shown that physically more active people have a lower risk of being diagnosed with an anxiety disorders (Baumeister et al., 2017), but these findings are inconsistent (Felez-Nobrega et al., 2021).

Systematic reviews investigating relations between PA and anxiety symptoms support the posture of PA's protective effects on having anxiety disorders (Teychenne et al., 2015; Kandola et al., 2018). However, some review studies report inconclusive results in examining the relationship between PA and anxiety, specifically with LPA (Felez-Nobrega et al., 2021). Felez-Nobrega et al. (2020) found that self-reported MVPA and leisure SB (screen and non-screen based) but not LPA were significantly associated with lower trait anxiety, but no associations were found for device-based measures of PA and SB. On the another hand, SB has been reported as a risk factor for the presence of anxiety symptoms in a systematic review and meta-analysis based on 13 observational studies, including one objective PA assessment (Allen et al., 2019). The same conclusions have been reported by a systematic review including nine observational studies (seven cross-sectional and two longitudinal; one objectively measured PA study), concluding that there is moderate evidence for a positive relationship between total SB and anxiety risk (i.e., anxiety risk increases as SB time increases) (Teychenne et al., 2015).

It is harder to find objectively measured SB and PA studies investigating associations with anxiety. One study that fit the criteria was a UK longitudinal cohort study with 4257 adolescents aged 12 at baseline, which found a positive association between SB at ages 12, 14, and 16 and anxiety symptoms at the age of 18, showing SB as a possible risk factor for increasing anxiety symptoms during adolescence (Kandola et al., 2022). By making a theoretical replacement, they also found lower anxiety symptoms by the age of 18 if one hour of daily SB at ages 12, 14, and 16, was replaced with LPA. Whereas, replacing SB with MVPA did not make any differences in anxiety symptoms. Another study in the adult population (n = 165) where SB and PA were measured by accelerometers reported that the PA pattern of people aged 18–65 years with depressive and/or anxiety disorders is associated with a high SB and low fulfillment of PA guidelines (low scores of MVPA) (Helgadóttir et al., 2015). There are not many studies investigating objective PA and anxiety relations, but the ones that were found show particularly SB associations with anxiety.

Current view on research studies examining relations between physical activity and depression and anxiety

According to a meta-meta-analysis PA reduces depression by a medium effect [95% CI: −0.93 to −0.06] and anxiety by a small effect (95% CI: −0.66 to −0.11) in general adult populations (Rebar et al., 2015). Physical activity's anxiolytic and antidepressant effects have been reported in several meta-analyses (Vancampfort et al., 2017; Schuch et al., 2018; Allen et al., 2019; Gianfredi et al., 2020) and review studies (Mammen & Faulkner, 2013; Teychenne et al., 2015; Vancampfort et al., 2017; Kandola et al., 2018). However, most of the general PA data is based on subjective PA studies. In PA measurement studies, cross-sectional and/or longitudinal associations with both depression and anxiety have been found with SB (Allen et al., 2019), LPA (Mammen & Faulkner, 2013; Felez-Nobrega et al., 2020) and MVPA (Felez-Nobrega et al., 2020; Marques et al., 2020). The relationship of SB and different PA levels with depression and anxiety has been studied, but there is a particular lack of evidence from objectively measured data studies.

The present study

Available evidence from several cross-sectional and longitudinal investigations suggests inverse relationships between light physical activity (LPA) and moderate-to-vigorous physical activity (MVPA) and depressive and anxiety symptoms, and positive relationships between sedentary behavior (SB) and depression and anxiety. This study examined cross-sectional and longitudinal associations between objectively measured physical activity and symptoms of depression and anxiety among the general population using data from the Estonian Children Personality Behaviour and Health Study (ECPBHS).

The aim of the present study was to utilize a sample of longitudinal cohort in three study waves when subjects were 18, 25, and 33 years old to address two questions and four hypotheses. First, are device-measured sedentary behavior, light physical activity (LPA), and moderate-to-vigorous physical activity (MVPA) associated with depressive and anxiety symptoms among the sample of Estonian adults? Second, if yes, then what kind of cross-sectional and longitudinal associations exist between device-measured SB, LPA, and MVPA and depressive and anxiety symptoms among the sample of Estonian adults?

Based on the scientific literature, four hypotheses were formulated:

H1: individuals with higher levels of LPA and MVPA have less symptoms of depression;

H2: individuals with higher levels of LPA and MVPA at the age of 18 have less symptoms of depression at the ages of 25 and 33, and individuals with higher levels of LPA and MVPA at the age of 25 have less symptoms of depression at the age of 33 (see cross-lagged paths in Figure 1);

H3: individuals with less SB time have less symptoms of anxiety and depression;

H4: individuals with less SB time at the age of 18 have less symptoms of anxiety and depression at the ages of 25 and 33, and individuals with less SB time at the age of 25 have less symptoms of anxiety and depression at the age of 33 (see cross-lagged paths in Figure 1).

Method

Participants

The present study is based on the population-based sample data collected by the Estonian Children Personality Behaviour and Health Study (ECPBHS) (Harro et al., 2001). ECPBHS is a longitudinal multidisciplinary study that grew out of the original European Youth Heart Study (EYHS) in Estonia, initiated in 1998.

Participants in ECPBHS were invited from all public schools in Tartu City and County, of which 54 schools out of 56 agreed, and a random sample of 25 schools was selected using cluster sampling and probability proportional to school size. The sample represented the proportion of urban and rural, Estonian and Russian (two main ethnic groups in Estonia) boys and girls of certain ages, 9 and 15 years old, living in one county. In the first ECPBHS study wave in 1998/99, all children of each sampled school at the age of 9 and 15 years and their parents were asked to participate, and 76% of them agreed. The agreement rate was the highest in urban Estonian girls and the lowest in younger Russian children (Harro jt., 2001). This study is based on the ECPBHS data from follow-up studies of the younger cohort who participated in the third study wave in 2007/2008 (the first wave in the present study), the fourth study wave in 2014/2015 (the second wave in the present study), and the fifth study wave in 2022/2023 (the third wave in the present study).

Measures

Depressive symptoms: Montgomery-Asberg Depression Rating Scale self-reported version (MADRS-S)

Depressive symptoms were measured in all three study waves with a self-assessment version of the Montgomery-Asberg Depression Rating Scale (MADRS-S) (Svanborg & Asberg, 1994). MADRS-S is a 9-item scale constructed on the basis of the original expert-rated scale of MADRS (Montgomery & Asberg, 1979). Like in MADRS, the total score is the sum of all answered items, where a score of 0–6 indicate the absence of symptoms, while scores of 7–19 indicates mild depression, 20–34 indicate moderate depression, and 35-60 indicate severe depression (Snaith et al., 1986).

Anxiety symptoms: State-Trait Anxiety Inventory (STAI)

Anxiety was measured in all three study waves with an Estonian version of the self-report questionnaire State-Trait Anxiety Inventory (STAI) (Kreegipuu, 1997), a 40-item psychological test for adults designed to measure feelings of immediate anxiety that an individual feels at the current moment (state anxiety) and dispositional anxiety (trait anxiety) (Spielberg et al., 1983). STAI scores of 20-37 indicate no or mild anxiety symptoms, 38–44 indicate moderate anxiety symptoms, and 45–80 indicate severe anxiety symptoms (Spielberger et al., 1983). Only state anxiety was included in the present study.

Physical activity and sedentary behaviour: CSA Actigraph monitor (model GT1M)

The ActiGraph activity monitors (formerly known as the CSA activity monitor) are the most frequently used wearables to measure objective PA by researchers (Migueles et al., 2017). ActiGraph monitors were used in two study waves, in 2007/2008 and 2014/2015, to measure physical activity and sedentary behaviour objectively. An accelerometer was worn for 6 consecutive days (including at least one weekend day) on the right hip during the daytime. Participants removed accelerometers during all aquatic activities (e.g., bathing), and prior to analysis, data from partial days of wear (1st day and 6th day) were removed. Only subjects who had at least 3 consecutive days of data with one weekend day and at least 8 consecutive hours of physical activity results per day met the criteria and were involved in the present study.

Physical activity and sedentary behaviour: GENEActiv

To measure physical activity and sedentary behaviour objectively, the GENEActiv accelerometers were used in one study wave, in 2022/2023. An accelerometer was worn on individuals' non-dominant wrist for 7 consecutive full and two partial days. Prior to analyses, data from partial days of wear (1st day and 9th day) were removed. Only subjects who had at least 3 consecutive days of data with one weekend day and at least 20 consecutive hours of physical activity results per day met the criteria and were involved in the present study.

Procedure

The mental health data were collected in the laboratory, and objective physical activity data were collected in a free-living setting. Participants gave their written informed consent in all study waves. All the studies were approved by the University of Tartu Research Ethics Committee.

Data analysis

Data preparation and statistical analyses were carried out using the R programming language in R environment 4.1.1 (R Core Team, 2021). For data permutation, the physical activity data were reintegrated into 60-second intervals in all study waves (Konstabel et al., 2019). Non-wear periods were excluded based on an algorithm proposed and validated by Choi and colleagues (2012). According to Trost et al. (2011) conclusion, "Of the five sets of cut points examined, only the EV cut points provided acceptable classification accuracy for all four levels of physical activity intensity," the Evenson cut-off points were applied in the present study for the first and second waves of PA data. Cut-off points were 0-100 counts/min for SB, 100-2296 counts/min for LPA, and 2296+ counts/min for MVPA (Evenson et al., 2008). Third wave PA data cut-off points were 0-50 mg for SB, 50-110 mg for LPA, 110+ mg for MVPA (Migueles et al., 2019).

To describe and evaluate the distributions of the study variables to ensure they meet the required assumptions for primary study analysis, we first computed descriptive statistics (sample sizes, means, standard deviations, skewnesses, and kurtoses) of sedentary behaviour, light PA, MVPA, depression, and anxiety in all three study waves. To carry out parametric analyses, we used the dispersion range between -2 and +2 for skewnesses and kurtoses, otherwise, non-parametric analyses for correlations and ANOVAs were used.

Correlation coefficients for three study waves of data on different physical activity levels (SB, LPA, and MVPA) and depressive and anxiety symptoms were carried out to investigate associations longitudinally and cross-sectionally (see Table 1). Repeated-measures ANOVAs (parametric for anxiety; non-parametric for PA levels and depression) were carried out to evaluate differences between physical activity scores and mental health scores with three time points (see Table 2). Post hoc tests were used to identify exactly which groups differ from each other (see Table 2).

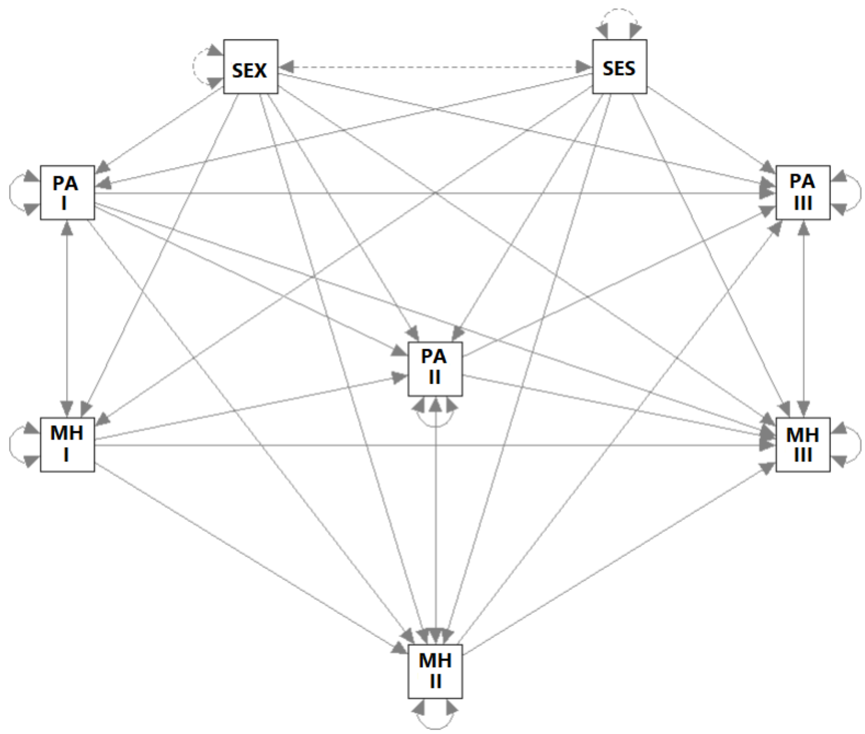
We assessed the cross-sectional and longitudinal associations between physical activity levels and mental health variables (depression and anxiety) by using cross-lagged panel analysis with R package lavaan (Rosseel, 2012). Cross-lagged panel models (CLPM) are used to evaluate longitudinal data where each observation or person is recorded at multiple points in time (Kearney, 2015). CLPM estimates the directional impact variables have on one another over time. Six cross-lagged panel models were created to investigate the present study's research questions and hypotheses, which are illustrated by two model structures (see Figure 1 and Figure 2) made by using the R package semPlot (Epskamp, 2019).

Observed scores on physical activity and mental health across the three study waves were assessed with CLPM, where cross-sectional associations are shown by two-way arrows and longitudinal associations by one-way arrows (see Figure 1). All models created include lag-2 effects, which provide stronger control for the presence of confounding factors (Lüdtke & Robitzsch, 2022). Figure 1 shows the model structure for physical activity and mental health.

Sex and socioeconomic status were also taken under control, as they have shown relationships with mental health and physical activity variables (Sher & Wu, 2023).

Figure 1

A cross-lagged model of physical activity and mental health for three waves of data



Note. Cross-sectional and longitudinal paths between within-individual physical activity and within-individual mental health (depression or anxiety). SES = socioeconomic status; PA = physical activity; MH = mental health; I = the first study wave; II = the second study wave; III = the third study wave.

Result

Correlation coefficients and ANOVA

Table 1 shows the sample sizes and correlation coefficients of physical activity levels, depression, and anxiety among the sample of Estonian adults. In the first wave, correlation coefficients show cross-sectional associations between anxiety and LPA ($r = -.09$; $p < .05$) and anxiety and MVPA ($r = -.12$; $p < .01$). The second wave shows cross-sectional associations between anxiety and MVPA ($r = -.08$; $p < .05$) and depression and MVPA ($r = -.13$; $p < .001$). The third wave shows cross-sectional associations between anxiety and LPA ($r = -.13$; $p < .05$), anxiety and MVPA (r = -.1; $p < .05$), and depression and MVPA (r = -.1; $p < .05$). By correlation coefficients, longitudinal associations were found between second wave MVPA and third wave depression (r = -.1; $p < .05$), and first wave MVPA and second wave anxiety (r = -.06; $p < .05$). Longitudinal associations were not found between LPA and both anxiety and depression.

Repeated-measures ANOVAs showed significant differences between all three study waves and all the variables (SB, LPA, MVPA, depression, anxiety), and by conducting post hoc tests, significant differences between variable scores from three study waves were found (except for MVPA's second and third wave and depression's first and third wave) (see Table 2).

Cross-lagged panel models

Table 3 provides statistics about all six created models. All CLPMs were statistically significant, and their fit statistics were good: Model 1 (SB, Dep): $\chi2$ = 247.43, p < .001; Model 2 (SB, Anx): $\chi2$ = 238.02, p < .001; Model 3 (LPA, Dep): $\chi2$ = 262.54, p < .001), Model 4 (LPA, Anx): $\chi2$ = 262.40, p < .001; Model 5 (MVPA, Dep): $\chi2$ = 252.32, p < .001; Model 6 (MVPA, Anx): $\chi2$ = 248.60, p < .001.

Figure 2 illustrates Model 1 (SB, Dep) cross-sectional associations (two-way arrows) and longitudinal associations (one-way arrows) between SB and depression (see Table 4). By Model 1 (SB, Dep), SB measured at the first wave significantly predicted both cross-sectional depression (β = .13; p = .043) and longitudinal depression (β = -.14; p = .020) at the third wave. No other significant paths were found between SB and depression by Model 1 (SB, Dep). By Model 2 (SB, Anx), no significant path directions between SB and anxiety were found (see Table 5).

By Model 3 (LPA, Dep) (see Table 6) and by Model 4 (LPA, Anx) (see Table 7), no statistically significant cross-sectional or longitudinal paths between LPA and both depression and anxiety were found.

By Model 5 (MVPA, Dep), MVPA measured at the second wave significantly predicted cross-sectional depression (β = -.18; p =.009) and longitudinal depression (β = -.14; p = .025) measured at the third wave (see Table 8). Model 5 (MVPA, Dep) also shows a significantly important cross-sectional prediction between MVPA and depression (β = -.13; p =.022) measured at the third wave. By Model 6 (MVPA, Anx), MVPA measured at the third wave significantly predicts cross-sectional depression (β = -.20; p = .001), but no significant longitudinal paths were found (see Table 9).

Table 1

Correlation coefficients between physical activity levels, depression, and anxiety

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. SB I	-														
2. LPA I	**.33*** **	-													
3. MVPA I	-.19	.19	-												
4. SB II	**.25***	**-.19 ** **	-.02	-											
5. LPA II	-.06	**.34*** **	.03	**-.52*** **	-										
6. MVPA II	-.1	.1	**.26***	-.07	.04	-									
7. SB III	.09	-.06	.08	.19	0	-.09	-								
8. LPA III	-.04	**.3*** **	.07	-.08	**.33** **	.06	**-.3*** **	-							
9. MVPA III	.02	.24	-.08	-.12	.17	.12	**-.28*** **	**.51*** **	-						
10. Dep I	.02	-.03	.01	-.05	-.05	**-.02***	.02	-.02	.04	-					
11. Dep II	-.05	.06	-.03	-.02	.07	**-.13*** **	-.01	0	-.02	**.49*** **	-				
12. Dep III	-.2	.08	.01	-.04	.07	**-.1***	.05	-.07	**-.1***	**.36*** **	**.56*** **	-			
13. Anx I	-.01	**-.09***	**-.12** **	.05	.07	**-.02***	-.04	.02	.11	**.55*** **	**.4*** **	**.17** **	-		
14. Anx II	-.04	-.05	**-.06***	-.03	.08	**-.08***	-.16	.03	.1	**.31*** **	**.49*** **	**.21*** **	**.4*** **	-	
15. Anx III	-.12	-.05	-.06	.06	-.06	-.01	-.1	**-.13***	**-.1***	**.24*** **	**.41*** **	**.54*** **	**.35*** **	**.46*** **	
16. *n*	302	302	302	331	331	331	403	403	403	419	422	419	424	421	418

Note. SB = sedentary behaviour; LPA = light physical activity; MVPA = moderate to vigorous physical activity; Dep = depression; Anx = anxiety; I = the first study wave; II = the second study wave; III = the third study wave; *n* = sample size. * *p* <.05. ** *p* <.01. *** *p* <.001.

Table 2

Differences in physical activity levels, depression, and anxiety across the three study waves

Variable	Wave 1 *M (SD)*	Wave 2 *M (SD)*	Wave 3 *M (SD)*	*Q (F)*	*p*
SB	537.22 (39.30)[b,c]	474.60 (27.01)[a,c]	758.36 (116.60)[a,b]	258.62	< **.001**
LPA	244.72 (89.30)[b,c]	283.39 (99.69)[a,c]	179.04 (76.49)[a,b]	177.40	< **.001**
MVPA	43.38 (17.00)[b,c]	33.25 (22.71)[a]	32.66 (17.21)[a]	14.30	< **.001**
Depression	7.59 (5.30)[b]	6.92 (5.27)[a,c]	8.34 (6.70)[b]	11.15	**.004**
Anxiety	32.81 (8.30)[b,c]	30.37 (7.16)[a,c]	32.01 (9.07)[a,b]	(8.32)	**.016**

Note. All three study waves of each factor were concluded. Non-parametric, one-way within-subjects ANOVA (*Q* = Friedman's chi-square) and parametric, repeated-measures ANOVA were used. SB = sedentary behaviour; LPA = light physical activity; MVPA = moderate to vigorous physical activity.

[a]Different from wave 1.

[b]Different from wave 2.

[c]Different from wave 3.

Table 3

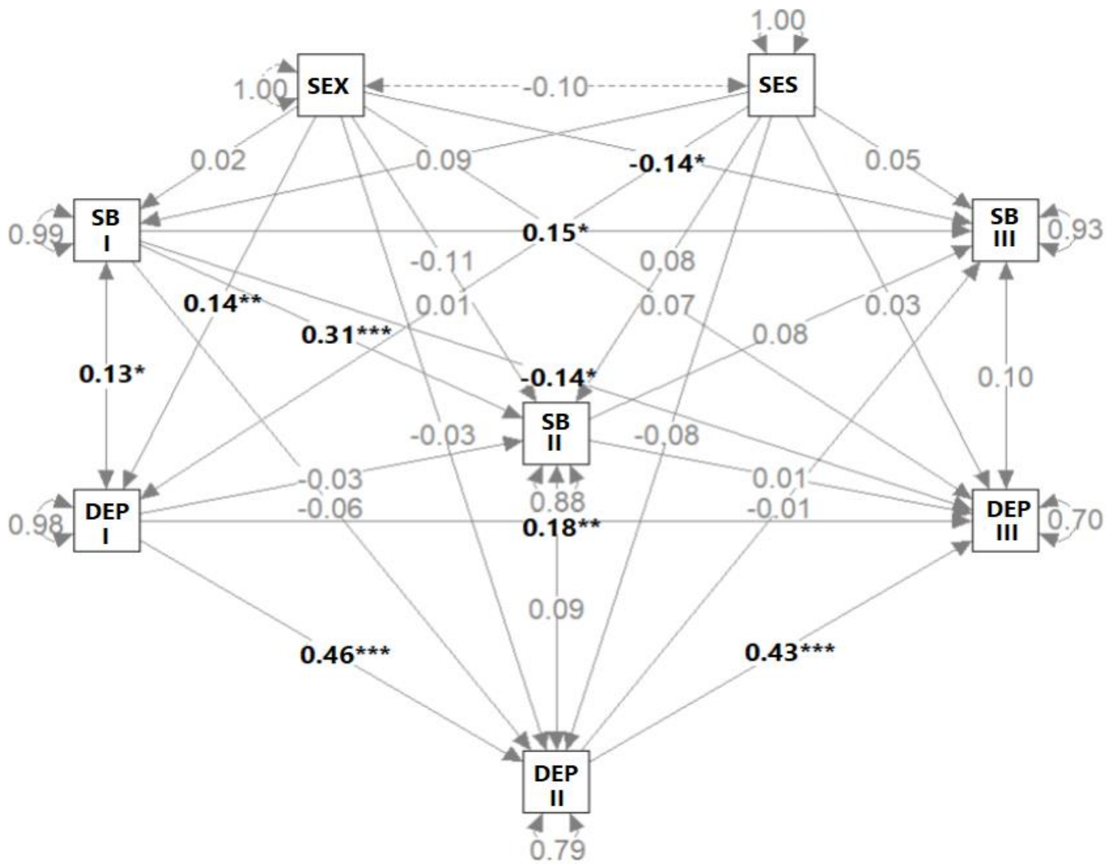
Fit statistics of physical activity and mental health cross-lagged panel models

Model	χ2	p	RMSEA	CFI	SRMR	AIC	BIC
1 (SB, Dep)	247.43	<**.001**	.060	0.994	.011	16512.13	16662.06
2 (SB, Anx)	238.02	<**.001**	.000	1.000	.011	17257.32	17403.30
3 (LPA, Dep)	261.54	<**.001**	.000	1.000	.002	16094.79	16244.78
4 (LPA, Anx)	262.35	<**.001**	.000	1.000	.001	16832.62	16982.55
5 (MVPA, Dep)	252.32	<**.001**	.000	1.000	.003	13892.65	14042.58
6 (MVPA, Anx)	248.60	<**.001**	.019	0.998	.013	14635.20	14781.18

Note. *χ2* = chi-square; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; SRMR = Standardized Root Mean Square Residual; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; SB = sedentary behaviour; LPA = light physical activity; MVPA = moderate to vigorous physical activity; Dep = depression; Anx = anxiety.

Figure 2

A cross-lagged panel model of sedentary behaviour and depression



Note. Cross-sectional and longitudinal paths (standardized) between within-individual sedentary behaviour and within-individual depression. Three waves of data were included in the analysis. SB = sedentary behaviour; Dep = depression; I = the first study wave; II = the second study wave; III = the third study wave. * p <.05. ** p <.01. *** p <.001.

Table 4

Cross-lagged panel model of cross-sectional and longitudinal paths pertaining to sedentary behaviour and depression

Path			*B*	*SE*	*β*	*z*	*p*
SB I	→	SB II	0.32	0.07	.31	4.36	**<.001*** **
SB II	→	SB III	0.10	0.09	.08	1.17	.243
SB I	→	SB III	0.20	0.10	.15	2.02	**.043***
DEP I	→	DEP II	0.46	0.05	.46	9.24	**<.001*** **
DEP II	→	DEP III	0.53	0.07	.43	7.75	**<.001*** **
DEP I	→	DEP III	0.22	0.07	.18	3.24	**.001****
DEP I	→	SB II	-0.59	1.08	-.03	-0.54	.586
DEP II	→	SB III	-0.23	1.20	-.01	-0.19	.849
SB I	→	DEP II	-0.01	0.01	-.06	-0.97	.334
SB I	→	DEP III	-0.01	0.01	-.14	-2.33	**.020***
SB II	→	DEP III	0.01	0.01	.01	0.20	.841
SEX	→	SB I	4.20	10.97	.02	0.38	.702
SES	→	SB I	2.31	1.58	.09	1.47	.143
SEX	→	SB II	-21.68	11.68	-.11	-1.86	.063
SES	→	SB II	2.25	1.67	.08	1.35	.178
SEX	→	SB III	-31.67	13.13	-.14	-2.41	**.016***
SES	→	SB III	1.77	1.90	.05	0.94	.349
SEX	→	DEP I	1.56	0.55	.15	2.83	**.005****
SES	→	DEP I	0.01	0.08	.01	0.11	.911
SEX	→	DEP II	-0.34	0.53	-.03	-0.64	.525
SES	→	DEP II	-0.13	0.08	-.08	-1.61	.107
SEX	→	DEP III	0.93	0.64	.07	1.45	.146
SES	→	DEP III	0.06	0.09	.03	0.61	.539
SB I	↔	DEP I	60.32	29.85	.13	2.02	**.043***
SB II	↔	DEP II	37.72	29.73	.09	1.27	.204
SB III	↔	DEP III	61.41	36.13	.10	1.70	.089

Note. *B* = unstandardized coefficient, *SE* = standard error for the unstandardized coefficient, *β* = standardized coefficient; SB = sedentary behaviour; DEP = depression; I = the first study wave; II = the second study wave; III = the third study wave. * p <.05. ** p <.01. *** p <.001.

Table 5

Cross-lagged panel model of cross-sectional and longitudinal paths pertaining to sedentary behaviour and anxiety

Path	***B***	***SE***	***β***	***z***	***p***
SB I → SB II	0.32	0.08	.30	4.25	**<.001****
SB II → SB III	0.12	0.09	.10	1.32	.185
SB I → SB III	0.17	0.10	.13	1.62	.105
ANX I → ANX II	0.40	0.05	.45	8.89	**<.001*****
ANX II → ANX III	0.45	0.07	.38	6.82	**<.001*****
ANX I → ANX III	0.26	0.06	.24	4.38	**<.001*****
ANX I → SB II	1.04	0.71	.09	1.47	.142
SB I → ANX II	-0.01	0.01	-.07	-1.21	.226
SB I → ANX II	-0.30	0.89	-.02	-0.33	.739
SB I → ANX III	-0.01	0.01	-.09	-1.38	.169
SB II → ANX III	0.01	0.01	.10	1.59	.111
SEX → SB I	3.63	11.01	.02	0.33	.742
SES → SB I	2.67	1.59	.10	1.69	.092
SEX → SB II	-22.91	11.58	-.12	-1.98	**.048***
SES → SB II	2.71	1.70	.10	1.60	.110
SEX → SB III	-30.97	13.20	-.13	-2.35	**.019***
SES → SB III	1.71	1.91	.05	0.90	.369
SEX → ANX I	-0.26	0.85	-.02	-0.30	.763
SES → ANX I	-0.36	0.12	-.15	-2.91	**.004****
SEX → ANX II	0.66	0.73	.05	0.91	.365
SES → ANX II	0.03	0.11	.02	0.29	.771
SEX → ANX III	1.61	0.86	.09	1.88	.060
SES → ANX III	0.09	0.13	.03	0.69	.492
SB I ↔ ANX I	5.12	44.88	.01	2.02	.909
SB II ↔ ANX II	-17.57	37.87	-.03	1.27	.643
SB III ↔ ANX III	60.49	49.02	.07	1.70	.217

Note: B = unstandardized coefficient, *SE* = standard error for the unstandardized coefficient, *β* = standardized coefficient; SB = sedentary behaviour; ANX = anxiety; I = the first study wave; II = the second study wave; III = the third study wave. * *p* <.05. ** *p* <.01. *** *p* <.001.

Table 6

Cross-lagged panel model of cross-sectional and longitudinal paths pertaining to light physical activity and depression

Path	*B*	*SE*	*β*	*z*	*p*
LPA I → LPA II	0.45	0.09	.35	5.29	**<.001*** **
LPA II → LPA III	0.18	0.07	.19	2.57	**.010** **
LPA I → LPA III	0.23	0.09	.20	2.63	**.009** **
DEP I → DEP II	0.46	0.05	.46	9.22	**<.001*** **
DEP II → DEP III	0.53	0.07	.43	7.83	**<.001*** **
DEP I → DEP III	0.21	0.07	.17	3.09	**.002** **
DEP I → LPA II	-0.36	0.96	-.02	-0.38	.708
DEP II → LPA III	0.09	0.83	.01	0.11	.913
LPA I → DEP II	0.01	0.01	.05	0.86	.390
LPA I → DEP III	0.01	0.01	.03	0.54	.587
LPA II → DEP III	0.01	0.01	.04	0.65	.518
SEX → LPA I	3.16	8.40	.02	0.38	.707
SES → LPA I	-2.43	1.21	-.12	-2.01	**.045***
SEX → LPA II	-11.59	10.47	-.65	-1.11	.268
SES → LPA II	-4.93	1.50	-.19	-3.28	**.001** **
SEX → LPA III	9.80	9.03	.06	1.09	.278
SES → LPA III	-0.67	1.34	-.03	-0.50	.616
SEX → DEP I	1.56	0.55	.15	2.83	**.005** **
SES → DEP I	0.01	0.08	.01	0.12	.906
SEX → DEP II	-0.35	0.53	-.03	-0.65	.513
SES → DEP II	-0.13	0.08	-.08	-1.62	.105
SEX → DEP III	0.92	0.64	.07	1.43	.152
SES → DEP III	0.06	0.10	.031	0.62	.536
LPA I ↔ DEP I	-23.43	22.71	-.064	-1.03	.302
LPA II ↔ DEP II	-31.64	26.39	-.083	-1.20	.231
LPA III ↔ DEP III	-30.16	25.04	-.070	-1.20	.228

Note. B = unstandardized coefficient, *SE* = standard error for the unstandardized coefficient, *β* = standardized coefficient; LPA = light physical activity; DEP = depression; I = first study wave; II = second study wave; III = third study wave. * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 7

Cross-lagged panel model of cross-sectional and longitudinal paths pertaining to light physical activity and anxiety

Path	*B*	*SE*	*β*	*z*	*p*
LPA I → LPA II	0.45	0.08	.35	5.28	**<.001****
LPA II → LPA III	0.17	0.07	.18	2.40	**.017***
LPA I → LPA III	0.24	0.09	.21	2.75	**.006****
ANX I → ANX II	0.40	0.05	.45	8.93	**<.001*****
ANX II → ANX III	0.46	0.07	.38	7.01	**<.001*****
ANX I → ANX III	0.27	0.06	.25	4.58	**<.001*****
ANX I → LPA II	0.01	0.63	.01	0.01	.992
ANX II → LPA III	-0.32	0.61	-.03	-0.53	.598
LPA I → ANX III	0.01	0.01	.07	1.00	.318
LPA II → ANX III	-0.01	0.01	-.13	-1.84	.065
LPA I → ANX II	0.01	0.01	.04	0.72	.472
SEX → LPA I	3.32	8.42	.024	0.40	.693
SES → LPA I	-2.49	1.21	-.12	-2.05	**.041***
SEX → LPA II	-12.18	10.32	-.07	-1.18	.238
SES → LPA II	-5.15	1.52	-.20	-3.39	**.001*****
SEX → LPA III	9.88	9.04	.06	1.09	.274
SES → LPA III	-0.71	1.35	-.03	-0.53	.599
SEX → ANX I	-0.25	0.85	-.02	-0.30	.765
SES → ANX I	-0.36	0.12	-.15	-2.92	**.004****
SEX → ANX II	0.65	0.73	.04	0.88	.377
SES → ANX II	0.03	0.11	.01	0.25	.803
SEX → ANX III	1.14	0.85	.06	1.35	.117
SES → ANX III	0.04	0.13	.02	0.31	.754
LPA I ↔ ANX I	-45.83	34.33	-.08	-1.34	.182
LPA II ↔ ANX II	12.63	33.46	.02	0.38	.706
LPA III ↔ ANX III	-24.79	33.92	-.04	-0.73	.465

Note. *B* = unstandardized coefficient, *SE* = standard error for the unstandardized coefficient, *β* = standardized coefficient; LPA = light physical activity; ANX = anxiety; I = first study wave; II = second study wave; III = third study wave. * $p < .05$. ** $p < .01$. *** $p < .001$

Table 8

Cross-lagged panel model of cross-sectional and longitudinal paths pertaining to moderate to vigorous physical activity and depression

Path	*B*	*SE*	*β*	*z*	*p*
MVPA I → MVPA II	0.29	0.06	.36	5.15	**<.001****
MVPA II → MVPA III	0.09	0.05	.12	1.75	.080
MVPA I → MVPA III	-0.03	0.04	-.05	-0.67	.506
DEP I → DEP II	0.45	0.05	.45	9.10	**<.001*****
DEP II → DEP III	0.50	0.07	.40	7.21	**<.001*****
DEP I → DEP III	0.21	0.07	.17	3.25	**<.001****
DEP I → MVPA II	-0.16	0.24	-.04	-0.66	.509
DEP II → MVPA III	0.01	0.18	.01	0.08	.940
MVPA I → DEP II	-0.01	0.01	-.04	-0.71	.476
MVPA I → DEP III	-0.01	0.02	-.01	-0.19	.848
MVPA II → DEP III	-0.04	0.02	-.14	-2.25	**.025***
SEX → MVPA I	-5.23	3.28	-.10	-1.60	.111
SES → MVPA I	1.08	0.47	.14	2.29	**.022***
SEX → MVPA II	-5.37	2.66	-.12	-2.02	**.044***
SES → MVPA II	0.16	0.39	.03	0.41	.679
SEX → MVPA III	0.78	1.94	.02	0.40	.687
SES → MVPA III	-0.65	0.28	-.13	-2.33	**.020***
SEX → DEP I	1.57	0.55	.15	2.83	**.005****
SES → DEP I	0.01	0.08	.01	0.11	.909
SEX → DEP II	-0.40	0.54	-.04	-0.75	.452
SES → DEP II	-0.13	0.08	-.08	-1.61	.107
SEX → DEP III	0.56	0.65	.04	0.88	.381
SES → DEP III	0.06	0.09	.03	0.62	.537
MVPA I ↔ DEP I	-6.89	8.91	-.05	-0.77	.439
MVPA II ↔ DEP II	-17.85	6.80	-.18	-2.63	**.009****
MVPA III ↔ DEP III	-12.14	5.31	-.13	-2.29	**.022***

Note. B = unstandardized coefficient, *SE* = standard error for the unstandardized coefficient, *β* = standardized coefficient; MVPA = moderate to vigorous physical activity; DEP = depression; I = first study wave; II = second study wave; III = third study wave. * p <.05. ** p <.01. *** p <.001.

Table 9

Cross-lagged panel model of cross-sectional and longitudinal paths pertaining to moderate to vigorous physical activity and anxiety

Path	***B***	***SE***	***β***	***z***	***p***
MVPA I → MVPA II	0.29	0.06	.36	5.03	**<.001****
MVPA II → MVPA III	0.10	0.05	.13	1.89	.059
MVPA I → MVPA III	-0.03	0.04	-.04	-0.61	.539
ANX I → ANX II	0.40	0.05	.45	8.88	**<.001*****
ANX II → ANX III	0.45	0.07	.37	6.77	**<.001*****
ANX I → ANX III	0.27	0.06	.25	4.75	**<.001*****
ANX I → MVPA II	-0.10	0.16	-.04	-0.60	.547
ANX II → MVPA III	0.17	0.13	.07	1.28	.200
MVPA I → ANX II	-0.02	0.0.2	-.08	-1.41	.158
MVPA I → ANX III	-0.01	0.02	-.04	-0.68	.498
MVPA II → ANX III	-0.01	0.03	-.02	-0.22	.825
SEX → MVPA I	-5.23	3.28	-.10	-1.59	.111
SES → MVPA I	1.08	0.47	.14	2.28	**.023***
SEX → MVPA II	-5.26	2.64	-.12	-1.99	**.046***
SES → MVPA II	0.11	0.39	.02	0.28	.776
SEX → MVPA III	0.70	1.930	.02	0.36	.718
SES → MVPA III	-0.63	0.28	-.13	-2.27	**.023***
SEX → ANX I	-0.26	0.85	-.02	-0.30	.764
SES → ANX I	-0.36	0.12	-.15	-2.91	**.004****
SEX → ANX II	0.47	0.74	.03	0.65	.519
SES → ANX II	0.04	0.11	.02	0.34	.732
SEX → ANX III	1.23	0.86	.07	1.44	.151
SES → ANX III	0.11	0.13	.04	0.88	.377
MVPA I ↔ ANX I	-5.63	13.39	-.03	-0.42	.674
MVPA II ↔ ANX II	-4.40	8.48	-.03	-0.52	.604
MVPA III ↔ ANX III	-24.37	7.29	-.20	-3.34	**.001****

Note. *B* = unstandardized coefficient, *SE* = standard error for the unstandardized coefficient, *β* = standardized coefficient; MVPA = moderate to vigorous physical activity; ANX = anxiety; I = first study wave; II = second study wave; III = third study wave. * p <.05. ** p <.01. *** p <.001

Discussion

In this study, we examined cross-sectional and longitudinal associations between objectively measured physical activity (sedentary behaviour, light PA, MVPA) and mental health (depression, anxiety) among a sample of Estonian adults in three study waves when subjects were 18, 25, and 33 years old. Cross-sectional and longitudinal associations were investigated by using cross-lagged panel models.

We hypothesized that individuals with higher levels of LPA and MVPA have less symptoms of depression cross-sectionally and longitudinally, as found by previous research (Schuch et al., 2017; Kandola et al., 2020). Hypotheses about cross-sectional and longitudinal associations between depression and LPA and MVPA found partial confirmation by CLPMs, but only with MVPA. By CLPMs, individuals with higher levels of MVPA at the age of 25 report significantly less symptoms of depression at the age of 33 (β = -.14). According to CLPMs, cross-sectional analysis showed significant associations between individuals with a higher level of MVPA and less symptoms of depression at the ages of 25 (β = -.18) and 33 (β = -.13). No cross-sectional or longitudinal associations were found between LPA and depression by CLPMs.

In previous studies, associations between anxiety and both LPA and MVPA had not been consistent enough for formulating a hypothesis (Helgadóttir et al., 2015; Kandola et al., 2022). With subjective MVPA, there have been studies with statistically significant associations between MVPA and anxiety (Felez-Nobrega et al., 2021), as well as studies finding statistically significant cross-sectional but no longitudinal associations between subjective MVPA and anxiety (McDowell et al., 2019). In CLPMs, a cross-sectional association was found between individuals with a higher level of MVPA and less symptoms of anxiety at the age of 33 (β = -.20). By correlation coefficients, we found significant cross-sectional associations between individuals with higher level of MVPA and less symptoms of anxiety in all three study waves, at the ages of 18 (r = -.12), 25 (r = -.08), and 33 (r = -.1). Only one longitudinal association between MVPA and anxiety was found by correlation coefficients: individuals with higher scores of MVPA at the age of 18 had less symptoms of anxiety at the age of 25 (r = -.06). As CLPMs and correlation coefficients give controversial associations between PA and anxiety, it is recommended to study them more closely.

About SB and mental health, we hypothesized that SB is positively associated with depression and anxiety, and this hypothesis was partially supported. According to CLPMs, individuals at the age of 33 showed significant positive cross-sectional associations between SB and depression (β = .13). No associations with anxiety were found. We also hypothesized that an individual's previous SB score is longitudinally positively associated with depression and anxiety, and this hypothesis also received partial confirmation. Conversely, according to CLPMs, individuals with higher levels of SB at the age of 18 reported significantly less symptoms of depression at the age of 33 (β = -.14). There may be conflicting results between the first and third wave data with previous research (Kandola et al., 2020), as the 15-year gap may be too long to assess long-term effects. No other statistically significant cross-sectional or longitudinal results were found between SB and depression or SB and anxiety by CLPMs.

Previous studies have found more consistent results with SB and MVPA than LPA with anxiety and depression (Tully et al., 2020; Felez-Nobrega et al., 2021). By CLMPs, we also found that among the sample of Estonian adults, MVPA was cross-sectionally and longitudinally associated with depression, and SB was associated with cross-sectional depression in some study waves. According to CLPMs, we found a cross-sectional association between MVPA and anxiety, but no longitudinal associations were found. As in previous studies (Rebar et al., 2015), MVPA's cross-sectional associations were more consistent with depression than with anxiety by CLPMs. However, by correlation coefficients, associations between MVPA and anxiety were more consistent than those between MVPA and depression. By CLPMs, no cross-sectional or longitudinal associations between LPA and depression or LPA and anxiety were found. However, correlation coefficients independently showed two cross-sectional negative associations between anxiety and LPA. As said before, different results from CLPMs and correlation coefficients highlight the need to investigate associations between anxiety and PA more closely and to use more comprehensive methods to study cross-sectional and longitudinal associations.

According to our analyses, not many cross-lagged associations between physical activity and mental health were found: MVPA predicted cross-sectional depressive and anxiety symptoms, and SB predicted cross-sectional depressive symptoms. The causality of PA and mental health associations was not well established, as more cross-sectional than longitudinal associations were found by CLPMs; only in one study wave did SB and MVPA predict depression longitudinally. Adding sex and socioeconomic status to CLPMs showed some associations between different PA levels and both depression and anxiety throughout the models, highlighting their need to be controlled. According to CLPMs' findings, to keep anxiety and depressive symptoms low and prevent depression in the future, it is recommended to use interventions that decrease SB levels and increase MVPA levels.

Strengths, limitations, and future directions

There are several strengths to this thesis. To start with, we included sex and socioeconomic status as potential confounding variables and added lag-2 effects to the CLPMs to provide stronger control for the presence of confounding (Lüdtke & Robitzsch, 2022). We used models for investigating associations between PA and mental health, which seems important as they include more variables than just those under the study, and correlation coefficients may give different results, probably due to taking fewer variables into account. Moreover, in contrast to most social science studies, we used a population-based sample, not university students, which consequently should make our findings more appropriate to the general population. In fact, we studied both cross-sectional and longitudinal relations between three different PA levels and both depression and anxiety to get a more complete view on the topic, which is not common in similar multiwave studies. Furthermore, we studied objectively measured PA, which still has been understudied in PA and mental health relation studies (Silfee et al., 2018).

From a methodological perspective, we used different criteria for the minimum time of PA data necessary between the three study waves. It can be seen from the correlation coefficients that the third wave's PA and mental health data are differently associated than the first and second waves' data, which had the same minimum time criteria (see Table 1). Furthermore, we used both wrist (ActiGraph) and waist (GENEActive) - worn devices for data collection between different study waves. Data collected from the wrist accelerometer has more confounding variables (e.g., hand movement with little to no movement occurring at the hip) that may have affected third-wave PA data. One way to handle confounding variables in wrist-worn accelerometers is by combining the accelerometer's data with another objective method, for instance, pedometers (Harris et al., 2009; Weber et al., 2023), which can be done in future studies.

One limitation of used mental health data was using short self-reported questionnaire results as a source of depressive and anxiety symptoms. Involving Mini International Neuropsychiatric Interview (MINI) results as a source of diagnoses would have been more accurate. However, it was decided so as the MINI was conducted in only one study wave. For future studies, we recommend measuring diagnoses in every study wave, for instance, by using the Composite International Diagnostic Interview (CIDI) (Oöpik et al., 2006).

We also recommend using models for investigating PA and mental health associations, as we saw different results given by correlation coefficients and models. We advise being careful with interpreting and generalizing regular correlation and regression associations if they are not taking other confounding variables under control. Finally, by interpreting our conflicting results between SB and depression, a 15-year-long window might be too long for assessing long-term effects. Therefore, we recommend having shorter time windows than 15 years between study waves.

Conclusion

In conclusion, we demonstrate that objectively measured sedentary behaviour and MVPA, but not LPA, might be related to depression cross-sectionally and longitudinally, and MVPA with cross-sectional anxiety in a general population. In our study, the findings that are not consistent highlight the need to investigate the cross-sectional and longitudinal associations between different levels of objectively measured PA and mental health symptoms of depression and anxiety more closely. Moreover, models that can take most likely confounders, such as sex and socioeconomic status, under control should be used. Furthermore, these findings highlight the necessity of focusing more on PA usage, decreasing SB levels, and increasing MVPA levels to keep anxiety and depressive symptoms low and prevent depression. Taken together, the results highlight cross-sectional and longitudinal associations between depression and both SB and MVPA, and cross-sectional associations between anxiety and MVPA.

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