Physical activity patterns and risk of depression in young adulthood: a 20-year cohort study since childhood

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Abstract

Purpose Little is known about how physical activity patterns during childhood and adolescence are associated with risk of subsequent depression. We examined prospective and retrospective associations between leisure physical activity patterns from childhood to adulthood and risk of clinical depression in young adulthood.

Methods Participants (759 males, 871 females) in a national survey, aged 9-15 years, were re-interviewed approximately 20-years later. Leisure physical activity was self-reported at baseline (1985) and follow-up (2004-2006). To bridge the interval between the two time-points, historical leisure activity from age 15 years to adulthood was self-reported retrospectively at follow-up. Physical activity was categorized into groups that, from a public health perspective, compared patterns that were least beneficial (persistently inactive) with those increasingly beneficial (decreasing, increasing and persistently active). Depression (major depressive or dysthymic disorder) was assessed using the Composite International Diagnostic Interview.

Results Compared with those persistently inactive, males who were increasingly and persistently active had a 69 % to 65 % reduced risk of depression in adulthood respectively (all $p < 0.05$). In retrospective analyses, females who were persistently active had a 51 % reduced risk of depression in adulthood ($p = 0.01$). Similar but non-significant trends were observed for leisure physical activity in females and

historical leisure activity in males. Results excluded those with childhood onset of depression and were adjusted for various sociodemographic and health covariates.

Conclusions Findings from both prospective and retrospective analyses indicate a beneficial effect of habitual discretionary physical activity since childhood on risk of depression in young adulthood.

Keywords Depression, Epidemiology, Physical Activity, Population-based, Prospective

Introduction

The lifetime prevalence of major depression increases from childhood with around 20 % of the population experiencing a depressive episode by young adulthood [1]. Concurrently, physical activity levels tend to decline between childhood and young adulthood [2]. While the health benefits of physical activity in childhood and adolescence are well established [3], it is unclear how physical activity patterns over time may be associated with the risk of developing depression. Clarifying the efficacy of physical activity in the prevention of depression during this critical life stage would be an important advance in public health.

Population-based studies indicate that habitual physical activity is associated with reduced risk of depression in adults [4]. Further, intervention studies indicate a beneficial effect of exercise on depressive symptoms in adults with depression [5]. In contrast, research examining the prospective relationship between physical activity in childhood and adolescence, and depression is scant [6] with only a few studies having examined associations that extend into adulthood [7-10]. While some studies indicate an inverse association between leisure-time physical activity and risk of emotional [11] and psychological distress [9], depressive symptoms [12-15], dysthymic disorder [12], and major depressive disorder [8, 12], other results are equivocal [7, 10, 16]. Methodological limitations including brief follow-up periods [8, 11, 14, 15], use of a single-item to assess physical activity [11, 14], and assessment of physical activity frequency only [7-10, 12, 13] rather than both frequency and

duration may account for mixed findings. Further, most studies have used symptom scales rather than more clinically salient diagnostic criteria to assess depression.

We have previously demonstrated cross-sectional associations between discretionary physical activity and i) depressed mood in childhood [17] and ii) depression in young adulthood [18]. Current analyses examine the effect of persistent physical activity and changes (if any) in physical activity from childhood to adulthood on risk of depression in adulthood. This study extends previous research by i) analyzing data over a 20-year period from a large national population cohort; ii) examining physical activity patterns during the transition from childhood to adulthood and iii) using diagnostic criteria to assess depression. We hypothesized that compared with being persistently inactive, progressively more beneficial leisure physical activity patterns (i.e., decreasing, increasing and persistently active) from childhood to adulthood would be associated with a decreased risk of depression in young adulthood over a 20-year follow-up.

Methods

Description of cohort

The Childhood Determinants of Adult Health Study is a 20-year follow-up of 8,498 school-children who participated in the 1985 Australian Schools Health and Fitness Survey (ASHFS), when aged 7-15 years. Sampling procedures and methods of data collection are described elsewhere [17]. Briefly, participants were selected using a

two-stage (school, then student) probability sampling process that was designed to yield a self-weighted sample. The first stage of sampling resulted in a nationally representative sample of 109 schools selected from each state and territory in Australia with probability proportional to enrolment. The second stage utilized simple random sampling to select ten males and ten females from each age group at each school. Parental and child consents were obtained and approval sought from the Director General of Education in each state and territory.

Twenty years later, 6,840 (81 %) of the baseline sample were traced and 5,170 (61 %) were enrolled and provided follow-up data. Of these, 2,315 attended one of 34 study clinics held around Australia and completed depression assessment. Participants aged 7-8 years in childhood (n = 491) were not eligible as they did not complete questionnaires at baseline. In total, 1,630 clinic attendees (aged 27-36 years) completed the baseline and follow-up physical activity and depression measures used in the current analyses. Figure 1 illustrates the recruitment and retention of cohort participants. The study was approved by the Southern Tasmania Health and Medical Human Research Ethics Committee and all participants provided written informed consent.

Insert Figure 1 here

Sample attrition

Baseline comparisons between those who did and did not attend a study clinic in adulthood were only possible for those aged 9-15 years (n = 6,412) in 1985, as younger children did not complete questionnaires. In childhood, clinic non-attendees (n = 4,782) were more likely than clinic attendees to speak a language at home other than English (13.5 % versus 11.0 %, p = 0.01), report poorer general health (22.0 % versus 18.0 %, p = 0.001) and were more likely to be male (52.2 % versus 46.6 %, p < 0.001). There were no significant differences in childhood between clinic non-attendees and clinic attendees in mean age (both 11.9 years, p = 0.54), prevalence of depressed mood (8.9 % versus 8.0 %, p = 0.31) and minutes of past-week physical activity (442 versus 434, p = 0.51).

Measures

Baseline (1985)

For convenience, participants in 1985 are termed 'children' though ages span both childhood and adolescence. Information regarding sociodemographics, health and physical activity was collected using a questionnaire developed by Coonan and Dwyer [19]. Trained data collectors read questionnaire instructions to children in groups of four and supervised completion. Children (9-15 years only) self-reported past-week frequency and duration of school and extracurricular sport and exercise providing an estimate of minutes of past-week discretionary (leisure) physical activity. Children also completed a timed 1.6 km (1 mile) run/walk to estimate

cardiorespiratory fitness. For testing, children were organized into small groups that ran on level, measured circuits ranging in length from 0.2 to 0.4 km. Time to complete the 1.6 km run/walk was adjusted for measured body weight and reverse ranked.

As ASHFS was not originally designed to be a research study no reliability or validity information was available for the physical activity questionnaire. However, self-reported physical activity using this questionnaire indicates reasonable face and construct validity [17]. For example, boys reported more physical activity than girls and physical activity increased with age in boys, while girls' physical activity decreased with age in early adolescence. Further, total past-week physical activity from this questionnaire demonstrated a positive association with cardiorespiratory fitness (r = 0.21) similar to those observed for other self-report measures among children [20].

Depressed mood was assessed using the single item 'During the past few weeks, how often have you felt depressed or unhappy?' from Bradburn's Negative Affect Scale [21], with responses dichotomized as 'often' versus 'sometimes/never'. The Negative Affect Scale has been found to be a reliable and valid indicator of psychological distress when additional adjustment is made for the confounding effects of physical illness [22]. This scale has demonstrated adequate reliability and

validity [23] with depressed mood exhibiting the strongest discriminatory validity of all single items [21].

Sociodemographic and health information collected included age, sex, child and parental birthplace, language spoken at home, living arrangements, school-assessed and self-reported scholastic ability, self-reported health status, alcohol use, current smoking and parental smoking status. Area based socio-economic status was derived using the Australian Bureau of Statistics Socioeconomic Index for Areas [24].

Follow-up (2004-2006)

Participants received questionnaires prior to attending a study clinic where the Composite International Diagnostic Interview was completed, pedometers were issued, and body mass index (BMI) and cardiorespiratory fitness were assessed.

International Physical Activity Questionnaire

Physical activity in adulthood was assessed using the long version of the International Physical Activity Questionnaire (IPAQ) [25]. Weekly minutes of leisure physical activity were used to indicate discretionary physical activity in adulthood as, conceptually, it was most aligned to the childhood physical activity measure. The IPAQ demonstrates very good levels of repeatability and fair to moderate validity when compared to accelerometer data [26].

Historical Leisure Activity Questionnaire

In order to bridge the interval between physical activity assessment in childhood (aged 9-15 years) and adulthood, leisure activity from age 15 years to adulthood was self-reported retrospectively at follow-up using a self-administered version of the Historical Leisure Activity Questionnaire (HLAQ) [27]. Inclusion of this questionnaire allowed for a comprehensive examination of changes (if any) in physical activity patterns across the developmental trajectory from childhood through to adulthood. Originally developed by Kriska and colleagues, this modified questionnaire assessed participation in habitual leisure activity over four prior age periods (15-19, 20-24, 25-29, and 30+ years). Participants identified those leisure and sporting activities in which they participated more than 10 times and provided an estimate of the number of years, months per year and hours per week spent in each activity during each age period. To assist recall, 28 popular sport and physical activities relevant to young Australians were included [28]. Participants added activities not listed under 'other' activities. Average hours of leisure activity per week were estimated for each prior age period truncating the last two age periods (25-29 years and 30+ years) to current age.

This version has demonstrated reasonable validity for ranking participants in this cohort by their level of retrospective leisure-time physical activity. Total historical leisure activity from the HLAQ was significantly correlated with past-week sports participation (r = 0.09 to 0.23) and cardiorespiratory fitness (r = 0.08 to 0.21) in

childhood and past-week leisure physical activity (r = 0.13 to 0.46) and cardiorespiratory fitness (r = 0.09 to 0.29) in adulthood [29]. Correlations between the youngest age period (15-19 years) and self-reported discretionary sport in childhood (when aged 13 to 15 years) were r = 0.22 for boys and r = 0.23 for girls (both $p < 0.001$) [29]. Correlations in childhood were comparable to those observed between discretionary physical activity and total energy expenditure (r = 0.21 to 0.24) in adolescents aged 13-18 years [30]. This indicates that retrospectively recalled leisure activity using the HLAQ is a reasonably valid indicator of leisure physical activity levels in childhood in the current cohort. Correlations in adulthood also corresponded to those between current activity and cardiorespiratory fitness in young adults (r = 0.18 to 0.21) [31]. Further, studies indicate that recall of physical activity over the previous ten years is reliable [32] and that the HLAQ is reproducible in young adults [33].

Pedometers

Following detailed instructions from trained staff, participants wore a pedometer (Yamax Digiwalker SW-200) for 7-days and kept a pedometer diary from which average daily steps values were calculated. Participants recorded the date, the number of hours per day that the pedometer was worn, the total steps per day and any time spent active while not wearing the pedometer (e.g. swimming). Data were deemed valid if daily wear time was > 8 hours and a minimum of 4-days of reading was collected.

Cardiorespiratory fitness

Cardiorespiratory fitness in adulthood was estimated based on physical work capacity at a heart rate of 170 beats/minute (PWC170) using a standardized protocol [34] on a Monark bicycle ergometer. PWC170 measures were adjusted for lean body mass estimated from the sum of four skinfolds using standard equations [35].

Depression

Participants completed the depression module of the self-administered computerized Composite International Diagnostic Interview (CIDI-Auto, version 2.1) [36]. The reliability and validity of the computerized version has been confirmed using an Australian sample [37]. Participants who met the *DSM-IV* criteria for major depressive disorder and/or dysthymic disorder in the previous 12-months were defined as depression cases [38]. Participants not meeting these criteria were defined as non-cases. *DSM-IV* organic exclusion and diagnostic hierarchy rules were used in making diagnoses.

Sociodemographic and health information

Age, sex, marital status, education level, main source of income, current occupation, smoking status, and number of live births (females only) were collected by self-report. Physical health status was assessed with the physical health component summary scale (PCS-12) of the Short-Form Survey (SF-12v2) [39]. Measurements of

height and weight were taken by trained staff using a Leicester stadiometer (Invicta, UK) and Heine scales (Dover, USA) and body mass index (BMI) (kg/m^2) calculated and categorized according to standard BMI cut-points [40].

Statistical analysis

Prospective associations between discretionary (leisure) physical activity in childhood and depression in adulthood were examined *a priori* using log-binomial regression. Associations between physical activity in childhood and depression in adulthood are almost certainly influenced by change in physical activity from childhood to adulthood. Accordingly, the physical activity classification used in the current analysis attempts to account for both baseline physical activity and changes (if any) in physical activity over time.

Physical activity patterns were defined using a method similar to that employed in other studies that examined change in risk factors from childhood to adulthood [41, 42]. Discretionary physical activity in childhood (adjusted for age at baseline) and leisure physical activity in adulthood were categorized into 'low', 'moderate' and 'high' strata based on tertile cut-points. For males, median physical activity values for low, moderate and high strata were 1.00, 3.45 and 10.00 hours per week respectively in childhood and 0.00, 2.00 and 5.15 hours per week respectively in adulthood. Similarly, median physical activity values for low, moderate and high

strata for females were 0.90, 3.00 and 8.00 hours per week in childhood and 0.00, 2.00 and 5.00 hours per week in adulthood.

To examine the effect of persistent physical activity and changes in activity from childhood to adulthood on depression in adulthood, physical activity was categorized into groups that, from a public health perspective, compared patterns that were least beneficial (persistently inactive) with those increasingly beneficial (decreasing, increasing and persistently active), on the basis of the three activity tertiles described previously [41]. This approach assesses change in physical activity rank within the cohort over time rather than change in absolute physical activity levels. Participants in the low group at both time points were deemed 'persistently inactive'; those who moved from the high or moderate group to the low group were deemed 'decreasing'; those who moved from the low group to the moderate or high group were deemed 'increasing'; and those who moved from the moderate to the high group, the high to the moderate group or were in the moderate or high group at both time points were deemed 'persistently active'. Figure 2 illustrates the formation of physical activity patterns from childhood to adulthood.

Insert Figure 2 here

The interpretation of these groups is based on the premise that most of the mental health benefits of physical activity are observed when individuals move out of the

lowest or sedentary categories of physical activity into the more active or non-sedentary categories . In the current study, those with persistent moderate physical activity are likely therefore to have similar mental health benefits as those with persistently high physical activity [4, 18].

To examine whether this categorization adequately discriminated participants by their level of physical activity, we evaluated the association between objectively measured cardiovascular fitness from childhood to adulthood for each level of the leisure physical activity variable. Change in cardiorespiratory fitness in an individual is strongly associated with change in habitual energy expenditure and leisure-time physical activity [43]. We assessed change in cardiorespiratory fitness over time by calculating age- (in childhood) and sex-specific standardized scores (z-scores) in childhood (1.6 km run/walk) and adulthood (PWC170). Childhood z-scores were then subtracted from adult z-scores to generate change in z-scores. The relationship between mean change in cardiorespiratory fitness z-scores and leisure physical activity patterns was examined using one way analysis of variance.

Historical leisure activity was ranked within each of the five-year age periods and variability was smoothed by regression modeling of the ranked data with time. To examine relative change in historical leisure activity from age 15 to adulthood, modeled ranks were used to determine persistence of activity by categorizing each participant into three groups based on tertile cut-points at the youngest time point,

and determining if their rank had moved to another category by the oldest time point using the method described above.

Using those 'persistently inactive' as the reference group, relative risks (RR) and 95 % confidence intervals (CI) of depression in adulthood from i) leisure physical activity patterns and ii) historical leisure activity patterns were estimated using log-binomial regression [44]. Potential covariates were selected based on a bivariate association at $p < 0.25$ and retained in the model if the exposure coefficient varied by at least 10 % upon covariate removal [45]. Childhood and adult factors identified *a priori* as potential confounders of the association between physical activity and depression are those described previously. Covariates included in final models are displayed in table footnotes. Only participants with complete data for all covariates were included in these analyses. BMI in adulthood was hypothesized *a priori* to act as a potential confounder and/or mediator of the relationship between physical activity and depression [46] and was therefore examined separately.

Those currently pregnant were excluded from models due to the known differences in etiology of depression and physical activity patterns in these women [47]. To account for baseline depression, those reporting age of onset of depression younger or equal to age at baseline were excluded from leisure physical activity models. Likewise, those reporting age of onset of depression < 15 years were excluded from historical leisure activity models. *N*-values are presented in table footnotes.

To examine possible bias due to depression at the time of physical activity self-report, spearman correlations between current leisure physical activity (IPAQ) and pedometer data (mean steps/day) in adulthood by depression status were compared.

Analyses were conducted separately by sex due to the known sex differences in physical activity during adolescence [2] and performed using Stata version 9.2 (Statacorp, 2005). Statistical comparisons were treated as significant at $\alpha = 0.05$ (two-tailed).

Results

Description of cohort

Overall, 1,630 participants (759 males, 871 females) provided leisure physical activity data in childhood and adulthood and completed the depression module of the CIDI-Auto. Of these, 1,496 (695 males, 801 females) additionally provided historical leisure activity data and 1,380 (640 males, 740 females) provided pedometer data in adulthood. Table 1 describes the sociodemographic and health characteristics of the analysis sample. In regards to current occupation, sex differences were observed with a higher proportion of females being in white collar positions (25 % versus 6 %) and a higher proportion of males being in blue collar positions (30 % versus 4 %) ($p < 0.001$). Differences were also observed for BMI with a higher proportion of males being overweight or obese (63 % versus 39 %) ($p < 0.001$).

Insert Table 1 here

Depression

Overall 36 males and 100 females met the criteria for major depressive disorder and 11 males and 11 females met the criteria for dysthymic disorder. Seven males and nine females met the criteria for both major depressive and dysthymic disorder. Accordingly, prevalence of depression was 5.3 % (n = 40; 95 % CI 3.8-7.1) for males and 11.7% (n = 102; 95 % CI 9.7-14.0) for females ($p < 0.001$). Similarly, for the sub-sample with historical leisure activity data, prevalence of depression was 5.0% (n = 35; 95 % CI 3.6-6.9) for males and 11.6% (n = 93; 95 % CI 9.5-14.0) for females ($p < 0.001$).

Associations between physical activity in childhood and depression in adulthood

There was no significant association between discretionary physical activity in childhood and depression in adulthood in females ($p > 0.05$). For males, there was a non-significant trend for those in the highest tertile of activity to have an approximate 55 % lower risk of depression in adulthood compared with those in the lowest tertile of activity ($p = 0.06$), after excluding those with an age of onset of depression in childhood and adjustment for mother's place of birth, childhood smoking status and age in adulthood.

Associations between leisure physical activity patterns from childhood to adulthood and depression in adulthood

Mean increase in cardiovascular fitness z-scores was associated with leisure physical activity patterns from childhood to adulthood for both males (persistently inactive, −0.75; decreasing, -0.14; increasing, -0.06; persistently active, 0.31; $p < 0.001$) and females (persistently inactive, -0.85; decreasing, -0.35; increasing, 0.14; persistently active, 0.30; $p < 0.001$).

Using those persistently inactive as the reference group, we then estimated unadjusted and adjusted associations between leisure physical activity patterns from childhood to adulthood, and depression in adulthood (Table 2). For males, those increasingly and persistently active had a 69 % and 65 % reduced risk of depression in adulthood respectively, compared with those persistently inactive following adjustment (both $p < 0.05$). While not statistically significant a similar trend was observed for females, with those persistently active having a 38 % lower risk of depression.

Insert Table 2 here

Associations between historical leisure activity patterns from childhood to adulthood and depression in adulthood

Similarly, unadjusted and adjusted associations between historical leisure activity patterns from childhood to adulthood, and depression in adulthood were estimated (Table 3). For females, those persistently active had a 51 % lower risk of depression compared with those persistently inactive following adjustment ($p = 0.01$). A large but non-significant 51 % lower risk of depression in adulthood was observed for those increasingly active from childhood to adulthood ($p = 0.06$). For males, a non-significant trend was observed with those persistently active having a 45 % lower risk of depression compared with those persistently inactive.

Insert Table 3 here

Additional analyses

The addition of BMI to multivariable models had minimal impact on associations between physical activity and depression in females for leisure physical activity patterns and historical leisure activity patterns (data not shown). Similarly, the addition of BMI to multivariable models in males had a negligible effect on associations for leisure physical activity patterns and historical leisure activity patterns (data not shown) suggesting BMI did not mediate or confound the relationship between physical activity patterns and depression in the current cohort.

Including those with age of onset of depression equal or younger than age at baseline (6 males, 4 females) did not affect the adjusted associations between leisure

physical activity patterns and depression for males or females (data not shown). Including those with age of onset of depression < 15 years (7 males, 10 females) had a negligible influence, attenuating adjusted associations between historical leisure activity patterns and depression marginally for males and females (data not shown).

Finally, associations between current leisure physical activity and mean steps/day were $r = 0.09$ for cases and $r = -0.01$ for non-cases for males (both $p > 0.05$), and $r = 0.22$ for cases and $r = 0.20$ for non-cases for females (both $p < 0.05$), suggesting that self-reported physical activity in adulthood was not substantially biased by depression, particularly for females.

Discussion

To our knowledge, this study is the first to examine associations between leisure-time physical activity patterns from childhood to adulthood and risk of depression in young adults over a 20-year follow-up. Using two different measures, physical activity was assessed both prospectively and retrospectively and categorized into four physical activity trajectories. Results indicate that, particularly for males, those who increased or maintained activity from childhood to adulthood had a decreased risk of depression in adulthood. Adjusting for diverse sociodemographic and health characteristics including depressed mood in childhood did not affect associations. Likewise, associations were not confounded or mediated by BMI.

Cross-sectional associations between discretionary physical activity and i) depressed mood in childhood [17], and ii) depression in adulthood [4, 18] have previously been demonstrated. However, a key unresolved research question is whether physical activity in childhood confers any additional protection to subsequent depression to that of current activity. Compared with those who were inactive at both time points in the current study, there was a trend for decreasingly active males to have a 60 % decreased risk of depression even though physical activity rank declined in adulthood. Furthermore, females who were persistently active in both childhood and adulthood had a 38 % decreased risk of depression. While non-significant, these effect sizes suggest that childhood physical activity may make an additional contribution over and above that of current activity. Physical activity involving (competitive) sport or moderate-to-vigorous intensity activities, which are more common in childhood [2], may be particularly protective. Indeed, we have demonstrated that our cohort appear to depend on physical activity involving sport (males) and being structured in nature (females) to derive mental health benefits in childhood [17].

The analysis examining retrospectively assessed leisure activity patterns during the interval between baseline and follow-up provides supportive evidence with similar results to the analysis using prospectively assessed physical activity. Associations for males were non-significant however the small number of cases in each physical activity category limited the statistical power required to examine these associations.

Furthermore, while the assessment of leisure physical activity using the IPAQ included those activities of at least moderate intensity, the HLAQ also included lower intensity activities such as fishing and golf. A minimum threshold of intensity may be required for males to derive mental health benefits. Indeed inverse prospective associations between vigorous-intensity leisure physical activity and incidence of depression in men have been demonstrated [48].

While comparing studies is difficult due to differing methodology, results extend previous short-term prospective cohort studies demonstrating associations between habitual leisure physical activity and decreased incidence of major depression [12], minor depression [8, 12], and depressive symptoms [8, 13, 14] in adolescents, and prospective associations between regular sporting activity during adolescence and psychological distress in young adults over a 15-year period [9]. In contrast, Ströhle and colleagues found that compared with being sedentary, regular physical activity was associated with a 50 % decrease in incidence of major depressive disorder (assessed by the CIDI) in males aged 18-24 years but not females [8]. However, physical activity was assessed using just four items regarding type and frequency of sports, potentially biasing results towards males.

There are several mechanisms by which physical activity may protect against depression [49]. For example, physical activity might influence depression via central monoamine functioning [50] or by stimulating endorphin levels [51]. Data

from animal models also support a neurochemical pathway for the relationship between physical activity and depression [52]. Recent evidence indicates the effect of exercise on depressive symptoms is moderated by 5-HTTLPR genotype, suggesting that mechanisms responsible for the alleviation of symptoms are similar for both exercise and SSRI treatment [53]. Associations may also be explained by common genetic factors influencing both exercise behavior and depressive symptoms rather than a causal effect of exercise [54]. Psychological factors such as increased self-esteem, self-efficacy and social interaction may also be influential. For example, participation in physical activity and organized sport during adolescence may provide a social network that supports and protects individuals from depressive symptoms [55, 56].

Despite the prospective design of the current study, observed associations may be bidirectional with depressive symptoms such as anhedonia, psychomotor retardation and fatigue contributing to lower levels of physical activity. Indeed recent evidence implicates elevated depressive symptoms during adolescence with decreased participation in sporting activity in young adulthood [57]. In the current analysis, while those who reported onset of depressive symptoms at baseline were excluded from analyses, individuals experiencing an episode of depression during follow-up may have reduced their physical activity. In addition, those with current depression may have had lower levels of physical activity at follow-up leading to an increased prevalence of depression in the 'persistently inactive' and 'decreasing'

categories, as observed. Associations between subjective and objectively measured physical activity provide some assurance that self-reported physical activity in adulthood was not extensively biased by depression. However, comparisons between leisure physical activity and mean steps/day must be interpreted with caution as pedometer data also include non-discretionary activity (e.g. work physical activity).

A second clear limitation is the lack of assessment of depression at baseline. While we used age of onset of depressive symptoms (reported in adulthood) as an exclusion criterion and adjusted for depressed mood in childhood, information regarding depression diagnoses in childhood was unavailable. Thus misclassification of those with depression onset in childhood is a potential source of bias. Further, while the Negative Balance Scale has been used extensively in population surveys, the measurement properties of the scale using juvenile populations remain unclear. Future prospective studies using more contemporary and psychometrically sound measures of childhood depression may provide further insight into the nature of any prospective associations.

Another possible limitation is the use of self-report measures of physical activity and depression. The HLAQ relied on retrospective recall of leisure activities over the intervening period from baseline to follow-up. However, self-reported historical physical activity has been found to be reliable [32] and reproducible in young adults

[33]. Evaluations of the IPAQ also indicate acceptable measurement properties [26]. Furthermore, diagnostic interviews for depression, including the CIDI, have been shown to improve standardization of diagnosis, eliminate clinician bias and offer high reliability and consistency of administration [58]. Another potential limitation is the different measures of physical activity used at baseline and follow-up. However, assessing adults' physical activity with a survey specifically designed for children would be incongruous. Finally, we were unable to examine the differential effects of aerobic and nonaerobic physical activity using the current self-report measures. Both aerobic and anaerobic physical activity interventions have been found to be efficacious in reducing depression and depressive symptoms [59]. Further research incorporating detailed assessment of the type of physical activity is required to disentangle these effects.

Measurement error and unmeasured potential confounders, inevitable in observational studies, may have also influenced results. While associations were not affected by adjustment for the most salient potential confounders, the possibility of residual confounding remains. For example, while current physical health status was assessed, associations may have been influenced by recurring physical illness during the interval from baseline to follow-up. Finally, like other long-term prospective cohort studies, attrition was evident at follow-up. However, absolute differences at baseline between participants and non-participants at follow-up were small and there were no significant differences in baseline physical activity and depressed

mood suggesting that bias due to differential loss to follow-up was likely to be minimal.

Using a geographically dispersed population-based cohort of young adults, this study is one of the first to examine the influence of habitual leisure-time physical activity patterns from childhood to adulthood on depression in adulthood. Key strengths include a national sample of youth, long-term follow-up, measured height and weight, extensive assessment of physical activity trajectories from childhood to adulthood, and use of diagnostic criteria to assess depression. A wide range of potential confounders were examined, and findings were robust to excluding cases of depression with childhood onset.

Conclusions

The present study found that, particularly for males, increasing or maintaining discretionary physical activity from childhood to adulthood relative to one's peers is prospectively associated with a decreased risk of depression. Given that physical activity is a potentially modifiable risk factor, the public health implications of these findings are substantial. Childhood to early adulthood is a critical developmental period when physical activity levels decline [2] and depressive symptoms commence or increase [60]. Strategies aimed at maintaining physical activity participation from childhood and initiating physical activity in young people has potential for reducing the morbidity and subsequent treatment burden of depressive disorders.

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Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Fig 1. Flowchart of recruitment and retention of cohort participants

Fig 2. Formation of physical activity patterns from childhood to adulthood

Table 1 Characteristics of participants in childhood (1985) and adulthood (2004-2006)

Characteristic	Females *n* = 871		Males *n* = 759	
Childhood (1985)				
Language spoken at home, (%)				
English	785	(90.1)	665	(87.6)
Other	86	(9.9)	93	(12.3)
Missing	*0*	(*0.0*)	*1*	(*0.1*)
Self-reported health status, (%)				
Very good/good	711	(81.6)	626	(82.5)
Average/poor	160	(18.4)	133	(17.5)
Depressed mood[a], (%)				
Often	85	9.8	45	5.9
Sometimes/never	780	89.5	706	93.0
Missing	*6*	*0.7*	*8*	*1.1*
Physical activity (mins/wk)[b], mean (SD)	285	(376)	339	(373)
Adulthood (2004-2006)				
Age, mean (SD)	32.3	(2.1)	32.4	(2.1)
Current occupation, (%)				
Manager/Professional	441	(50.6)	448	(59.0)
White collar	221	(25.4)	44	(5.8)
Blue collar	34	(3.9)	228	(30.0)
Not in labor force	165	(18.9)	25	(3.3)
Missing	*10*	(*1.2*)	*14*	(*1.8*)
Marital status, (%)				
Married	526	(60.4)	425	(56.0)
Living as married	120	(13.8)	109	(14.4)
Divorced/Separated	36	(4.1)	19	(2.5)
Single	189	(21.7)	206	(27.1)
SF-12 PCS, mean (SD)				
Physical Component Summary	54.0	(6.7)	54.1	(6.3)
Missing	*29*		*22*	
Live births, (%)				
none	383	(44.0)		
one	159	(18.3)		
two	232	(26.6)		
three or more	97	(11.1)		
BMI[c], (%)				
Healthy weight (BMI<25)	498	(61.2)	282	(37.1)
Overweight (BMI≥25 & <30)	195	(24.0)	355	(46.8)
Obese (BMI≥30)	120	(14.8)	122	(16.1)
Physical activity (mins/wk)[d], mean (SD)	157	(188)	169	(210)

Abbreviations: BMI, Body Mass Index; CDAH, Childhood Determinants of Adult Health; SD, standard deviation; SF-12v2, Short-Form Survey (version 2).

[a] Depressed mood in childhood (Affect Balance Scale).

[b] Discretionary (leisure) physical activity in past week.

[c] Excludes those currently pregnant (*n* = 61).

[d] Leisure physical activity from the International Physical Activity Questionnaire.

Table 2 Relative risks and 95 % confidence intervals for depression by leisure physical activity patterns from childhood to adulthood

Physical activity	*N*	% Cases	RR	95 % CI	*p*	adjRR[b]	95 % CI	*p*	adjRR[c]	95 % CI	*p*
Females	*n* = 791[a]										
Persistently inactive	101	14.9	1.00	Reference		1.00	Reference		1.00	Reference	
Decreasing	164	16.5	1.11	(0.62, 1.98)	0.73	1.05	(0.59, 1.87)	0.87	1.04	(0.58, 1.85)	0.90
Increasing	182	10.4	0.70	(0.37, 1.32)	0.27	0.75	(0.40, 1.42)	0.38	0.73	(0.39, 1.38)	0.34
Persistently active	344	9.0	0.61	(0.34, 1.08)	0.09	0.62	(0.35, 1.12)	0.11	0.62	(0.35, 1.11)	0.11
Males	*n* = 731[a]										
Persistently inactive	95	9.5	1.00	Reference		1.00	Reference		1.00	Reference	
Decreasing	156	4.5	0.47	(0.18, 1.23)	0.13	0.40	(0.15, 1.05)	0.06	0.40	(0.15, 1.05)	0.06
Increasing	147	3.4	0.36	(0.12, 1.04)	0.06	0.32	(0.11, 0.92)	0.03	0.31	(0.11, 0.92)	0.03
Persistently active	333	3.6	0.38	(0.17, 0.88)	0.02	0.35	(0.15, 0.81)	0.01	0.35	(0.15, 0.81)	0.01

Abbreviations: CDAH, Childhood Determinants of Adult Health; CI, confidence interval; RR, relative risk.

[a] Includes those who completed the physical activity questionnaire in childhood, the International Physical Activity Questionnaire in adulthood and questions about confounding variables only. Those currently pregnant (*n* = 61) or with age of onset of depression younger than or equal to age in childhood (6 males, 4 females) excluded.

[b] Log-binomial models additionally adjusted for self-reported health status and language spoken at home in childhood, and number of live births (females only), current occupation and age in adulthood.

[c] Additionally adjusted for depressed mood (Affect Balance Scale).

Table 3 Relative risks and 95 % confidence intervals for depression by historical leisure activity patterns from 15 years to adulthood

Physical activity	*N*	% Cases	RR	95 % CI	*p*	adjRR[b]	95 % CI	*p*	adjRR[c]	95 % CI	*p*
Females	*n* = 697[a]										
Persistently inactive	118	15.3	1.00	Reference		1.00	Reference		1.00	Reference	
Decreasing	115	7.4	1.14	(0.64, 2.04)	0.66	1.07	(0.61, 1.87)	0.81	1.07	(0.61, 1.87)	0.81
Increasing	122	8.2	0.54	(0.26, 1.12)	0.10	0.50	(0.24, 1.03)	0.06	0.49	(0.24, 1.02)	0.06
Persistently active	342	7.9	0.52	(0.30, 0.90)	0.02	0.49	(0.28, 0.85)	0.01	0.49	(0.28, 0.85)	0.01
Males	*n* = 655[a]										
Persistently inactive	98	4.1	1.00	Reference		1.00	Reference		1.00	Reference	
Decreasing	122	4.9	1.20	(0.35, 4.15)	0.77	1.21	(0.38, 3.85)	0.75	1.18	(0.36, 3.75)	0.80
Increasing	119	4.2	1.03	(0.28, 3.73)	0.97	0.85	(0.26, 2.80)	0.79	0.84	(0.26, 2.79)	0.78
Persistently active	316	2.5	0.62	(0.19, 2.02)	0.43	0.56	(0.19, 1.64)	0.29	0.55	(0.19, 1.61)	0.28

Abbreviations: CDAH, Childhood Determinants of Adult Health; CI, confidence interval; RR, relative risk.

[a] Includes participants who additionally completed the Historical Leisure Activity Questionnaire at follow-up and questions about confounding variables only. Those currently pregnant (*n* = 58) or with age of onset of depression younger than 15 years (7 males, 10 females) excluded.

[b] Log-binomial models adjusted for number of live births (females only), SF-12 Physical Component Summary, marital status, current occupation and age in adulthood.

[c] Additionally adjusted for depressed mood (Affect Balance Scale).