Change in device-measured physical activity assessed in childhood and adolescence in relation to depressive symptoms: general population-based cohort study

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Abstract

Aim: Evidence for a link between physical activity and mental health in young people is hampered by methodological shortcomings. By utilising repeat assessments of device-measured physical activity, we examined the association of within-individual variation in free-living activity over 7 years with depressive symptoms.

Methods: This was a prospective cohort study of a nationally representative sample of children born in the UK (n=4,898). Physical activity was quantified using accelerometry at age 7 and age 14. Main outcome was depressive symptoms, based on the Short Moods and Feelings Questionnaire, assessed at age 14.

Results: After adjustment for socio-economic status, body mass index, and psychological problems at baseline, higher levels of light intensity activity at age 7 in girls was associated with a lower likelihood of having depressive symptoms at follow up (odds ratio, 0.79; 95% CI, 0.61, 1.00), although no associations were observed for moderate to vigorous activity or sedentary behaviour. Girls who transitioned from low baseline activity to higher levels at follow up experienced a lower risk of depressive symptoms (odds ratio, 0.60; 95% CI, 0.39 – 0.92) compared to the inactive reference category. Null associations were observed in boys. Participants who consistently met the currently recommendation of 60 min-d moderate-vigorous activity at both age 7 and 14 years of age experienced the lowest risk of depressive symptoms (odds ratio, 0.55;95% CI, 0.34, 0.88).

Conclusion: To prevent depressive symptoms in adolescence, policies to increase physical activity from mid-childhood may have utility.

What is already known

- Observational studies suggest that higher levels of physical activity (PA) are associated with a lower risk of depressive symptoms in younger people.
- Evidence is hampered by a lack of prospective data, a reliance on self-reported measures of activity, and concerns regarding the time-varying characteristics of PA.

What this study adds

- We use longitudinal data with repeat assessments of device-measured PA to examine prospective associations with depressive symptoms.
- Girls who transitioned from low baseline PA to higher PA at follow up had lower odds of depressive symptoms.
- Participants who consistently met the PA guidelines of 60 min-d moderate-vigorous intensity at both age 7 and 14 years of age experienced the lowest risk of depressive symptoms.

Introduction

Mental disorders, including depression, account for a large proportion of the burden of disease in young people worldwide.[1,2] As well as being an important public health concern in their own right, mental illness in young people impacts upon a range of later outcomes including educational achievements, illicit drug use, self-harm, sexual health, life expectancy and chronic somatic disease.[1,3-5] In many individuals, first onset of depression occurs in adolescence,[6] and even sub-clinical symptoms during this period are associated with increased risk of adulthood disorder,[7] magnifying the need to understand and prevent experience of moderate levels of distress. While evidence-based treatments exist,[2] these are not universally effective, so raising the need to identify modifiable, policy-relevant risk factors. Behavioural strategies such as physical activity (PA) may therefore be a particularly important approach in the prevention of depression.

A series of observational studies suggest that higher levels of PA are associated with a lower risk of depressive symptoms in younger people.[8,9] While informative, these studies are subject to several methodological constraints that hamper data interpretation. A major concern is the preponderance of cross-sectional studies,[8] a methodological design that is subject to reverse causation whereby physical inactivity may be linked to poor psychological health but the converse may also be the case. A second issue concerns the time-varying nature of PA, particularly during the transition from childhood to adolescence,[10] that a single assessment of PA will fail to capture. Third, the near-exclusive use of self-reported PA measures in these studies raises well-documented concerns regarding response bias[11] and hampers the ability to explore PA across the full behaviour spectrum, including sedentary time.

Some of these issues can be overcome by the use of randomised controlled trials,[12] that employ non-exercise control groups. However, that PA may be beneficial for many dimensions of health means that the long term encouragement of sedentary behaviour is ethically unacceptable. An alternative approach is to use an observational study setting[13] with repeat assessments of PA whereby changes in activity are tracked and related to the occurrence of psychological problems. If data on change in PA were also objectively gathered on repeat occasions, as opposed to being ascertained via self-report,[14] then, in addition to increasing confidence in the results, the full range of free-living activity would also be captured, including sedentary behaviour which may exert its own influence on health. Repeat assessment of device-measured PA in sufficiently large cohorts is, however, rare. For the first time to our knowledge, we used data from a large-scale, nationally representative prospective cohort study with repeat assessments of device-measured PA to examine the association of changes in free-living PA over a 7 year period with depressive symptoms.

Methods

Participants

A nationally representative sample of children born in the UK was recruited into The Millennium Cohort Study (MCS) between September 2000 and January 2002. The study has been described in full elsewhere.[15] In brief, eligible children were identified from child welfare benefit records, a scheme covering nearly all families in the UK. To date, there have been 6 waves of data collection (at ages 9 months, 3, 5, 7, 11 and 14 years). We used the fourth wave when participants were aged 7 years as the baseline for the present study as this was the first occasion that device-measured PA data were gathered. Interviewers visited the cohort members' homes and conducted face-to-face interviews with both parents. Ethical approval

was granted by the Northern and Yorkshire Multi-Centre Research Ethics Committee of the NHS.

Physical activity assessment

During the fourth wave of data collection when participants were aged 7 (2008/9), PA and sedentary time were measured over a 7-day period using the waist-worn uni-axial Actigraph GT1M accelerometer (Actigraph, Pensacola, Florida, US). Sedentary time was defined as <100 counts per minute, light PA (LPA) as 100-2241, and moderate-to-vigorous (MVPA) as >2241.[16] The PA assessments were repeated at age 14 using a tri-axial accelerometer (GENEActiv, Activinsights Ltd., Cambs, UK) placed on the non-dominant wrist for two full 24h periods on a randomly selected week and weekend day.[17] Data were downloaded using GENEActiv software and raw data processed using the GGIR package in R (https://cran.r-project.org/web/packages/GGIR/GGIR.pdf),[18] which includes auto-calibration and non-wear detection functions. The principal output was Euclidean Norm Minus One (ENMO) which is a measure of mean acceleration over a 24-hour period from the 3 axes (sagittal, frontal and vertical) relative to the horizontal plane.

Depressive symptoms

At baseline when study members were 7 years of age, psychological distress was assessed using parental reports from the Strengths and Difficulties questionnaire (SDQ), a 25 item tool using 3 point likert scale which has demonstrated good reliability and validity for use in population-based surveys.[19] The SDQ was originally validated on a nationwide sample of 10,438 British 5-15 year-olds, demonstrating internal consistency (mean Cronbach α= 0.73),

cross-informant correlation (mean: 0.34), and retest stability after 4 to 6 months (mean: 0.62).[19] A total difficulties score was derived by summing subscales of hyperactivity, emotional symptoms, conduct problems, and peer problems; a higher score denoting greater distress. At follow-up, when cohort members when aged 14, the Short Moods and Feelings Questionnaire (SMFQ) was utilised.[20] Consisting of 13 items, a score of 12 points or higher indicates greater depressive symptoms. In the present cohort, the SMFQ demonstrated strong internal reliability (Cronbach's alpha=0.93). Several studies have reported moderate to high criterion validity for discriminating 7 to 17-year-olds with and without major depressive episodes using the Diagnostic Interview Schedule for Children as the criterion standard.[21,22]

Covariates

Covariates for the present analyses were selected *a priori* based on existing evidence,[8,9] and included parental social occupational class, (using the Registrar General's classification: professional and managerial occupations; skilled, non-manual occupations; skilled manual occupations; and, routine and manual occupations), and body mass index (BMI: weight [kg] / height $[m]^2$) as calculated from baseline height and weight. Height was taken using a Leicester height measure stadiometer with a Frankfurt Plane card. Weight was measured using Tanita scales (BF-522W), to the nearest 0.1kg. Although BMI may be viewed as being on the intermediate pathway between PA and depression, we made an a priori decision to model BMI as a confounder based on previous studies.[8]

Statistical analysis

We carried out two sets of analyses. In the first, we related baseline assessment of PA to depressive symptoms 7 years later, and in the second we explore the association of change in PA between 7 and 14 years of age with subsequent depressive symptoms. In analyses where we categorised depressive symptoms at follow-up, we used logistic regression to compute odds ratios with accompanying 95% confidence intervals to summarise the relation with sedentary behaviour, LPA, and MVPA at baseline; where a continuous scores was used for depressive symptoms, linear regression produced beta coefficients. In these analyses we adjusted for parental socio-economic category based on occupation, BMI (continuous variable), device wear time, and total SDQ score at baseline. The relation of MVPA and LPA with depressive symptoms was mutually adjusted while sedentary behavior was adjusted for MVPA only.[23] Second, to compute PA change between age 7 to 14 years we used continuous counts-min and ENMO mean acceleration data at baseline and follow up, respectively, to categorise participants into 'high' or 'low' activity based on the sex-specific median split. We then created four activity groups based on PA measurement at both time points (low – low; low – high; high – low; high – high). We have previously found evidence of selection bias in those participants providing valid accelerometry data,[24] thus we used weighted analyses based on the accelerometry sub-sample. Given the marked gender differences in depressive symptoms and PA during the adolescent developmental period all analyses were stratified by sex. We also explored the impact of reverse causality by removing from the analyses study members regarded as a 'case' at baseline (SDQ score >16). All analyses were conducted using SPSS version 22 with statistical significance set at $p<0.05$.

Results

Based on the inclusion criteria (at least 2 days with ≥10 h wear time)[16], 6,675 study members (3176 boys) provided viable accelerometry data at baseline (Table S1). After exclusion of those with missing covariate and follow-up data, the analytic sample comprised 4,763 participants. Excluded participants were more likely to come from more socio-economically deprived families (semi routine/routine occupation: 33.1 vs 23.6%, p=0.001), and had higher mental health problems (SDQ score at baseline: 7.5±5.3 vs 6.2±4.6, p=0.001), than those included, although there were no differences in physical activity (605 ±161 vs 601 ±148 cpm, p=0.24) or BMI (16.4±2.3 vs. 16.4±2.0 kg/m^2, p=0.59).

PA at 7 years of age and depression at 14 years

In table 1 we show the baseline characteristics of study members according to baseline PA. Participants in the highest PA tertile at baseline were much more likely to be boys but socioeconomic status and BMI were similar across PA groups.

At follow-up, 16.4% of the sample were regarded as a case based on their depressive symptoms. Baseline LPA was inversely associated with later depressive symptoms in girls but not in boys. No associations were observed for MVPA or sedentary behaviour (Table 2). With there being a moderate correlation between LPA and sedentary time (r=0.35), we re-ran the analyses making mutual adjustment. The association between LPA and depressive symptoms was largely unchanged (highest tertile of LPA, OR=0.80; 95% CI, 0.61 – 1.05) although associations with sedentary and depressive symptoms were entirely attenuated after adjustment for LPA (highest tertile of sedentary, OR=1.00; 95% CI, 0.75 – 1.34). To explore reverse causality, we repeated the analyses after removing 6.7% of the sample displaying psychological

distress (SDQ scores >16) at baseline. The pattern of results was essentially the same (Table S2). For example, in girls there was lower odds of elevated depressive symptoms in the highest tertile of LPA (OR=0.78; 95% CI, 0.60 – 1.00), and null associations remained for sedentary and MVPA.

Change in PA and depressive symptoms

Change in PA was calculated for a sample of 2,416 participants who had available device-measured PA data from age 7 and 14. The four activity groups were generally evenly distributed, and participant characteristics are displayed in Table S3. A total of 1063 (44%) children in this sample changed PA category between baseline and follow up. There was evidence that, relative to those children who remained inactive over the observation period, participants who transitioned from low baseline activity to higher activity at follow up had lower odds of depressive symptoms, particularly in girls (OR=0.60; 0.39 – 0.92) (Table 3). Participants who were less active at follow up had the same risk of having depressive symptoms as children who were inactive throughout. The results were largely replicated when we categorised participants based on meeting the current PA guidelines (60 min-d MVPA) using thresholds to define MVPA (>2241 cpm Actigraph[16]; >100 mg GENEActiv[25]). Participants that met PA guidelines both at baseline and follow-up displayed the lowest odds of depressive symptoms (OR=0.55; 0.34, 0.88) as did participants who met guidelines at follow up but not at baseline (Figure 1).

We repeated the analyses using the continuous PA data. The results showed that higher PA (per SD mean acceleration) by age 14 was inversely associated with depressive symptoms (OR=0.53; 0.33 – 0.86) after adjustment for PA at baseline.

In sensitivity analyses the associations of PA change and depressive symptoms were not changed when we removed participants displaying psychological distress (SDQ scores >16) at baseline (Table S4).

Discussion

Our results show an association of baseline LPA, and increases in PA between childhood and adolescence with lower risk of depressive symptoms. Associations were observed in girls but not boys. A key feature of the present study was the repeat assessments of device-measured PA which allowed us to examine the effects of within-individual free-living PA variation over 7 years on depressive symptoms. Indeed, associations between MVPA and depressive symptoms only emerged when we utilised data at age 7 and age 14, highlighting the importance of collecting repeat data. In randomised controlled trials of paediatric populations it would be unethical to assign participants to a control group instructed to maintain very low levels of PA for a prolonged period of time. Indeed, the use of appropriate control groups in this field has been a source of debate and possible bias.[12, 26] Further, free-living activity measures are ecologically more informative than highly structured, often supervised training regimes typically found in trials which often yield high drop-out raising concerns regarding long-term sustainability.

Study limitations

We cannot discount the possibility of residual confounding due to unmeasured or superficially assessed covariates. For example, physical illness may have driven both inactivity and depressive symptoms, although the present sample were largely healthy. Also, while our outcome was depressive symptoms rather than diagnosis, the SMFQ has demonstrated acceptable criterion validity.[21,22] Parental rather than self-report of psychological distress in

childhood is a potential source of bias. As anticipated,[24] participants included in our analytical sample were more socio-economically advantaged that those who dropped out. Weightings were used to partly overcome selection biases, although exclusion of more deprived cohort members with greater mental health issues may have partially diluted our findings. While device-measured PA overcomes some of biases associated with self-reported PA,[11] this approach only provides data for a small time window in participants' lives and this may not be a true reflection of their habitual behaviour. The devices employed differed at age 7 and 14, both in terms of the wear position (hip versus wrist) and the brand. Absolute differences are, however, likely to be small[27] and our different approaches to categorising participants at each time point based on distribution of raw acceleration versus thresholds to define MVPA volume, produced a similar pattern of results. Our data showing that PA was relatively unstable over time are consistent with previous work on tracking of PA from childhood to adolescence.[10] A lack of information regarding variations in PA and depressive symptoms in the intervening years between age 7 and 14 is a limitation as depressive symptoms such as anhedonia, psychomotor retardation, and fatigue during the interval between baseline and follow-up may have contributed to lower PA levels.

Comparison with existing studies

Previous observational studies have been unable to robustly assess PA–depression associations due to several methodological constraints. As indicated, there is a paucity of prospective studies, in particular none that have captured PA change at separate time points. The only two longitudinal studies to have investigated associations of device-measured PA with depression produced conflicting findings[28,29]; MVPA assessed at baseline was associated with lower risk of major depression in 6 yr old children followed up over a 4 yr period[28] although no such association was found in a cohort of teenagers followed for approximately 3 years.[29] The

impact of LPA was not examined in either study. Previous work using self-reported PA has largely shown positive associations with MVPA.[8] Self-reported MVPA is often derived from questions on sports participation, which may have favourable effects on mental health through, for example, social support mechanisms. In contrast, device-measured MVPA is devoid of any context and simply reflects movement, possibly explaining the mixed findings. In adult populations some data suggest that light/moderate intensity PA has greater anti-depressive effects,[30] benefits on positive mood,[31] and on reducing symptoms of fatigue compared with vigorous intensity.[32]

Consistent with prior work[33] the prevalence of depressive symptoms was higher in girls in our study. Associations between PA and depressive symptoms were also far stronger in girls. The reasons for these sex differences are unclear. In boys type and intensity of PA may be more important (e.g. team sports). Biological mechanisms might explain higher vulnerability to depression in adolescent girls.[34] Thus, PA may help partly stabilise biological imbalances during adolescence linked to depression. Social mechanisms may also exist, for example, body dissatisfaction and self-esteem may be reasons for inactivity in girls that may partly drive mental health.

Meaning of the study: possible explanations and implications for clinicians and policymakers

Treatment considerations for clinical depression in young people suggest that patients should be offered advice on the benefits of regular PA.[35] Given that even sub-clinical symptoms in adolescence are associated with adverse outcomes suggests that attention should also focus on PA in the prevention of depression, promoting intervention far earlier.

Conclusion

Using observational data to examine within-individual variation over a 7 years follow up period we demonstrate that increases in PA are associated with lower risk of depressive symptoms in girls. Policies to increase PA might benefit from focussing on mid-childhood to early adolescence, when PA is particularly changeable.

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Table 1. Baseline characteristics of study members according to baseline physical activity (n=4,763)

	Physical activity tertile (cpm)		
	Low (<527 cpm)	Medium (527 – 653 cpm)	High (>653 cpm)
Age, yr	7.2± 0.2	7.2± 0.2	7.2± 0.2
Sex (% boys)	35.5	51.0	63.7
Occupational social class (% Professional/Managerial)	32.4	31.4	31.2
Total SDQ score	6.7± 4.4	6.7± 4.6	7.4± 5.2
Body mass index ($kg.m^{-2}$)	16.7± 2.3	16.7± 2.0	16.2± 1.6
MVPA (min/d)	41±9	60± 9	86± 18
LPA (min/d)	260±38	284± 37	299 ±37
Sedentary (min/d)	440 ±59	391 ±46	344 ± 48.0
Actigraph wear time (total min across all days)	4181 ± 1332	4198 ± 1220	4020 ± 1274

Strengths and Difficulties questionnaire (SDQ); Moderate – vigorous physical activity (MVPA); Light physical activity (LPA)

Table 2. Prospective association between physical activity at baseline and depressive symptoms at aged 14 stratified by sex

	Boys		**Girls**	
Baseline activity	**% SMFQ ≥12**	**Odds ratio (95% CI)†**	**% SMFQ ≥12**	**Odds ratio (95% CI)†**
Sedentary				
Low (<6hr/d)	7.4	1.0 (Ref)	22.3	1.0 (Ref)
Medium (6 – 7 hr/d)	7.5	0.95 (0.65, 1.39)	23.6	1.18 (0.92, 1.52)
High (>7 hrd)	9.0	1.08 (0.68, 1.69)	22.5	1.15 (0.85, 1.54)
LPA				
Low (<4.5 hr/d)	8.1	1.0 (Ref)	23.5	1.0 (Ref)
Medium (4.5 – 5 hr/d)	7.3	0.91 (0.63, 1.32)	23.2	0.90 (0.72, 1.13)
High (>5 hr/d)	8.5	1.06 (0.72, 1.56)	21.7	0.79 (0.61, 1.00)
MVPA				
Low (<51 min/d)	9.4	1.0 (Ref)	23.0	1.0 (Ref)
Medium (51 – 69 min/d)	7.6	0.80 (0.54, 1.19)	23.0	1.05 (0.85, 1.29)
High (>69 min/d)	7.5	0.85 (0.58, 1.25)	22.3	1.09 (0.84, 1.41)

Odds ratios are adjusted for: total SDQ score at baseline, Actigraph wear time, parental occupational social class, body mass index at baseline. Analyses of MVPA and LPA are mutually adjusted; analyses of sedentary behavior are adjusted for MVPA.

Table 3. Association between change in activity from aged 7 to 14 and depressive symptoms aged 14 stratified by sex

PA change category		Boys			Girls		
Baseline PA[¥]	**Follow-up PA**	**Cases/N**	**% SMFQ ≥12**	**Odds ratio (95% CI)[†]**	**Cases/N**	**% SMFQ ≥12**	**Odds ratio (95% CI)[†]**
Low	Low	27/318	8.5	1.0 (Ref)	75/343	23.1	1.0 (Ref)
Low	High	18/282	6.4	0.81 (0.43, 1.52)	40/279	14.6	0.60 (0.39, 0.92)
High	Low	21/252	8.3	1.31 (0.48, 3.55)	67/283	24.1	0.84 (0.44, 1.64)
High	High	25/355	7.0	1.12 (0.41, 3.03)	81/381	22.7	0.72 (0.37, 1.40)

Effect estimates are adjusted for: total SDQ score at baseline, parental occupational social class, body mass index at baseline, PA at baseline (cpm)