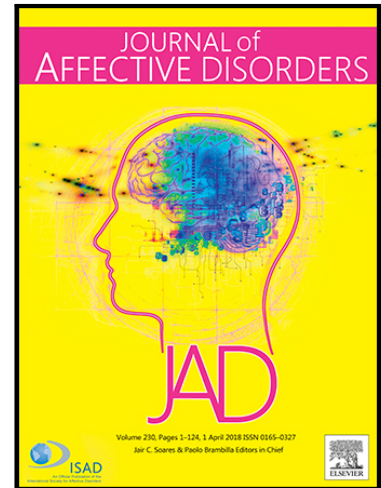# Journal Pre-proof

Impact on adolescent mental health of replacing screen-use with exercise: A prospective cohort study

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Impact on adolescent mental health of replacing screen-use with exercise: A prospective cohort study

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Keywords

Depression, sedentary behaviour, physical activity, screen time, distress

Highlights

- Recommendations to reduce adolescents' screen time assume all forms of screen time are inherently harmful for mental health
- We found that potentially replacing an hour of social media or television with team sports was prospectively associated with less emotional distress in adolescents three years later
- There was no evidence of associations between video gaming or general computer use with emotional distress
- The complex relationship between screen time and mental health warrants more nuanced investigation and tailored recommendations

Abstract

Background

Screen-based device use could increase the risk of adolescent depression. Distinct modalities of screen-use may have differential effects on mental health. We used compositional data analysis to examine how theoretically replacing different screen-uses with exercise might influence future adolescent emotional distress.

Methods

In 4,599 adolescents (55% female) from a nationally-representative, prospective cohort, we used time-use diary data at age 14 to estimate daily screen use (television, social media, video game, general computer use) and exercise (team sport and individual exercise). The outcome was emotional distress at age 17, assessed using the emotional symptoms subscale of the Strengths and Difficulties Questionnaire.

Results

Theoretically replacing 60 minutes of total screen time with exercise at age 14 was associated with a 0.05 (95%CI -0.08, -0.02) score reduction on the emotional symptoms' subscale at 17 in fully-adjusted models. Replacing 60 minutes of television or social media use with team sports was associated with a reduction of 0.17 (95%CI, -0.31, -0.04) and 0.15 (95%CI, -0.29, -0.01) in emotional symptom scores, respectively. We found no change in emotional symptom scores when replacing video game or general computer use with team sport, or when replacing any screen time with individual exercise.

Limitations

No direct measure of depressive symptoms at follow-up.

Conclusions

Replacing any screen time with exercise could reduce emotional distress, but the largest effect sizes were associated with replacing time in television watching and social media with team sports. Recommendations to limit screen-use in adolescents may require a nuanced approach for protecting mental health.

Introduction

Depression is a leading cause of years lost to disability in adolescents (1) with an incidence that has increased by around 50% since 1990 (2). It is associated with a range of psychiatric symptoms that include persistent low mood, fatigue, apathy, and hopelessness. Depressive symptoms commonly emerge during adolescence with reduced social and occupational or academic functioning, and persistent mental health problems in the future (3,4). However, effective population-level approaches for preventing depressive symptoms in adolescents are lacking (5,6), despite its substantial economic costs (7).

Sedentary behaviour refers to low energy expenditure activities in sitting, lying, or reclining postures (8). Time in sedentary behaviour typically increases during adolescence (9,10), largely due to the use of screen-based devices (11). Some population-level data suggest high sedentary behaviour during adolescence is associated with an increased risk of depressive symptoms (12), but findings have been inconsistent (13–15). Clarifying this relationship is important as international activity guidelines increasingly make strong recommendations to limit screen-use in adolescents but with a low certainty of evidence (16). One of the major evidence-weaknesses is that studies focusing on possible relationship with mental health have largely used cross-sectional designs that are unable to determine the direction of causality (13–15). Some of the inconsistencies between previous findings may also be due to defining the exposure as overall time in sedentary behaviour, or in a specific type of sedentary behaviour such as watching television. While general screen time may provide a proxy indicator of overall sedentary behaviour in young people (11), different screen-based devices can provide distinct experiences with the potential to influence the brain and mental health.

For example, social media and video gaming provide platforms for social interactions, which are absent from watching television, could reduce feelings of isolation or loneliness that are

associated with the risk of depressive symptoms in adolescents (17). Among adults, spending more time in mentally-passive sedentary behaviours (e.g., watching television) is associated with an increased risk of depression, but there is no or an inverse association with mentally-active behaviours (e.g., computer use) (18–21). However, studies comparing different types of screen time in adolescents have been scarce and inconsistent. Studies in adolescents have found that high social media, computer, or television use is associated with poorer mental health outcomes (13,22–24), but not always video game use (13,22,25). Some studies have found protective associations between video gaming and mental health in adolescents (25–27). The factors underlying the relationship between screen time with mental health in adolescents can be complex (28,29), likely extend beyond the impacts of lower energy expenditure levels (30), and warrant a more nuanced investigation into different screen time modalities.

Another consideration that previous studies overlook (12–15) is with how best to replace screen-use. Structured physical activity can effectively reduce depressive symptoms in adolescents (31). Higher physical activity volumes are also associated with a lower incidence of depression in the population (32). In addition to biological factors, physical activity may influence depressive symptoms through psychosocial pathways, such as improving self-esteem or facilitating social support (30). The extent to which physical activity or exercise (a subset of physical activity) influences these pathways may differ by modality. For example, team sports incorporate cooperative and potentially more sociable elements that may have additional benefits for reducing depressive symptoms than individual exercise does (33–35).

Reducing sedentary behaviour may have mental health benefits in adolescents, but addressing all screen time is challenging given its pervasiveness in modern life. Targeted approaches aiming to replace potentially detrimental screen time modalities with optimal physical activity modalities could have a more meaningful impact on reducing depression risk in

adolescents than generalised approaches to decrease screen time or increase exercise. We used data from a large nationally representative cohort of adolescents in the UK to examine how theoretically replacing daily television, video game, social media, or general computer use with individual exercise or team sports at age 14 may affect emotional distress at age. We refer to emotional distress as emotional symptom scores, a component of internalising symptoms that are associated with mood disorders in adolescents (36–38). We also examined sex as a potential effect modifier. Adolescent use of different screen time modalities varies by sex (39) and a meta-analysis of mostly cross-sectional studies identified sex as an effect modifier of the relationship between screen-time and depressive symptoms (13).

We expected that total screen time at baseline would be associated adversely with emotional distress at follow up and exercise would be beneficially associated with emotional distress, such that theoretically replacing screen time with exercise would be associated with lower emotional distress scores. We also expected that replacing daily time watching television or using social media with individual exercise or team sport would be associated with lower emotional symptom scores, but not video gaming or computer use. We also hypothesised that these associations would differ by sex.

Methods

Participants

The Millennium Cohort Study includes a nationally representative sample of 18,552 families and 18,818 children in the UK, born between September 2000 and January 2002 (40). People from socially disadvantaged areas, ethnic minorities, or Wales, Scotland, and Northern Ireland were oversampled to increase representation. The cohort includes seven sweeps of

data collection on social, environmental, psychological, and biological factors from families and children. We used data from sweeps six (11,872 adolescents aged 14) and seven (10,757 adolescents aged 17). We defined our sample as 4,599 participants who completed time-use diaries at baseline (38.7% of total sample at sweep six). A flowchart of participants included in this study is available in Figure 1 of the Supplementary Materials. The Millennium Cohort Study has ethical approval from the National Health Service Research Ethics Committee and all data is accessible from the UK Data Service.

Outcome

Our outcome was emotional distress as an indicator of possible depression and anxiety symptoms measured using the continuous emotional symptoms subscale of the Strengths and Difficulties Questionnaire (SDQ). The SDQ is a common screening tool for emotional and behavioural problems in children and adolescents with five subscales: emotional symptoms, conduct problems, hyperactivity, peer problems, and prosocial behaviour (41). Each subscale consists of five questions on a 3-point scale from 'not true' (0 score) to 'true' (2 score), to a total score of 10, with higher scores indicating greater problems. We used the emotional symptoms subscale, which includes items that could indicate depression or anxiety symptoms over the last six months, such as mood, worry, fear, and physical symptoms. We refer to this as 'emotional distress' throughout. Scores on the emotional symptom subscale correlate with the Development and Well-being Assessment (DAWBA), a detailed psychiatric interview for screening psychiatric symptoms in children and adolescents (38). Parents or caregivers (95% mothers, 4% fathers, 1% other) filled out the SDQ about the adolescent at ages 14 (baseline, confounding variable) and 17 (outcome).

Exposures

The exposures were total daily screen time and exercise, and daily time in specific screen-based behaviours: watching television (e.g., DVDs and downloaded videos), using social media (e.g., Twitter, Facebook, BBM, Snapchat), playing video games (e.g., mobile gaming), general computer use (internet browsing and programming, not time on social networking sites), individual exercise (e.g., cycling, jogging, walking, active travel, swimming, individual ball games including tennis or badminton) or team sports (e.g., football or hockey). Daily time-use variables were recorded by 24-hour time-use diaries completed over two randomly selected days, one in the week and the other at the weekend (42). Time use diaries have been validated against objective measures of physical activity at the individual and group level, including accelerometers and wearable cameras (43). They are also subject to less recall bias than questionnaires that aim to assess time in an activity for a typically day or week, such as social media use (44). Participant's time use in 1 or 10-minute blocks between 4am to 4am the following day, using a list of 44 possible activities in a web, smartphone, or paper diary. To simulate a week-long recording period, we multiplied data from the weekday by 5 and the weekend by 2. We then used the mean value of time across both week and weekend days in each activity as our exposure variables. Total daily screen time and exercise variables were the sum of time in specific screen-based (television, social media, video games, and computer use) and exercise (individual exercise and team sport) behaviours, respectively.

Confounding variables

We selected confounding variables using our theoretical understanding and existing literature on the potential relationship between screen time, physical activity, and emotional distress.

We formally represented our causal assumptions of these relationships using directed acyclic

graphs (Figure 2 of the Supplementary Materials), which informed our models *a priori*.

Confounding variables included: Sex, socioeconomic position (Index of Multiple

Deprivation), body mass index, social support (Social Provisions Scale, short form), baseline

emotional distress (SDQ emotional symptoms subscale), self-esteem (Shortened Rosenberg

Self-esteem Scale), and maternal mental health (self-reported diagnosis of depression or

anxiety).

Analyses

We reported descriptive statistics as frequencies and percentages or arithmetic means,

medians, Gini mean difference (GMD) and interquartile ranges continuous variables. GMD is

the average absolute difference between two independent values, which provides a measure

of dispersion that is robust to asymmetrical distributions (45).

Main analyses

We used compositional data analysis methods for the main analysis. Compositional data

analysis is a method for handling data representing proportions of a finite whole, such as

periods of different activities within a day, recently applied to physical activity data (46,47).

The method allows the assessment of associations between daily screen time and mental

health, while accounting for all other periods of the day, and also to estimate the potential

impact of replacing screen time with other activities. Compositional methods and the

application to activity data are described in detail elsewhere (46).

We examined the association of total daily screen time and exercise at baseline and emotional distress at follow up, and the potential effect of theoretically replacing screen time with exercise. The 24-hour composition for these models included total daily screen time, exercise, and other (sum of time spent in all other periods in the day, including sleep). We then examined the potential effect of replacing time in each screen-based behaviour (television, social media, video game, and general computer use) for time in individual exercise or team sport. The 24-hour composition for these models included daily time in television, social media, video game, general computer use, individual exercise, team sports, or other. We also examined whether these associations differ by sex, as an effect modifier.

We created log-ratio coordinates that represent each composition, which we used as exposure variables in standard generalized linear regression models. The log-ratio coordinates represent information on one part of the composition (i.e., screen time) relative to all other parts of the composition (i.e., exercise and other). We used an isometric log-ratio transformation, which produces a total number of log-ratio coordinates numbering fewer than the total number of parts. As log-ratios cannot contain values of zero for any exposure, we replaced zeroes with plausible small values using an imputation algorithm (48). For example, the composition for our first models included two log-ratio coordinates for each participant, representing their complete 24-hour composition:

$$\sqrt{\frac{1}{2}}\ln\frac{screen\ time}{(exercise.\,other)} \quad \sqrt{\frac{2}{2}}\ln\frac{exercise}{(other)}$$

The first coordinate is the ratio between screen time (numerator) and the geometric mean of all other parts (denominator). Including both coordinates in the same regression model is necessary to fully account for all parts of the day, but only the first coordinate is interpretable as it contains information on the exposure of interest relative to the rest. To examine a

different exposure of interest, we reordered the formula such that exercise becomes the numerator of the first coordinate. We followed the same procedure to create a second set of log-ratio coordinates for specific screen-based and exercise behaviours, rotating the numerator to examine each exposure of interest. We then ran separate generalised linear regression models using the log-ratio exposures (separate models) with emotional distress as the outcome variable and adjustments for all confounding variables.

These provide base models to assess the overall direction of associations between each exposure and the outcome. However, the base model coefficients do not provide information on the magnitude of association between exposure and outcome as this requires increasing or decreasing time in the exposure. To estimate the effect of theoretically replacing time in an exposure, we used a change-matrix procedure (46). This procedure uses the coefficients in the base models to estimate how replacing time in the exposure of interest (e.g., screen time) with other parts of the composition (e.g., exercise) might affect emotional symptom scores. We use the term theoretical replacements as the estimates are based on simulations rather than actual changes in baseline exposures. We examined how theoretically replacing 1 to 60 minutes of screen time per day with exercise or 1 to 60 minutes of television, social media, video game, or general computer use time with the equivalent durations of individual exercise or team sports might affect emotional symptom scores. We back transformed all log-ratio coordinates into minutes per day to aid interpretation of the final models.

Secondary analyses

To investigate sex as a possible effect modifier, we ran the base models with sex as an interaction term with the first log-ratio coordinate for each exposure variable and stratified analyses accordingly. We also reran our main analyses after excluding participants with

elevated depressive symptoms at baseline (a Moods and Feelings Questionnaire score of ≥10) (49). To assess the possible bias from attrition, we reran the base models in a complete sample (n = 4,599) with imputed missing data using multiple imputation models with chained equations. Additional details on these multiple imputation models are included in the Supplementary Materials (Methods 1).

Results

Participant characteristics

The initial sample included 4,599 participants and 3,511 (76.3% of initial sample) were included in the complete cases analysis (see Figure 1 of the Supplementary Materials). The mean emotional symptoms score was 1.84 (GMD = 2.1) at baseline and 3.62 (GMD = 2.77) at follow up. Table 1 contains baseline characteristics for our sample.

-- Insert table 1------------------------------------

Main analysis

We found a positive association between overall screen time at baseline with emotional distress at follow up (coefficient = 0.14, 95%CI, 0.07,0.20, $p < 0.001$) in our fully adjusted base models, accounting for overall exercise and all other daily activities (see Table 1 of the Supplementary Materials). There was an inverse correlation between exercise and emotional distress (coefficient = -0.05, 95%CI, -0.10, 0.01, $p = 0.05$) in fully adjusted base models (see Table 2 of the Supplementary Materials).

Table 2 shows the estimated effect of theoretically replacing 1 to 60 minutes of screen time per day with the equivalent time of exercise at age 14 on emotional distress at age 17. We present the replacements in increments of 10 minutes in this table. Replacing 60 minutes of any screen time with exercise was associated with a 0.05 (95%CI -0.08, -0.02) lower emotional symptom score.

--- Insert Table 2-----------------------------------

Table 3 shows the estimated effect of replacing 1 to 60 minutes of different screen time modalities per day with the equivalent time of individual exercise or team sports on emotional distress. Replacing 60 minutes of television (coefficient = -0.04, 95%CI, -0.09, 0.01), video gaming (coefficient = -0.01, 95%CI, -0.01, 0.05), social media (coefficient = -0.02, 95%CI, -0.05, 0.01), or computer use (coefficient = -0.01, 95%CI, -0.03, 0.05) with individual exercise was not associated with lower emotional symptom scores at follow up. Replacing 60 minutes of television (coefficient = -0.17, 95%CI, -0.31, -0.04) or social media (coefficient = -0.15, 95%CI, -0.29, -0.01) with team sports was associated with lower emotional symptom scores. We found no association when replacing video gaming (coefficient = -0.05, 95%CI, -0.18, 0.09) or computer use (coefficient = -0.07, 95%CI, -0.22, 0.08) with team sports.

-- Insert Table 3-----------------------------------

Sensitivity analysis

We found no evidence of effect modification by gender, when including gender as an interaction term with screen time or exercise ($p > 0.05$). The base models did not substantively change after dropping participants with elevated depressive symptoms (Table 3, Supplementary Materials) or in a full sample with imputed data (Table 4, Supplementary Materials).

Discussion

Main findings

This is the first prospective study using compositional methods to examine how theoretically replacing different screen time modalities with two domains of exercise might affect emotional distress in adolescents. We found that while adjusting for all other periods of the day, theoretically replacing an hour of daily screen time with an hour of exercise at age 14 was associated with a 0.05 lower emotional symptom scores at age 17. Increasing team sports by 60 minutes in place of the equivalent durations of television or social media use at age 14 was associated with 0.17 and 0.15 lower emotional symptom scores at age 17, respectively. Replacing video gaming or computer use with team sport at 14 was not associated with lower emotional symptom scores at age 17. Increasing individual exercise for any screen time modality at 14 was not associated with emotional symptom scores at 17. We found no evidence that sex modified these associations, and the results were robust to a series of sensitivity analyses.

These findings broadly align with those of previous studies showing positive associations between time in sedentary behaviour or using screen-based devices and the risk of depressive symptoms in adolescents (13,14). However, our analytical approach provides a more nuanced picture that shows differences between screen time and exercise modalities. These nuances

highlight the importance of understanding screen time by its components that each may differentially influence mental health and using methods that account for behaviours in a 24-hour context and can estimate replacement effects. The effect sizes in our study are also smaller than in previous research (13,14).

Only replacing time watching television or using social media (with team sports) was associated with lower emotional symptom scores. Previous studies have found each of these modalities to be associated with an increased risk of depressive symptoms in adolescents, mostly with cross-sectional study designs (13,14). Replacing video gaming and general computer use with any exercise modality was not associated with lower emotional symptom scores. This aligns with previous findings that mentally-active sedentary behaviours do not necessarily increase the risk of depressive symptoms in adults and may reduce risk in some cases (18–21). Several recent studies in adolescents have found association between some screen time modalities (e.g., watching television or using social media) and the risk of depression, but not video gaming (13,22), which may even have protective associations with mental health (25–27).

Only replacing screen time modalities with team sports was associated with lower emotional symptom scores at follow up. The social and cooperative aspects of team sports may provide additional mental health benefits (33–35) that are lacking in individual exercises, such as running. These social mechanisms may have a more immediate impact on mental health, whereas individual exercise could primarily influence mental health through biological pathways that emerge over a longer period, such as structural changes in the hippocampus or reductions in oxidative stress (30).

Strengths and limitations

Key strengths of this study include the large, nationally representative sample with repeated measures over a 3-year follow-up period. The prospective study design, adjustment for baseline emotional distress, and sensitivity analysis excluding participants with elevated depressive symptoms helps to reduce the risk of confounding by reverse causation. Measuring activity using time-use diaries also provided complete 24-hour data that is absent in previous studies using questionnaires that focus on quantifying time in individual behaviours over a typical or specified period. Using 24-hour data also facilitated the use of compositional methods. These methods can appropriately adjust for the co-dependence of time in daily behaviours and estimate how replacing different sedentary behaviours may influence emotional distress, while adjusting for time in other behaviours throughout the day. We also used a priori DAGs to inform our models and a series of sensitivity analyses to test the robustness of our findings, including e-values to assess unmeasured confounding and multiple imputation models to assess attrition bias.

One limitation is the use of an emotional symptoms' subscale of the SDQ. The scale is not a direct measure of depression or anxiety symptoms, which is of primary interest here. However, the SDQ covers internalising symptoms and demonstrates good predictive value for mood disorders in adolescents (36,37). The SDQ was also completed by the parent rather than adolescent, which could increase measurement error. However, parental completion of the SDQ is common for adolescents and these scores have a good predictive value for psychopathologies (50). There could also be error measuring the exposure with time-use diaries, which rely on self-report that are subject to memory, recall, and social desirability bias. There could be some overlap between time-use categories, such as cycling or running in a team rather than as an individual activity as we classed it here. However, time-use diaries are less susceptible to these biases than traditional self-report questionnaires and provide more reliable and valid estimates of time use (51–53).

The exposure data are from 2015 to 2016. Given the rapid development of new technology in this area, the nature, and patterns of screen-use in adolescents may have diverged since that time. These patterns may continue to diverge following recent developments, such as the COVID-19 outbreak and release of recommendations to limit recreational screen-time in young people by the World Health Organization (54). Engagement in screen time and exercise and emotional symptom scores were relatively low in this sample, indicated by the lower inter-quartile range being 0 across all variables. This reduced our statistical power to estimate associations and may have contributed to the small effect sizes. We also lacked data on the nature of screen-use that may influence their associations with emotional distress. For example, the type of video game or nature of interactions on social media can create different experiences that are more harmful or beneficial for a young persons' mental health.

Our results could also be subject to bias from missing data. While we imputed data for all participants within our defined sample, we did not account for attrition in the wider Millennium Cohort that included 18,818 children at baseline. There could also have been residual confounding biasing our findings, such as sleep quality or duration. We used e-values to assess the possibility of a single unmeasured confounding variable influencing our results, but it is possible that multiple unmeasured variables could accumulate to nullify the observed associations.

Implications and future research

Emotional distress including depression and anxiety are leading sources of global disability and symptoms typically onset during adolescence. High sedentary behaviour is common during adolescence and may increase the risk of depression and anxiety symptoms (12,55). By virtue of facilitating sedentary behaviour, excessive use of screen-based devices could

increase the risk of depressive symptoms. However, our findings suggest possible benefits for reducing daily time spent using television or social media and not video gaming or computer use on emotional distress in adolescents. Each screen-time modality in our study encompasses a distinct user experience that is unlikely to influence mental health in a uniform way. The complexity highlighted by our findings bring into question the appropriateness of continuing to group such diverse activities under the guise of screen time when discussing adolescent mental health. International activity guidelines make strong recommendations for limiting screen-use in young people without sufficient evidence of harm (16). These results indicate suggest a more tailored approach for reducing time in specific sedentary activities, where they could become harmful, such as excessive television use.

Future research should focus on examining how the use of specific screen-based devices may influence adolescent mental health, using prospective study designs, robust measurement, and appropriate analytical methods. The thresholds at which time spent using a screen-based device becomes harmful to mental health may differ by modality. For example, video games can provide a stimulating experience, where users can interact with a complex environment, follow immersive storylines, and solve problems. They also offer a platform for social interactions in a cooperative or competitive environment. Fewer of these mentally-active and social features are available when watching television, which may have a lower threshold than video gaming for when the behaviour starts to increase mental health risks. Screen-based devices typically function as tools for engaging in various activities and more detail is needed on the nature of screen-use beyond how much time is spent. For example, an hour of using social media to interact with peers could be beneficial, while an hour of passively scrolling through activity feeds may be less stimulating, potentially even indicating subclinical depressive symptoms.

Future research should also focus on delineating the mental health benefits of different exercise domains. Exercise is broadly beneficial for reducing or preventing depressive symptoms. A recent exposure-wide Mendelian randomisation study in adults highlighted the importance of social support as a protective factor and television watching as a possible risk factor for depressive symptoms (56). Physical activities that encompass social and cooperative elements, such as team sports, may have additional benefits for mental health and warrant further investigation.

Conclusion

We found that emotional distress was positively associated with total daily screen time and negatively associated with exercise in adolescents. Theoretically replacing daily time using screen-based devices with exercise at age 14 was associated with a reduction in emotional symptom scores at age 17. However, there was only an association when replacing social media or television time with team sports, not with individual exercises, such as jogging. Theoretically replacing video game or general computer use with any domain of exercise at age 14 was not associated with emotional symptom scores at 17. The relationships of screen-based device use and mental health are complex and more tailored recommendations for limiting screen-use in young people could be beneficial. Future research should explore the differential relationships of individual screen-use modalities with mental health and examine the nature of screen-use activities beyond the duration of use.

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Declarations of interest

No authors have any financial or personal conflicts of interest to declare in relation to the submitted work.

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Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

Data availability

Details for accessing the data used in this study are available from the UK Data Service.

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Characteristic	Overall, N = 4,599	Male, N = 1,952	Female, N = 2,352

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Ethnicity			
White	3,765 (87%)	1,613 (88%)	1,967 (88%)
Mixed	30 (0.7%)	11 (0.6%)	17 (0.8%)
Indian	122 (2.8%)	61 (3.3%)	56 (2.5%)
Pakistani and Bangladeshi	220 (5.1%)	72 (3.9%)	120 (5.4%)
Black or Black British	92 (2.1%)	40 (2.2%)	41 (1.8%)
Other	76 (1.8%)	35 (1.9%)	35 (1.6%)
Household income quintiles			
1 (lowest)	580 (13%)	215 (12%)	299 (13%)
2	732 (17%)	285 (16%)	398 (18%)
3	915 (21%)	406 (22%)	463 (21%)
4	1,068 (25%)	458 (25%)	569 (25%)
5 (highest)	1,008 (23%)	468 (26%)	505 (23%)
Index of multiple deprivation score	5.75 (3.39) 6.00 (3.00-8.00)	5.97 (3.34) 6.00 (3.00-9.00)	5.71 (3.38) 6.00 (3.00-8.00)
Self-esteem score	9.37 (3.09) 10.00 (7.00, 10.00)	8.50 (2.82) 9.00 (6.00-10.00)	10.06 (3.09) 10.00 (9.00 11.00)
Social support score	3.45 (0.713) 3.00 (3.00-4.00)	3.44 (0.69) 3.00 (3.00-4.00)	3.46 (0.73) 3.00 (3.00-4.00)
MFQ score	6.10 (5.43) 5.00 (2.00-9.00)	4.8 (4.19) 4.0 (2.0-6.00)	7.19 (6.17) 6.0 (3.0-10.0

Total SDQ score	7.06 (5.75) 6.00 (3.00-10.00)	7.11 (5.71) 6 (3.00-10.00)	6.88 (5.64) 6 (3.00-9.00
SDQ emotional symptoms	1.84 (2.12) 1.00 (0-3.00)	1.45 (1.81) 1 (0-2.00)	2.13 (2.29) 2 (0-3.00)
Days eaten >2 portions of fruit or vegetables	4.61 (1.09) 4.00 (4.00-5.00)	4.58 (1.10) 4.00 (4.00-5.00)	4.65 (1.08) 4.00 (4.00-5.00)
Maternal depression or anxiety	1,125 (26%)	486 (25%)	639 (27%)
BMI	21.28 (4.29) 20.46 (18.47-23.24)	20.7 (3.8) 19.8 (18.0-22.4)	21.8 (4.36) 21.0 (18.9-23.7)
TV	123.2 (130.6) 102 (0-190)	122.2 (135.4) 100 (0-191)	125.3 (126.2) 109 (20-187)
Social media	41.88 (61.65) 0 (0-60)	26.72 (43.42) 0 (0-30)	52.64 (70.65) 26 (0-70
Gaming	73.54 (114) 0 (0-108)	140.2 (169) 91 (0-220)	19.11 (34.16) 0 (0-0)
Computer	35.43 (57.21) 0 (0-40)	39.88 (65.55) 0 (0-40)	33.36 (52.52) 0 (0-40)
Individual exercise	80.79 (97.19) 52 (0-120)	85.79 (105.3) 52 (0-120)	78.34 (92.29) 51 (0-115
Team sports	22.64 (40.39) 0 (0-0)	39.97 (66.01) 0 (0-50)	8.76 (16.5) 0 (0-0)
Sleep	577.8 (146.5) 584 (520-645)	583.1 (145.8) 585 (526-650)	574.5 (144) 581 (512-64

Statistics presented: n (%); Mean (GMD) Median (25%-75%)

Table 1. Included sample characteristics by sex

Table 2. Estimated change in emotional symptom scores for theoretical replacements of

Activity to reduce	Activity to increase	Increment of change in minutes	Coefficient	Lower 95% confidence interval	Upper 95% confidence interval
Screen time	Exercise	10	-0.009	-0.015	-0.003
		20	-0.018	-0.029	-0.006
		30	-0.026	-0.043	-0.010
		40	-0.034	-0.055	-0.013
		50	-0.042	-0.068	-0.017
		60	-0.050	-0.080	-0.020

screen time with exercise

The coefficient is from generalised linear regression models and are interpretable as the predicted change in emotional symptom scores at follow up per 10-minute replacement of screen time with exercise at baseline. All models are adjusted for confounding variables that include sex, socioeconomic position, body mass index, social support, baseline emotional distress, self-esteem, and maternal mental health.

Table 3. Estimated change in emotional symptom scores for theoretical replacements of individual screen time and exercise behaviours

Activity to reduce	Activity to increase	Increment of change in minutes	Coefficient	Lower 95% confidence interval	Upper 95% confidence interval
Television	Individual exercise	10	-0.007	-0.015	0.001
Video games	Individual exercise		0.026	0.008	0.045
Social media	Individual exercise		-0.003	-0.037	0.030
Computer	Individual exercise		0.021	-0.002	0.044
Television	Team sport		-0.116	-0.220	-0.013
Video games	Team sport		-0.026	-0.136	0.085
Social media	Team sport		-0.113	-0.222	-0.004
Computer	Team sport		-0.050	-0.168	0.068
Television	Individual exercise	20	-0.013	-0.029	0.003

Video games	Individual exercise		0.024	0.002	0.045
Social media	Individual exercise		-0.008	-0.023	0.008
Computer	Individual exercise		0.018	-0.007	0.044
Television	Team sport		-0.131	-0.244	-0.017
Video games	Team sport		-0.031	-0.153	0.090
Social media	Team sport		-0.126	-0.245	-0.007
Computer	Team sport		-0.057	-0.186	0.072
Television	Individual exercise	30	-0.020	-0.043	0.004
Video games	Individual exercise		0.021	-0.003	0.046
Social media	Individual exercise		-0.011	-0.030	0.008
Computer	Individual exercise		0.016	-0.013	0.044
Television	Team sport		-0.141	-0.261	-0.021
Video games	Team sport		-0.035	-0.162	0.093

Social media	Team sport		-0.133	-0.259	-0.007
Computer	Team sport		-0.062	-0.197	0.074
Television	Individual exercise	40	-0.026	-0.058	0.005
Video games	Individual exercise		0.019	-0.009	0.048
Social media	Individual exercise		-0.014	-0.037	0.009
Computer	Individual exercise		0.013	-0.018	0.045
Television	Team sport		-0.149	-0.274	-0.025
Video games	Team sport		-0.037	-0.169	0.095
Social media	Team sport		-0.138	-0.268	-0.008
Computer	Team sport		-0.065	-0.205	0.075
Television	Individual exercise	50	-0.034	-0.074	0.007
Video games	Individual exercise		0.018	-0.015	0.050
Social media	Individual exercise		-0.016	-0.043	0.010

Computer	Individual exercise		0.011	-0.023	0.046
Television	Team sport		-0.158	-0.287	-0.029
Video games	Team sport		-0.039	-0.174	0.096
Social media	Team sport		-0.142	-0.276	-0.008
Computer	Team sport		-0.067	-0.210	0.076
Television	Individual exercise	60	-0.041	-0.092	0.009
Video games	Individual exercise		0.016	-0.020	0.051
Social media	Individual exercise		-0.019	-0.049	0.011
Computer	Individual exercise		0.009	-0.028	0.047
Television	Team sport		-0.166	-0.300	-0.033
Video games	Team sport		-0.040	-0.178	0.098
Social media	Team sport		-0.145	-0.282	-0.008
Computer	Team sport		-0.069	-0.215	0.077

All models are adjusted for confounding variables that include sex, socioeconomic position,

body mass index, social support, baseline emotional distress, self-esteem, and maternal

mental health.