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Adolescent time-use and mental health: A cross-sectional, compositional analysis in the Millennium Cohort Study

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Abstract

Objectives

To examine the association of 24-hour time-use compositions with mental health in a large, geographically diverse sample of UK adolescents.

Design

Cross-sectional, secondary data analysis.

Setting

Millennium Cohort Study (sixth survey), a UK-based prospective birth cohort.

Participants

Data were available from 4642 adolescents aged 14 years. Analytical samples for weekday and weekend analyses were n=3485 and n=3468, respectively (45% boys, 85% White ethnicity).

Primary and secondary outcome measures

Primary outcome measures were the Strengths and Difficulties Questionnaire (SDQ; socioemotional behaviour), Mood and Feelings Questionnaire (MFQ; depressive symptoms) and Rosenberg Self-Esteem Scale (RSE; self-esteem). Behavioural exposure data was derived from 24-hour time use diaries.

Results

On weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Predicted differences in SDQ, MFQ and RSE were statistically significant for all models (weekday and weekend) that simulated the addition or removal of 15 minutes physical activity, with an increase in activity being associated with improved mental health and vice versa. Predicted differences in RSE were also significant for simulated changes

in electronic media use; an increase in electronic media use was associated with reduced self-esteem.

Conclusions

Small, but consistent, associations were observed between physical activity, electronic media use and selected markers of mental health. Findings support the delivery of physical activity interventions to promote mental health during adolescence, without the need to specifically target or protect time spent in other activities.

Keywords

Adolescence; Time-use; Physical activity; Sleep; Depression; Mental health; CoDA

Article summary: Strengths and limitations of the study

Strengths of this study:

- The large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments.
- Use of compositional data analysis of multiple behavioural exposures, which reflects that behaviour change inherently entails the reallocation of time between different domains of behaviour.

Limitations of this study:

- The cross-sectional design which precludes causal inference.
- The susceptibility of time-use diaries to recall and social desirability bias.
- Analyses were based upon a single day of assessment, which may not have been representative of typical behaviour patterns.

Introduction

The global adolescent population, estimated at 1.2 billion, is now larger than at any point in our history and represents approximately 16% of the global population.(1) Accordingly, research and policy activity to support the biological, social, emotional and behavioural development of this population has grown substantially in recent years.(2–4) Part of this wider movement has been a particular focus on mental health during adolescence, consistent with evidence that first diagnosis of a mental disorder often occurs during this period.(5–7) Surveillance data on adolescent mental health remains limited, but there is evidence of increasing prevalence of some conditions in recent years and substantial growth in demand for counselling and specialist mental health services.(8–11) Recent data from the Mental Health of Children and Young People survey, for example, indicated that between 1999-2017 the prevalence of having an emotional disorder (including anxiety and depression) increased from 4.3% to 5.5% in children aged 5-15 years.(12) From the same survey, cross-sectional data collected in 2017 showed that just over 10% of children in this age group had low self-esteem.(12) Interpretation of secular trend data on the prevalence of mental disorders in young people is complicated by a host of methodological, diagnostic and social factors, but it remains clear that a considerable proportion of the child and adolescent population experience mental ill health. A clearer understanding of factors that might predispose or protect children from mental health disorders will help in the development of preventative policies and practice.

A growing body of evidence indicates a role for health behaviours, such as sleep and physical activity, in the prevention of mental health disorders.(13–18) A recent US study, for example, found that over 1 year, sleep duration of less than 6 hours a night was associated with increased risk of anxiety disorders in adolescents aged 11-17 years.(16) This study adjusted for selected social and demographic covariates, but did not account for other health behaviours, such as

physical activity or sedentary behaviour. Given the finite time available each day, an increase in any behaviour (e.g. sleep) can only be achieved through a concomitant reduction in time allocated to one or more other activities (e.g. TV viewing). The nature of such reallocations has potentially important implications for health. The mental health benefits of increasing sleep duration, for example, may not be realised if they come at the expense of reduced physical activity, which is also positively associated with some mental health outcomes. Greater recognition of the complex inter-play between multiple behaviours and health has led to the adoption of sophisticated, and more appropriate, statistical methods and the establishment of new research networks to take the field forward.(19–23) This movement is reflected in new public health recommendations that provide guidance on the optimal composition of the entire (24h) day, rather than focussing on a single behaviour, such as physical activity or sleep.(24,25)

Previous research into the association of time-use composition with mental health in young people has focussed predominantly on health-related quality of life, captured within global measures or social / emotional health sub-scales.(26–28) Studies using cluster analysis to identify subgroups with distinct behavioural profiles have indicated that a lifestyle characterised by low physical activity and/or moderate to high sedentary behaviour was associated with poorer quality of life.(27,29) In contrast, Fairclough et al. (28) observed no differences in psychosocial quality of life for simulated substitutions between accelerometer-assessed sitting, light and moderate to vigorous intensity physical activity (MVPA) during the school day. One study to date has examined the association of time use with proxy-reported Strengths and Difficulties Questionnaire scores, observing that substituting time into MVPA from sleep, light intensity activity or sedentary time was associated with better mental health.(30) The relative lack of previous research on this topic, combined with the conflicting findings of what little evidence does exist, highlights the need for further research in this field.

Therefore, the objective of this study was to examine the cross-sectional associations between adolescents' time-use composition and selected markers of mental health and well-being.

Method

Sample and data collection

Data are from the Millennium Cohort Study (MCS), an observational cohort study of the social, economic, and health related circumstances of children born in the UK between September 2000 and January 2002.(31) The MCS is nationally representative and 18 552 families (18 818 children) were recruited in the first sweep. The sample was augmented with a further 701 children (692 families) born in the same period who had been missed previously, taking the total sample to 19,519. To date, there have been six waves of assessment (age nine months, three, five, seven, eleven, and fourteen years). This cross-sectional analysis uses data from the sixth wave of assessment (MCS6; data collection: January 2015-April 2016), conducted when participants were aged 14 years. 15 415 families were contacted for participation in MCS6; 11 884 participants from 11 726 families provided partial or complete data. MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786). The current study uses anonymised, publicly available data, obtained from the UK Data Service: https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

Patient and public involvement

The research question for this analysis was formulated by the authors (no patient involved). The content and methodology of the sixth sweep of MCS was informed by extensive development work to ensure relevance, participation and engagement amongst participants and their families. Full details are provided in the MCS sixth sweep technical report.(32)

Assessment of time-use

All participants from Wales, Scotland and Northern Ireland and approximately 80% of participants from England were invited to complete time-use diaries for two 24-hour periods (One week day and one weekend day. Days were selected at random by computer assisted personal interview (CAPI) software). The English sample was restricted due to limitations on the number of activity monitors available, which were deployed alongside the time-use diary. Only diary data are used for the current analysis. The diary was available in three formats: online (for completion on a desktop, laptop or netbook); using an App (for completion on a mobile phone or tablet); or on paper. Sixty-four percent of participants selected the App diary format, 29% used the online version and 7% the paper diary.(32)

For each day of assessment, participants recorded what they did from 4am to 4am the following day in 10-min timeslots. Participants also recorded where they were, who they were with and how much they liked each activity but these data are not considered here. The primary activity for each time-slot was selected from a list of 44 pre-defined activity codes, nested within 12 categories. Categories included 'sleep and personal care', 'school, homework and education', 'social time and family time' and 'Internet, TV and digital media'.(33) Due to the differing demands / opportunities afforded by being at school during the week, weekday and weekend data were analysed separately. For the weekday data, activity codes were collapsed into six mutually exclusive activity sets (see supplementary material): (1) Sleep; (2) Physical activity; (3) School-related activities; (4) Hobbies and socialising; (5) Electronic media; (6) Domestic, personal care and work-related activities. Weekend data were collapsed into five sets, omitting the school-related activities group. The five / six sets capture the entirety of participant's daily time use (24 h or 1440 min). Note that the sleep component represented all sleep occurring

between 4am and 4am. Therefore, it does not necessarily represent a full overnight sleep and may incorporate naps taken during the day.

Diaries with missing data (10 min slots with no activity indicated) were excluded from the analysis, as were those with no entries for 'sleep' or 'Domestic, personal care and work-related activities' (which included eating and getting dressed); these were deemed to be unreliable accounts of a complete day's activity. Zero values in any of the activity sets would preclude the use of compositional analysis, as log ratio coordinates cannot be applied to zero values.(34) Consistent with previous work using time-use data, zeros were replaced with small values of less than 10 min, drawing time from the other activity sets.(35,36)

Mental health

Three outcomes related to adolescent mental health were used in the analysis. Socioemotional behaviour was assessed using the Strengths and Difficulties Questionnaire (SDQ, version P4-17), completed by the parent or guardian.(37) The SDQ comprises 25-items relating to five subscales of five items each (Difficulties subscales: emotional problems, conduct problems, hyperactivity/inattention, peer relationship problems. Strengths subscale: prosocial behaviour). Answers are provided with reference to the previous six months and response options are 'Not true', 'Somewhat true' and 'Certainly true'. Example items: 'Often has temper tantrums or hot tempers'; 'Often unhappy, down-hearted or tearful'. A total difficulties score, derived as the sum of responses on the four difficulties subscales, was used in the analysis, consistent with previous research.(38,39) Higher scores indicate greater socioemotional difficulty. Depressive symptomology was assessed using the short-version (13-item) Mood and Feelings questionnaire (MFQ), completed by the participant.(40) Answers are given with reference to the previous two weeks. Response options are 'Not true', 'Sometimes' and 'True'.

Example items: 'I felt miserable or unhappy'; 'I didn't enjoy anything at all'. MFQ is scored as the sum of responses to all items, with higher scores suggesting more severe depressive symptoms. Global self-worth was self-reported using the five positive items from the Rosenberg Self Esteem Scale (RSE).(41) Response options are 'Strongly agree', 'Agree', 'Disagree' and 'Strongly disagree'. Example item: 'On the whole, I am satisfied with myself'. A total score, derived as the sum of responses to all items, was used in the analysis. For consistency with other outcomes, responses were recoded such that higher scores were indicative of lower self-esteem.

Covariates

Covariates were selected on the basis of previous research indicating that they may confound associations between exposure and outcome variables used in the current study.(15,16,30) The following constructs were selected: age, sex, adiposity (measured height and weight used to derive body mass index (BMI) category (42): underweight / normal, overweight, or obese) and equivalised family income (parent reported: <£20,800 annually, £20,800 to £31,300 annually, >£31,200 annually, missing or do not know).

Statistical analysis

Analyses were conducted using R open-source software (www.r-project.org) and the compositions and zCompositions packages for the analysis of compositional data (version 1.40-2).(43) Demographic and anthropometric characteristics of the analytical sample are presented as frequencies and percentages, means with standard deviation or medians with interquartile range as appropriate. Characteristics of those included / excluded from the analytical sample were compared using Student's t tests or chi-squared tests. Time (min/day) spent in each behavioural set is summarised for the raw time-use data (that which retained zero

values) using median and interquartile range. For the imputed time-use compositions (those in which zeros were replaced with small non-zero values, as described above), time in each behavioural set is presented as compositional means (geometric mean of each behaviour, linearly adjusted to collectively sum to 1440 minutes). Summary statistics are presented separately for week and weekend days. Due to the distribution of the health outcome data, associations between time use composition and mental health markers were examined using negative binomial regression.(44) Time-use compositions were expressed as sets of isometric log ratio (ILR) coordinates (R compositions, default ilr() transformation). The five and six part compositions for weekend and weekday time-use were expressed via four and five sets of ILR coordinates respectively. All models were adjusted for age, sex, weight status and family income. In preliminary analyses, models were additionally adjusted for ethnicity and maternal education. However, these variables demonstrated weak, non-significant associations with the outcomes and were subsequently dropped in the interests of model parsimony. Models were checked to ensure assumptions were not violated. Following procedures outlined in Dumuid et al. (19), we subsequently conducted compositional isotemporal substitution analyses to model the influence of reallocating fixed time durations (15 min) between pairs of behaviour sets on each of our mental health outcomes. Models were adjusted for the same covariates as described above and assessed for compliance with relevant statistical assumptions. When this model is subsequently used (in time reallocation of diary activities) to predict new values of the outcome, the predicted data are in log units, which makes it incompatible for mathematical operators such as subtraction to be used for estimation of differences. It is therefore necessary to transform the predicted values back into the original units (by taking the exponential) before estimating the differences in outcome due to time reallocation. In post-hoc analyses, we explored the shape of the association between behaviour reallocations of differing duration and selected outcomes. Specifically, we modelled predicted differences in SDQ, MFQ and

Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between physical activity and the mean of all remaining behavioural sets. In addition, we modelled predicted differences in MFQ and Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between electronic media and the mean of all remaining behavioural sets. Sets were combined for this analysis as the associations observed for paired reallocations between physical activity/electronic media and individual sets were highly consistent in direction and magnitude. Regression estimates are presented graphically for ease of interpretation.

Results

Data were available from 8625 diaries (person-days), obtained from 4642 participants. Of these, 1679 diaries were excluded due to missing data or non-reporting of sleep or domestic/personal care activities. The analytical samples for weekday and weekend analyses were n=3485 and n=3468 respectively. Characteristics of participants included in the weekday analyses are presented in Table 1. Overall, the weekday sample was 13.8 (0.5) years of age, 45% male and predominantly White ethnicity (85%). There were no differences in the demographic or anthropometric characteristics of the weekday and weekend analytical samples. Comparison of participants included / excluded from the analyses indicated that the analytical sample on average had a lower BMI (Inc: 21.2, Exc: 21.6; P=0.014), were more likely to be White ethnicity (Inc: 85% White, Exc: 76% White; P<0.001) and come from families with higher income (Inc: 31% highest quintile, Exc: 19% highest quintile; P<0.001).

TABLE 1 HERE

Time spent in each of the behavioural sets is presented in Table 2. Compositional means indicated that on weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Corresponding figures for the weekend were: 56% (sleep), 2% (physical activity), 10% (hobbies), 16% (electronic media) and 17% (domestic).

TABLE 2 HERE

Preliminary analyses indicated that after adjustment for age, sex, weight status and family income, the isometric log ratio coordinates for time-use composition were significantly associated with each of the outcome variables (P for isometric log ratio coordinates: SDQ, weekday P=0.018, weekend P<0.001; MFQ, weekday P<0.001, weekend P=0.023; RSE weekday P<0.001, weekend P<0.001). Compositional isotemporal substitution analyses were conducted to simulate the association with each outcome of reallocating 15 min between pairs of behavioural sets; results are presented in Tables 3 (weekdays) and 4 (weekend) respectively.

For all three outcomes, models that simulated the addition or removal of time from physical activity were statistically significant, with the addition of physical activity being associated with improved mental health and vice versa. The only exception to this trend was for MFQ and the substitution of time from domestic activities into physical activity at the weekend, wherein the upper bound of the 95% confidence interval marginally overlapped zero. Predicted differences were generally larger for the weekend analysis than the weekday analysis, but remained small at less than 0.3 of a unit of the outcome in all instances.

For the SDQ outcome, there were no statistically significant predicted differences for reallocations that did not include physical activity. For the Rosenberg outcome, all reallocations that included electronic media were statistically significant in the weekday data, with a reduction in time spent using electronic media associated with better mental health. This pattern was partially repeated in the weekend data, except that models simulating the reallocation of time from sleep and domestic activities into electronic media were non-significant. All predicted differences were less than 0.1 units. For MFQ, and in the weekday data only, reallocations between electronic media/sleep and electronic media/domestic activities were statistically significant, with a reduction in time spent using electronic media associated with better mental health.

TABLES 3 AND 4 HERE

Predicted differences in SDQ, MFQ and Rosenberg scores for a range of time reallocations to / from physical activity are presented in Figure 1. Consistent with the main analysis, figures show that simulated increases in physical activity were associated with reduced scores (negative predicted difference; better health) on each of the outcomes, whilst simulated reductions in physical activity were associated with higher outcome scores (positive predicted difference; worse health). In all scenarios, there was evidence of a curvilinear association, such that a modelled reduction in physical activity produced larger predicted differences in the outcomes than a modelled increase in physical activity of comparable duration. Predicted differences in MFQ and Rosenberg scores for a range of time reallocations to / from electronic media use are presented in Figure 2. Simulated increases in electronic media use were associated with increased scores (positive predicted difference; worse health) on each of the outcomes, whilst simulated reductions in electronic media use were associated with lower

outcome scores (negative predicted difference; better health). In the weekday data (Figure 2, panels A and C), the shape of the association appeared approximately linear throughout the range of reallocations tested. In the weekend data (Figure 2, panels B and D), there was evidence of slight deviation from linearity, wherein a modelled increase in electronic media use produced larger predicted differences in the outcomes than a modelled reduction in electronic media use of comparable duration.

FIGURES 1 AND 2 HERE

Discussion

In this large sample of UK adolescents, we found that simulated increases in physical activity were beneficially associated with socioemotional health, whilst comparable increases in electronic media use were adversely associated with depressive symptoms and self-esteem. Associations were largely consistent between week and weekend days, but remained small in magnitude across all behaviours and outcomes. Findings highlight a potential role for physical activity in supporting the socioemotional health of adolescents and provide insight into the possible content and timing of behaviour change interventions.

A simulated reallocation of 15 min from sleep, hobbies, electronic media use, school-related or domestic activities to physical activity was associated with better socioemotional health, reduced depression symptomology and improved self-esteem. This is consistent with previous research by Carson et al (30) who modelled the impact on SDQ scores of substituting time between sleep, sedentary time, light and moderate to vigorous intensity physical activity measured by accelerometry. More broadly, our findings corroborate existing evidence, both

observational and experimental, that physical activity may have a role in the prevention and treatment of mental ill health in young people.(45) The association of physical activity with all outcomes studied here was consistent in direction and magnitude for reallocations across all other behavioural domains, suggesting that the benefit of physical activity is universal and not dependent upon a reduction in any specific behaviour or group of behaviours. It should be acknowledged, nonetheless, that the associations were small in magnitude, perhaps indicating that physical activity alone may not be sufficient to bring about clinically meaningful benefits in the specific health markers examined here. Given the plethora of other known benefits of physical activity, however, our findings support the promotion of physical activity as part of a wider package of measures for the benefit of emotional and behavioural health during adolescence.

Across the range of behavioural substitutions examined, simulated increases in electronic media use were consistently associated with lower self-esteem (higher Rosenberg scores), with only a small number of non-significant predicted differences. We also observed an association between electronic media use and increased depression symptomology but this was confined to a small number of specific behavioural substitutions. Our findings align with a previous analysis in this sweep of the MCS, which reported adverse associations of social media, internet use, TV viewing and video gaming with depressive symptomology and self-esteem.(46) These studies add to a growing body of research examining the link between mental health and electronic media use, both traditional (eg TV viewing) and contemporary (eg social media).(47–50) At present the evidence appears equivocal, with findings sensitive to variations in measurement methodology and analysis.(48) This study adds to the evidence on this topic by making explicit the inter-connectedness of behaviours within the daily time-budget and adopting an analytical framework that can accommodate this complexity. As the evidence

evolves, this approach may become increasingly valuable as we move beyond the largely exploratory nature of existing studies towards research that can explicitly inform the targeting and content of public health policy and behaviour change interventions.

In our post-hoc analyses, we examined the shape of the association between physical activity, electronic media use and selected mental health markers, informed by the findings from our primary analysis (Figures 1 and 2). The size of the association between physical activity and MFQ, SDQ or Rosenberg scores varied according to whether our simulation added or removed time spent active. Specifically, predicted differences for a reduction in physical activity were approximately twice as large as those for an increase in physical activity; this was the case for all outcomes. This asymmetrical phenomenon has also been reported in other studies that have used compositional isotemporal substitution modelling, though it is not observed across all health outcomes (28,30) and was not evident in our models simulating multiple time reallocations for electronic media use. The reason for the disparity in effect sizes in our study is unclear, though it is appropriate to note that effect sizes remained small in all instances. It may reflect a plateau effect in the health benefits of physical activity, such that most benefit is gained from a moderate amount of activity and further increases above this level bring diminishing returns. This is consistent with the wider physical activity literature, particularly in adults, but the median activity level in the current sample was approx. 40 min / day, well below the recommended 60 min / day for this population.(51) As more research using compositional analytical techniques emerges, it will be possible to describe and investigate this trend in greater depth and establish whether it is a reflection of biological, statistical or some other underlying process.

A key limitation of the current study is the cross-sectional design, which precludes any conclusions about the direction of the associations observed. The isotemporal substitution model mimics within-person time reallocations, but remains a between-person comparison due to there being only 1 observation (point of assessment) per person. The findings are most appropriately interpreted as showing small differences in mental health status across durations of daily time allocated to physical activity and/or electronic media use. Numerous mental health conditions have lethargy or lack of engagement or energy within their diagnostic criteria (52), therefore reverse causality remains a highly plausible explanation for the associations observed in this study. In general, predicted differences in the weekend analysis were greater than those in the weekday analysis, which may also support this interpretation. Specifically with regard to physical activity, a larger proportion of weekday activity is non-volitional in nature, shaped by the more structured nature of the school day and associated routines.(45) This is reflected in evidence that the age-related decline in physical activity is smaller for weekdays than at the weekend and that weekday activity is less susceptible to seasonal variation.(53,54) It follows that a reduction in physical activity associated with mental ill health is likely to be greater at the weekend than during the week. This may account, in part, for our observation of a stronger association between physical activity and socioemotional health at weekends versus during the week.

Strengths and limitations

Keys strengths of this study include the large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments. In addition, daily activity was characterised in detail using 24-h time-use diaries. Concurrent analysis of multiple behavioural exposures is appropriate given that behaviour change inherently entails the reallocation of time between different domains of

behaviour. The following limitations are acknowledged. The cross-sectional design precludes causal inference and the possibility of reverse causality or bidirectional associations is acknowledged, as discussed above. Statistical models were adjusted for known demographic and anthropometric confounders, but residual confounding is possible due to measurement error or omission of unknown confounding variables. In addition, we did not explore non-linear associations in the current analysis; this would be valuable in future research, particularly with regard to the sleep dimension of time use. Time-use diaries, like other self-report instruments, are susceptible to recall and social desirability bias. Lastly, our analysis is based upon a single day of assessment, which may not be representative of typical behaviour patterns. However, measurement days were selected at random and short periods of assessment are typical in studies that employ time-use diaries in order to limit participant burden.(35)

Conclusion

This study adds to existing evidence on the association between lifestyle behaviours and mental health in adolescents. Our finding that substituting time from behaviours representing a number of different domains into physical activity was associated with better socioemotional health has important implications for intervention design, and should be examined further in longitudinal and experimental studies.

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Competing interests

None declared.

Author contributions

AJA conceived the research question, contributed to the statistical analysis and led on manuscript preparation. JRD conducted the statistical analysis, generated the figures and contributed to drafting segments of the methods and results. DD contributed to development of the research question and advised on the statistical analysis and interpretation of the results.

EK contributed to preparation of the introduction and discussion sections and interpretation of results. LS contributed to development of the research question, the analytical approach and interpretation of results. RT contributed to development of the research question and interpretation of results. CR contributed to development of the research question, the analytical approach and interpretation of results. RJN contributed to development of the research question, the analytical approach and interpretation of results. SJF contributed to development of the research question, the analytical approach and interpretation of results. All authors provided critical feedback on drafts of the manuscript and approved the final manuscript.

Data sharing statement

The datasets analysed during the current study are available from the UK Data Service: beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

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Tables

Table 1. Participant characteristics (Weekday sample; values are mean (SD) unless stated otherwise).

	Weekdays (n=3485)	
Demographics		
Sex (n (% male))	1561	(45)
Age (years)	13.8	(0.5)
BMI (kg/m^2)	21.2	(4.0)
Ethnicity (white, n (%))	2951	(85)
Family income (quintile, n (%))		
First (lowest)	327	(9)
Second	436	(13)
Third	686	(20)
Fourth	958	(28)
Fifth (highest)	1075	(31)
Country (n (%))		
England	2119	(61)
Scotland	506	(15)
Wales	486	(14)
Northern Ireland	374	(11)
Outcomes (median (IQR))		
SDQ	6.0	(3.0, 9.0)
MFQ	17.0	(14.0, 21.0)
RSE	10.0	(7.0, 10.0)

Weekend analysis, n=3468.

SD, standard deviation; BMI, body mass index; IQR, inter-quartile range; SDQ, Strengths and Difficulties Questionnaire; MFQ, Mood and Feelings Questionnaire; RSE, Rosenberg Self Esteem Scale

Table 2. Descriptive characteristics of time-use compositions (min/day)

	Raw composition Median (IQR)		Imputed composition Compositional mean*	
	Weekday	**Weekend**	**Weekday**	**Weekend**
Sleep	550 (500, 610)	630 (550, 690)	779.8	800.8
Physical activity	40 (0, 110)	30 (0, 120)	42.2	23.0
School-related	370 (0, 420)	NA	135.3	NA
Hobbies	90 (20, 200)	180 (60, 320)	85.2	144.9
Electronic media	170 (70, 290)	240 (120, 390)	161.8	226.0
Domestic	180 (120, 250)	200 (130, 300)	235.6	245.2

Weekday n=3485; Weekend n=3468
IQR, inter-quartile range; NA, not applicable
*Geometric mean adjusted to sum to 1440 min/day

Table 3. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekday analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

		Predicted difference		
Add 15 min…	**Remove 15 min…**	**SDQ**	**MFQ**	**Rosenberg**
Sleep	Physical activity	**0.0786 (0.0305, 0.1268)**	**0.0823 (0.0302, 0.1344)**	**0.0407 (0.0148, 0.0666)**
Sleep	School-related	0.0039 (-0.0080, 0.0158)	**-0.0149 (-0.0278, -0.0020)**	-0.0028 (-0.0092, 0.0036)
Sleep	Hobbies	-0.0028 (-0.0263, 0.0208)	-0.0195 (-0.0450, 0.0060)	0.0016 (-0.0111, 0.0143)
Sleep	Electronic media	-0.0016 (-0.0179, 0.0147)	**-0.0289 (-0.0466, -0.0112)**	**-0.0153 (-0.0241, -0.0065)**
Sleep	Domestic	0.0080 (-0.0128, 0.0289)	-0.0003 (-0.0229, 0.0223)	-0.0019 (-0.0131, 0.0094)
Physical activity	Sleep	**-0.0549 (-0.0891, -0.0207)**	**-0.0553 (-0.0923, -0.0183)**	**-0.0277 (-0.0461, -0.0093)**
Physical activity	School-related	**-0.0510 (-0.0846, -0.0173)**	**-0.0702 (-0.1066, -0.0337)**	**-0.0305 (-0.0486, -0.0124)**
Physical activity	Hobbies	**-0.0576 (-0.0950, -0.0202)**	**-0.0748 (-0.1154, -0.0343)**	**-0.0261 (-0.0463, -0.0060)**
Physical activity	Electronic media	**-0.0564 (-0.0900, -0.0229)**	**-0.0841 (-0.1205, -0.0477)**	**-0.0430 (-0.0610, -0.0249)**
Physical activity	Domestic	**-0.0469 (-0.0835, -0.0103)**	**-0.0556 (-0.0953, -0.016)**	**-0.0296 (-0.0493, -0.0099)**
School-related	Sleep	-0.0039 (-0.0151, 0.0073)	**0.0141 (0.0020, 0.0262)**	0.0026 (-0.0034, 0.0087)
School-related	Physical activity	**0.0747 (0.0275, 0.1220)**	**0.0963 (0.0452, 0.1475)**	**0.0433 (0.0179, 0.0687)**
School-related	Hobbies	-0.0066 (-0.0273, 0.0141)	-0.0055 (-0.0280, 0.0169)	0.0042 (-0.0069, 0.0154)
School-related	Electronic media	-0.0054 (-0.0195, 0.0087)	-0.0149 (-0.0302, 0.0005)	**-0.0127 (-0.0203, -0.0051)**
School-related	Domestic	0.0042 (-0.0142, 0.0225)	0.0137 (-0.0062, 0.0336)	0.0008 (-0.0091, 0.0106)
Hobbies	Sleep	0.0017 (-0.0186, 0.0221)	0.0174 (-0.0047, 0.0394)	-0.0011 (-0.0121, 0.0099)
Hobbies	Physical activity	**0.0804 (0.0318, 0.1291)**	**0.0996 (0.0469, 0.1523)**	**0.0395 (0.0134, 0.0657)**
Hobbies	School-related	0.0057 (-0.0122, 0.0236)	0.0024 (-0.0170, 0.0218)	-0.0039 (-0.0136, 0.0057)
Hobbies	Electronic media	0.0002 (-0.0195, 0.0198)	-0.0116 (-0.0329, 0.0097)	**-0.0165 (-0.0271, -0.0058)**
Hobbies	Domestic	0.0098 (-0.0150, 0.0346)	0.0170 (-0.0100, 0.0439)	-0.0030 (-0.0164, 0.0104)
Electronic media	Sleep	0.0011 (-0.0142, 0.0164)	**0.0270 (0.0104, 0.0437)**	**0.0141 (0.0058, 0.0224)**
Electronic media	Physical activity	**0.0798 (0.0330, 0.1266)**	**0.1094 (0.0587, 0.1600)**	**0.0548 (0.0297, 0.0800)**
Electronic media	School-related	0.0051 (-0.0086, 0.0188)	0.0121 (-0.0028, 0.027)	**0.0113 (0.0039, 0.0187)**
Electronic media	Hobbies	-0.0016 (-0.0235, 0.0204)	0.0074 (-0.0164, 0.0312)	**0.0157 (0.0038, 0.0275)**
Electronic media	Domestic	0.0092 (-0.0103, 0.0287)	**0.0267 (0.0056, 0.0478)**	**0.0122 (0.0017, 0.0227)**
Domestic	Sleep	-0.0078 (-0.0278, 0.0122)	0.0009 (-0.0208, 0.0226)	0.0018 (-0.0090, 0.0126)
Domestic	Physical activity	**0.0708 (0.0215, 0.1202)**	**0.0831 (0.0297, 0.1366)**	**0.0425 (0.0160, 0.0690)**
Domestic	School-related	-0.0038 (-0.0217, 0.0141)	-0.0140 (-0.0335, 0.0054)	-0.0010 (-0.0106, 0.0087)
Domestic	Hobbies	-0.0105 (-0.0373, 0.0164)	-0.0187 (-0.0478, 0.0104)	0.0034 (-0.0111, 0.0179)
Domestic	Electronic media	-0.0093 (-0.0287, 0.0101)	**-0.0280 (-0.0490, -0.0071)**	**-0.0135 (-0.0239, -0.0031)**

Table 4. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekend analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

Add 15 min…	Remove 15 min…	Predicted difference SDQ	MFQ	Rosenberg
Sleep	Physical activity	**0.2006 (0.1152, 0.2860)**	**0.1021 (0.0093, 0.1949)**	**0.077 (0.0316, 0.1223)**
Sleep	Hobbies	0.0117 (-0.0035, 0.0270)	0.0060 (-0.0106, 0.0226)	0.0039 (-0.0042, 0.0121)
Sleep	Electronic media	0.0048 (-0.0088, 0.0184)	-0.0097 (-0.0244, 0.0050)	**-0.0087 (-0.0160, -0.0014)**
Sleep	Domestic	-0.0008 (-0.0196, 0.0179)	0.0027 (-0.0176, 0.0230)	0.0004 (-0.0095, 0.0103)
Physical activity	Sleep	**-0.0959 (-0.1376, -0.0541)**	**-0.0513 (-0.0967, -0.0060)**	**-0.0381 (-0.0602, -0.0159)**
Physical activity	Hobbies	**-0.0843 (-0.1262, -0.0423)**	-0.0439 (-0.0896, 0.0017)	**-0.0333 (-0.0556, -0.0110)**
Physical activity	Electronic media	**-0.0911 (-0.1315, -0.0507)**	**-0.0596 (-0.1036, -0.0156)**	**-0.0459 (-0.0674, -0.0244)**
Physical activity	Domestic	**-0.0966 (-0.1419, -0.0513)**	-0.0473 (-0.0966, 0.0020)	**-0.0368 (-0.0609, -0.0127)**
Hobbies	Sleep	-0.0110 (-0.0252, 0.0032)	-0.0081 (-0.0236, 0.0074)	-0.0052 (-0.0128, 0.0024)
Hobbies	Physical activity	**0.1894 (0.1046, 0.2741)**	**0.0953 (0.0031, 0.1875)**	**0.0726 (0.0275, 0.1176)**
Hobbies	Electronic media	-0.0061 (-0.0191, 0.0069)	**-0.0164 (-0.0306, -0.0023)**	**-0.0131 (-0.0200, -0.0061)**
Hobbies	Domestic	-0.0117 (-0.0305, 0.0070)	-0.0041 (-0.0245, 0.0163)	-0.0039 (-0.0139, 0.0060)
Electronic media	Sleep	-0.0048 (-0.0179, 0.0083)	0.0064 (-0.0078, 0.0206)	0.0065 (-0.0005, 0.0135)
Electronic media	Physical activity	**0.1958 (0.1120, 0.2795)**	**0.1099 (0.0188, 0.2009)**	**0.0844 (0.0398, 0.1289)**
Electronic media	Hobbies	0.0070 (-0.0066, 0.0206)	0.0138 (-0.0010, 0.0285)	**0.0113 (0.0040, 0.0185)**
Electronic media	Domestic	-0.0055 (-0.0220, 0.0109)	0.0104 (-0.0075, 0.0283)	0.0077 (-0.0010, 0.0165)
Domestic	Sleep	0.0005 (-0.0175, 0.0185)	-0.0052 (-0.0247, 0.0143)	-0.0021 (-0.0116, 0.0075)
Domestic	Physical activity	**0.2012 (0.1134, 0.2890)**	**0.0982 (0.0028, 0.1937)**	**0.0757 (0.0291, 0.1224)**
Domestic	Hobbies	0.0123 (-0.0066, 0.0312)	0.0022 (-0.0184, 0.0227)	0.0027 (-0.0073, 0.0128)
Domestic	Electronic media	0.0053 (-0.0107, 0.0214)	-0.0135 (-0.0310, 0.0039)	**-0.0099 (-0.0184, -0.0014)**

Figure titles

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.

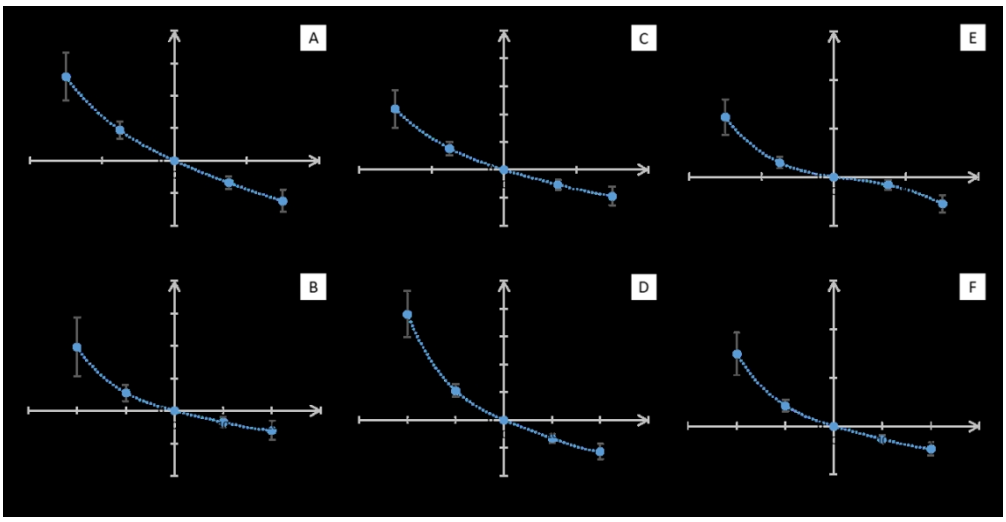

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.

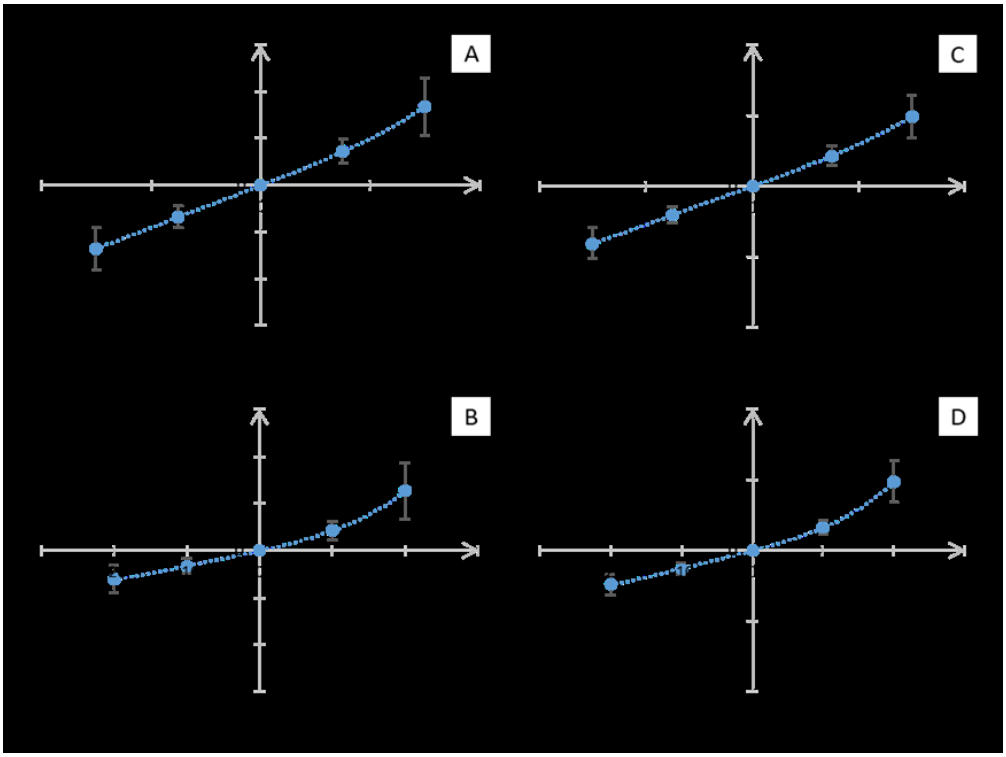

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.

Supplementary material

Table S1. Recoding of time-use diary entries into behavioural categories

Category name	Time-use diary: recorded activity
Sleep	Sleeping and resting
Physical activity	Cycling; Individual ball games and training (e.g. tennis, badminton); Jogging, running, walking, hiking; Team ball games and training (e.g. football, hockey); Swimming and other water sports; Other exercise and sports, dancing, keeping fit, skiing, gymnastics; Travel by physically active means (walk, bike etc.)
School-related activities	Homework; In class; School breaks; School clubs; Detention
Hobbies and socialising	Attending live sporting events; Cinema, theatre, performance, gig etc.; Exhibition, museum, library, other cultural events; Shopping (including window shopping, hanging out at shopping centre); Speaking, socialising face-to-face; Volunteering; Religious activities (including going to places of worship, praying etc.); Did nothing, just relaxing, bored, waiting; Hobbies, arts and crafts, musical activities, writing stories, poetry etc.; Reading (not for school); Other activities not listed
Electronic media	Speaking on the phone (including Skype, video calls); Answering emails, instant messaging, texting; Browsing and updating social networking sites (e.g. Twitter, Facebook, BBM, Snapchat); General internet browsing, programming (not time on social networking sites); Listening to music, radio, iPod, other audio content; Playing electronic games and Apps; Watch TV, DVDs, downloaded videos
Domestic, personal care and work-related activities	Personal care (including taking a shower/bath, grooming, getting dressed etc.); Paid work (including paid babysitting and paid work for the family); Unpaid work for family or other non-household members (e.g. help in family business); Cooking, cleaning, and shopping for the household; Fixing things around the house, fixing bike, gardening; Looking after brothers, sisters, other children in the household; Looking after parent or other adult in the households (medical or personal care); Pet care; Eating or drinking in a restaurant or café; Eating a meal; Eating a snack or having a drink; Travel by bus, taxi, tube, plane; Travel by car, van (including vehicles owned by friends and family)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6-9*
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	na
		(*c*) Explain how missing data were addressed	na
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	na
		(*e*) Describe any sensitivity analyses	na
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	na
		(c) Consider use of a flow diagram	na
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	11
Outcome data	15*	Report numbers of outcome events or summary measures	27

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	29-30
		(*b*) Report category boundaries when continuous variables were categorized	na
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	na
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10/figures
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Adolescent time-use and mental health: A cross-sectional, compositional analysis in the Millennium Cohort Study

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Abstract

Objectives

To examine the association of 24-hour time-use compositions with mental health in a large, geographically diverse sample of UK adolescents.

Design

Cross-sectional, secondary data analysis.

Setting

Millennium Cohort Study (sixth survey), a UK-based prospective birth cohort.

Participants

Data were available from 4642 adolescents aged 14 years. Analytical samples for weekday and weekend analyses were n=3485 and n=3468, respectively (45% boys, 85% White ethnicity).

Primary and secondary outcome measures

Primary outcome measures were the Strengths and Difficulties Questionnaire (SDQ; socioemotional behaviour), Mood and Feelings Questionnaire (MFQ; depressive symptoms) and Rosenberg Self-Esteem Scale (RSE; self-esteem). Behavioural exposure data was derived from 24-hour time use diaries.

Results

On weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Predicted differences in SDQ, MFQ and RSE were statistically significant for all models (weekday and weekend) that simulated the addition or removal of 15 minutes physical activity, with an increase in activity being associated with improved mental health and vice versa. Predicted differences in RSE were also significant for simulated changes

in electronic media use; an increase in electronic media use was associated with reduced self-esteem.

Conclusions

Small, but consistent, associations were observed between physical activity, electronic media use and selected markers of mental health. Findings support the delivery of physical activity interventions to promote mental health during adolescence, without the need to specifically target or protect time spent in other activities.

Keywords

Adolescence; Time-use; Physical activity; Sleep; Depression; Mental health; CoDA

Article summary: Strengths and limitations of the study

Strengths of this study:

- The large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments.
- Use of compositional data analysis of multiple behavioural exposures, which reflects that behaviour change inherently entails the reallocation of time between different domains of behaviour.

Limitations of this study:

- The cross-sectional design which precludes causal inference.
- The susceptibility of time-use diaries to recall and social desirability bias.
- Analyses were based upon a single day of assessment, which may not have been representative of typical behaviour patterns.

Introduction

The global adolescent population, estimated at 1.2 billion, is now larger than at any point in our history and represents approximately 16% of the global population.(1) Accordingly, research and policy activity to support the biological, social, emotional and behavioural development of this population has grown substantially in recent years.(2–4) Part of this wider movement has been a particular focus on mental health during adolescence, consistent with evidence that first diagnosis of a mental disorder often occurs during this period.(5–7) Surveillance data on adolescent mental health remains limited, but there is evidence of increasing prevalence of some conditions in recent years and substantial growth in demand for counselling and specialist mental health services.(8–11) Recent data from the Mental Health of Children and Young People survey, for example, indicated that between 1999-2017 the prevalence of having an emotional disorder (including anxiety and depression) increased from 4.3% to 5.5% in children aged 5-15 years.(12) From the same survey, cross-sectional data collected in 2017 showed that just over 10% of children in this age group had low self-esteem.(12) Interpretation of secular trend data on the prevalence of mental disorders in young people is complicated by a host of methodological, diagnostic and social factors, but it remains clear that a considerable proportion of the child and adolescent population experience mental ill health. A clearer understanding of factors that might predispose or protect children from mental health disorders will help in the development of preventative policies and practice.

A growing body of evidence indicates a role for health behaviours, such as sleep and physical activity, in the prevention of mental health disorders.(13–18) A recent US study, for example, found that over 1 year, sleep duration of less than 6 hours a night was associated with increased risk of anxiety disorders in adolescents aged 11-17 years.(16) This study adjusted for selected social and demographic covariates, but did not account for other health behaviours, such as

physical activity or sedentary behaviour. Given the finite time available each day, an increase in any behaviour (e.g. sleep) can only be achieved through a concomitant reduction in time allocated to one or more other activities (e.g. TV viewing). The nature of such reallocations has potentially important implications for health. The mental health benefits of increasing sleep duration, for example, may not be realised if they come at the expense of reduced physical activity, which is also positively associated with some mental health outcomes. Greater recognition of the complex inter-play between multiple behaviours and health has led to the adoption of sophisticated, and more appropriate, statistical methods and the establishment of new research networks to take the field forward.(19–24) This movement is reflected in new public health recommendations that provide guidance on the optimal composition of the entire (24h) day, rather than focussing on a single behaviour, such as physical activity or sleep.(25,26)

Previous research into the association of time-use composition with mental health in young people has focussed predominantly on health-related quality of life, captured within global measures or social / emotional health sub-scales.(27–29) Studies using cluster analysis to identify subgroups with distinct behavioural profiles have indicated that a lifestyle characterised by low physical activity and/or moderate to high sedentary behaviour was associated with poorer quality of life.(28,30) In contrast, Fairclough et al. (29) observed no differences in psychosocial quality of life for simulated substitutions between accelerometer-assessed sitting, light and moderate to vigorous intensity physical activity (MVPA) during the school day. One study to date has examined the association of time use with proxy-reported Strengths and Difficulties Questionnaire scores, observing that substituting time into MVPA from sleep, light intensity activity or sedentary time was associated with better mental health.(31) The relative lack of previous research on this topic, combined with the conflicting findings of what little evidence does exist, highlights the need for further research in this field.

Therefore, the objective of this study was to examine the cross-sectional associations between adolescents' time-use composition and selected markers of mental health and well-being.

Method

Sample and data collection

Data are from the Millennium Cohort Study (MCS), an observational cohort study of the social, economic, and health related circumstances of children born in the UK between September 2000 and January 2002.(32) The MCS is nationally representative and 18 552 families (18 818 children) were recruited in the first sweep. The sample was augmented with a further 701 children (692 families) born in the same period who had been missed previously, taking the total sample to 19,519. To date, there have been six waves of assessment (age nine months, three, five, seven, eleven, and fourteen years). This cross-sectional analysis uses data from the sixth wave of assessment (MCS6; data collection: January 2015-April 2016), conducted when participants were aged 14 years. 15 415 families were contacted for participation in MCS6; 11 884 participants from 11 726 families provided partial or complete data. MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786). The current study uses anonymised, publicly available data, obtained from the UK Data Service: https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

Patient and public involvement

The research question for this analysis was formulated by the authors (no patient involved). The content and methodology of the sixth sweep of MCS was informed by extensive development work to ensure relevance, participation and engagement amongst participants and their families. Full details are provided in the MCS sixth sweep technical report.(33)

Assessment of time-use

All participants from Wales, Scotland and Northern Ireland and approximately 80% of participants from England were invited to complete time-use diaries for two 24-hour periods (One week day and one weekend day. Days were selected at random by computer assisted personal interview (CAPI) software). The English sample was restricted due to limitations on the number of activity monitors available, which were deployed alongside the time-use diary. Only diary data are used for the current analysis. The diary was available in three formats: online (for completion on a desktop, laptop or netbook); using an App (for completion on a mobile phone or tablet); or on paper. Sixty-four percent of participants selected the App diary format, 29% used the online version and 7% the paper diary.(33)

For each day of assessment, participants recorded what they did from 4am to 4am the following day in 10-min timeslots. Participants also recorded where they were, who they were with and how much they liked each activity but these data are not considered here. The primary activity for each time-slot was selected from a list of 44 pre-defined activity codes, nested within 12 categories. Categories included 'sleep and personal care', 'school, homework and education', 'social time and family time' and 'Internet, TV and digital media'.(34) Due to the differing demands / opportunities afforded by being at school during the week, weekday and weekend data were analysed separately. For the weekday data, activity codes were collapsed into six mutually exclusive activity sets (see supplementary material): (1) Sleep; (2) Physical activity; (3) School-related activities; (4) Hobbies and socialising; (5) Electronic media; (6) Domestic, personal care and work-related activities. Weekend data were collapsed into five sets, omitting the school-related activities group. The five / six sets capture the entirety of participant's daily time use (24 h or 1440 min). Note that the sleep component represented all sleep occurring

between 4am and 4am. Therefore, it does not necessarily represent a full overnight sleep and may incorporate naps taken during the day.

Diaries with missing data (10 min slots with no activity indicated) were excluded from the analysis, as were those with no entries for 'sleep' or 'Domestic, personal care and work-related activities' (which included eating and getting dressed); these were deemed to be unreliable accounts of a complete day's activity. Zero values in any of the activity sets would preclude the use of compositional analysis, as log ratio coordinates cannot be applied to zero values.(35) Consistent with previous work using time-use data, zeros were replaced with small values of less than 10 min, drawing time from the other activity sets.(35,36)

Mental health

Three outcomes related to adolescent mental health were used in the analysis. Socioemotional behaviour was assessed using the Strengths and Difficulties Questionnaire (SDQ, version P4-17), completed by the parent or guardian.(37) The SDQ comprises 25-items relating to five subscales of five items each (Difficulties subscales: emotional problems, conduct problems, hyperactivity/inattention, peer relationship problems. Strengths subscale: prosocial behaviour). Answers are provided with reference to the previous six months and response options are 'Not true', 'Somewhat true' and 'Certainly true'. Example items: 'Often has temper tantrums or hot tempers'; 'Often unhappy, down-hearted or tearful'. A total difficulties score, derived as the sum of responses on the four difficulties subscales, was used in the analysis, consistent with previous research.(38,39) Higher scores indicate greater socioemotional difficulty. Depressive symptomology was assessed using the short-version (13-item) Mood and Feelings questionnaire (MFQ), completed by the participant.(40) Answers are given with reference to the previous two weeks. Response options are 'Not true', 'Sometimes' and 'True'.

Example items: 'I felt miserable or unhappy'; 'I didn't enjoy anything at all'. MFQ is scored as the sum of responses to all items, with higher scores suggesting more severe depressive symptoms. Global self-worth was self-reported using the five positive items from the Rosenberg Self Esteem Scale (RSE).(41) Response options are 'Strongly agree', 'Agree', 'Disagree' and 'Strongly disagree'. Example item: 'On the whole, I am satisfied with myself'. A total score, derived as the sum of responses to all items, was used in the analysis. For consistency with other outcomes, responses were recoded such that higher scores were indicative of lower self-esteem.

Covariates

Covariates were selected on the basis of previous research indicating that they may confound associations between exposure and outcome variables used in the current study.(15,16,31) The following constructs were selected: age, sex, adiposity (measured height and weight used to derive body mass index (BMI) category (42): underweight / normal, overweight, or obese) and equivalised family income (parent reported: <£20,800 annually, £20,800 to £31,300 annually, >£31,200 annually, missing or do not know).

Statistical analysis

Analyses were conducted using R open-source software (www.r-project.org) and the compositions and zCompositions packages for the analysis of compositional data (version 1.40-2).(43) Demographic and anthropometric characteristics of the analytical sample are presented as frequencies and percentages, means with standard deviation or medians with interquartile range as appropriate. Characteristics of those included / excluded from the analytical sample were compared using Student's t tests or chi-squared tests. Time (min/day) spent in each behavioural set is summarised for the raw time-use data (that which retained zero

values) using median and interquartile range. For the imputed time-use compositions (those in which zeros were replaced with small non-zero values, as described above), time in each behavioural set is presented as compositional means (geometric mean of each behaviour, linearly adjusted to collectively sum to 1440 minutes). Summary statistics are presented separately for week and weekend days. Due to the distribution of the health outcome data, associations between time use composition and mental health markers were examined using negative binomial regression.(44) Time-use compositions were expressed as sets of isometric log ratio (ILR) coordinates (R compositions, default ilr() transformation). The five and six part compositions for weekend and weekday time-use were expressed via four and five sets of ILR coordinates respectively. All models were adjusted for age, sex, weight status and family income. In preliminary analyses, models were additionally adjusted for ethnicity and maternal education. However, these variables demonstrated weak, non-significant associations with the outcomes and were subsequently dropped in the interests of model parsimony. Models were checked to ensure assumptions were not violated. Following procedures outlined in Dumuid et al. (19), we subsequently conducted compositional isotemporal substitution analyses to model the influence of reallocating fixed time durations (15 min) between pairs of behaviour sets on each of our mental health outcomes. Models were adjusted for the same covariates as described above and assessed for compliance with relevant statistical assumptions. When this model is subsequently used (in time reallocation of diary activities) to predict new values of the outcome, the predicted data are in log units, which makes it incompatible for mathematical operators such as subtraction to be used for estimation of differences. It is therefore necessary to transform the predicted values back into the original units (by taking the exponential) before estimating the differences in outcome due to time reallocation. In post-hoc analyses, we explored the shape of the association between behaviour reallocations of differing duration and selected outcomes. Specifically, we modelled predicted differences in SDQ, MFQ and

Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between physical activity and the mean of all remaining behavioural sets. In addition, we modelled predicted differences in MFQ and Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between electronic media and the mean of all remaining behavioural sets. Sets were combined for this analysis as the associations observed for paired reallocations between physical activity/electronic media and individual sets were highly consistent in direction and magnitude. The Generalised Linear Models that are used in the analysis, take the log of the outcome data before performing a regression with the explanatory variables. Regression estimates (and associated standard errors) are presented graphically for ease of interpretation.

Results

Data were available from 8625 diaries (person-days), obtained from 4642 participants. Of these, 1679 diaries were excluded due to missing data or non-reporting of sleep or domestic/personal care activities. The analytical samples for weekday and weekend analyses were n=3485 (29.3% of MCS6 participants) and n=3468 (29.2% of MCS6 participants) respectively. Characteristics of participants included in the weekday analyses are presented in Table 1. Overall, the weekday sample was 13.8 (0.5) years of age, 45% male and predominantly White ethnicity (85%). There were no differences in the demographic or anthropometric characteristics of the weekday and weekend analytical samples. Compared to those whose diaries did not meet our inclusion criteria (1679 diaries from n=1238 participants) the analytical sample on average had a lower BMI (Inc: 21.2, Exc: 21.6; P=0.014), were more likely to be White ethnicity (Inc: 85% White, Exc: 76% White; P<0.001) and come from families with higher income (Inc: 31% highest quintile, Exc: 19% highest quintile; P<0.001).

TABLE 1 HERE

Time spent in each of the behavioural sets is presented in Table 2. Compositional means indicated that on weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Corresponding figures for the weekend were: 56% (sleep), 2% (physical activity), 10% (hobbies), 16% (electronic media) and 17% (domestic).

TABLE 2 HERE

Preliminary analyses indicated that after adjustment for age, sex, weight status and family income, the isometric log ratio coordinates for time-use composition were significantly associated with each of the outcome variables (P for isometric log ratio coordinates: SDQ, weekday $P=0.018$, weekend $P<0.001$; MFQ, weekday $P<0.001$, weekend $P=0.023$; RSE weekday $P<0.001$, weekend $P<0.001$). Compositional isotemporal substitution analyses were conducted to simulate the association with each outcome of reallocating 15 min between pairs of behavioural sets; results are presented in Table 3 (weekdays) and Table 4 (weekend) respectively.

For all three outcomes, models that simulated the addition or removal of time from physical activity were statistically significant, with the addition of physical activity being associated with improved mental health and vice versa. The only exception to this trend was for MFQ and the substitution of time from domestic activities or hobbies into physical activity at the weekend, wherein the upper bound of the 95% confidence interval marginally overlapped zero

in both cases. Predicted differences were generally larger for the weekend analysis than the weekday analysis, but remained small at less than 0.3 of a unit of the outcome in all instances.

For the SDQ outcome, there were no statistically significant predicted differences for reallocations that did not include physical activity. For the Rosenberg outcome, all reallocations that included electronic media were statistically significant in the weekday data, with a reduction in time spent using electronic media associated with better mental health. This pattern was partially repeated in the weekend data, except that models simulating the reallocation of time from sleep and domestic activities into electronic media were non-significant. All predicted differences were less than 0.1 units. For MFQ, and in the weekday data only, reallocations between electronic media/sleep and electronic media/domestic activities were statistically significant, with a reduction in time spent using electronic media associated with better mental health.

TABLES 3 AND 4 HERE

Predicted differences in SDQ, MFQ and Rosenberg scores for a range of time reallocations to / from physical activity are presented in Figure 1. Consistent with the main analysis, figures show that simulated increases in physical activity were associated with reduced scores (negative predicted difference; better health) on each of the outcomes, whilst simulated reductions in physical activity were associated with higher outcome scores (positive predicted difference; worse health). In all scenarios, there was evidence of a curvilinear association, such that a modelled reduction in physical activity produced larger predicted differences in the outcomes than a modelled increase in physical activity of comparable duration. Predicted differences in MFQ and Rosenberg scores for a range of time reallocations to / from electronic

media use are presented in Figure 2. Simulated increases in electronic media use were associated with increased scores (positive predicted difference; worse health) on each of the outcomes, whilst simulated reductions in electronic media use were associated with lower outcome scores (negative predicted difference; better health). In the weekday data (Figure 2, panels A and C), the shape of the association appeared approximately linear throughout the range of reallocations tested. In the weekend data (Figure 2, panels B and D), there was evidence of slight deviation from linearity, wherein a modelled increase in electronic media use produced larger predicted differences in the outcomes than a modelled reduction in electronic media use of comparable duration.

FIGURES 1 AND 2 HERE

Discussion

In this large sample of UK adolescents, we found that simulated increases in physical activity were beneficially associated with socioemotional health, whilst comparable increases in electronic media use were adversely associated with depressive symptoms and self-esteem. Associations were largely consistent between week and weekend days, but remained small in magnitude across all behaviours and outcomes. Findings highlight a potential role for physical activity in supporting the socioemotional health of adolescents and provide insight into the possible content and timing of behaviour change interventions.

A simulated reallocation of 15 min from sleep, hobbies, electronic media use, school-related or domestic activities to physical activity was associated with better socioemotional health, reduced depression symptomology and improved self-esteem. This is consistent with previous

research by Carson et al (31) who modelled the impact on SDQ scores of substituting time between sleep, sedentary time, light and moderate to vigorous intensity physical activity measured by accelerometry. More broadly, our findings corroborate existing evidence, both observational and experimental, that physical activity may have a role in the prevention and treatment of mental ill health in young people.(45) The association of physical activity with all outcomes studied here was consistent in direction and magnitude for reallocations across all other behavioural domains, suggesting that the benefit of physical activity is universal and not dependent upon a reduction in any specific behaviour or group of behaviours. It should be acknowledged, nonetheless, that the associations were small in magnitude, perhaps indicating that physical activity alone may not be sufficient to bring about clinically meaningful benefits in the specific health markers examined here. Further research that incorporates other domains of physical activity, such as intensity or activity type, alongside duration, will be beneficial in establishing the direction and magnitude of the association with mental health. This point notwithstanding, and given the plethora of other known benefits of physical activity, our findings support the promotion of physical activity as part of a wider package of measures for the benefit of emotional and behavioural health during adolescence.

Across the range of behavioural substitutions examined, simulated increases in electronic media use were consistently associated with lower self-esteem (higher Rosenberg scores), with only a small number of non-significant predicted differences. We also observed an association between electronic media use and increased depression symptomology but this was confined to a small number of specific behavioural substitutions. Our findings align with a previous analysis in this sweep of the MCS, which reported adverse associations of social media, internet use, TV viewing and video gaming with depressive symptomology and self-esteem.(46) These studies add to a growing body of research examining the link between mental health and

electronic media use, both traditional (eg TV viewing) and contemporary (eg social media).(47–50) At present, the evidence appears equivocal, with findings sensitive to variations in measurement methodology and analysis.(48) Given the cross-sectional nature of this analysis, findings should be interpreted with caution due to the possibility of reverse causality or bi-directional associations. Nonetheless, this study adds to the evidence on this topic by making explicit the inter-connectedness of behaviours within the daily time-budget and adopting an analytical framework that can accommodate this complexity. As the evidence evolves, this approach may become increasingly valuable as we move beyond the largely exploratory nature of existing studies towards research that can explicitly inform the targeting and content of public health policy and behaviour change interventions.

In our post-hoc analyses, we examined the shape of the association between physical activity, electronic media use and selected mental health markers, informed by the findings from our primary analysis (Figures 1 and 2). The size of the association between physical activity and MFQ, SDQ or Rosenberg scores varied according to whether our simulation added or removed time spent active. Specifically, predicted differences for a reduction in physical activity were approximately twice as large as those for an increase in physical activity; this was the case for all outcomes. This asymmetrical phenomenon has also been reported in other studies that have used compositional isotemporal substitution modelling, though it is not observed across all health outcomes (29,31) and was not evident in our models simulating multiple time reallocations for electronic media use. The reason for the disparity in effect sizes in our study is unclear, though it is appropriate to note that effect sizes remained small in all instances. It may reflect a plateau effect in the health benefits of physical activity, such that most benefit is gained from a moderate amount of activity and further increases above this level bring diminishing returns. This is consistent with the wider physical activity literature, particularly

in adults, but the median activity level in the current sample was approx. 40 min / day, well below the recommended 60 min / day for this population.(51) As more research using compositional analytical techniques emerges, it will be possible to describe and investigate this trend in greater depth and establish whether it is a reflection of biological, statistical or some other underlying process.

A key limitation of the current study is the cross-sectional design, which precludes any conclusions about the direction of the associations observed. The isotemporal substitution model mimics within-person time reallocations, but remains a between-person comparison due to there being only 1 observation (point of assessment) per person. The findings are most appropriately interpreted as showing small differences in mental health status across durations of daily time allocated to physical activity and/or electronic media use. Numerous mental health conditions have lethargy or lack of engagement or energy within their diagnostic criteria (52), therefore reverse causality remains a highly plausible explanation for the associations observed in this study. In general, predicted differences in the weekend analysis were greater than those in the weekday analysis, which may also support this interpretation. Specifically with regard to physical activity, a larger proportion of weekday activity is non-volitional in nature, shaped by the more structured nature of the school day and associated routines.(45) This is reflected in evidence that the age-related decline in physical activity is smaller for weekdays than at the weekend and that weekday activity is less susceptible to seasonal variation.(53,54) It follows that a reduction in physical activity associated with mental ill health is likely to be greater at the weekend than during the week. This may account, in part, for our observation of a stronger association between physical activity and socioemotional health at weekends versus during the week.

Strengths and limitations

Keys strengths of this study include the large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments. In addition, daily activity was characterised in detail using 24-h time-use diaries. Concurrent analysis of multiple behavioural exposures is appropriate given that behaviour change inherently entails the reallocation of time between different domains of behaviour. The following limitations are acknowledged. The cross-sectional design precludes causal inference and the possibility of reverse causality or bidirectional associations is acknowledged, as discussed above. The analytical sample differed in its social and anthropometric characteristics compared to those who did not provide sufficient data to be included in the analysis, which may limit generalisability of our findings. Statistical models were adjusted for known demographic and anthropometric confounders, but residual confounding is possible due to measurement error or omission of unknown confounding variables. In addition, we did not explore non-linear associations in the current analysis; this would be valuable in future research, particularly with regard to the sleep dimension of time use. Time-use diaries, like other self-report instruments, are susceptible to recall and social desirability bias. Lastly, our analysis is based upon a single day of assessment, which may not be representative of typical behaviour patterns. However, measurement days were selected at random and short periods of assessment are typical in studies that employ time-use diaries in order to limit participant burden.(36)

Conclusion

This study adds to existing evidence on the association between lifestyle behaviours and mental health in adolescents. Our finding that substituting time from behaviours representing a number of different domains into physical activity was associated with better socioemotional

health has important implications for intervention design, and should be examined further in longitudinal and experimental studies.

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Competing interests

None declared.

Author contributions

AJA conceived the research question, contributed to the statistical analysis and led on manuscript preparation. JRD conducted the statistical analysis, generated the figures and contributed to drafting segments of the methods and results. DD contributed to development of the research question and advised on the statistical analysis and interpretation of the results. EK contributed to preparation of the introduction and discussion sections and interpretation of results. LS contributed to development of the research question, the analytical approach and interpretation of results. RT contributed to development of the research question and interpretation of results. CR contributed to development of the research question, the analytical approach and interpretation of results. RJN contributed to development of the research question, the analytical approach and interpretation of results. SJF contributed to development of the research question, the analytical approach and interpretation of results. All authors provided critical feedback on drafts of the manuscript and approved the final manuscript.

Data sharing statement

The datasets analysed during the current study are available from the UK Data Service: beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

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Ethics Statement

MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786).

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Tables

Table 1. Participant characteristics (Weekday sample; values are mean (SD) unless stated otherwise).

	Weekdays (n=3485)
Demographics	
Sex (n (% male))	1561 (45)
Age (years)	13.8 (0.5)
BMI (kg/m^2)	21.2 (4.0)
Ethnicity (white, n (%))	2951 (85)
Family income (quintile, n (%))	
First (lowest)	327 (9)
Second	436 (13)
Third	686 (20)
Fourth	958 (28)
Fifth (highest)	1075 (31)
Country (n (%))	
England	2119 (61)
Scotland	506 (15)
Wales	486 (14)
Northern Ireland	374 (11)
Outcomes (median (IQR))	
SDQ	6.0 (3.0, 9.0)
MFQ	17.0 (14.0, 21.0)
RSE	10.0 (7.0, 10.0)

Weekend analysis, n=3468.

SD, standard deviation; BMI, body mass index; IQR, inter-quartile range; SDQ, Strengths and Difficulties Questionnaire; MFQ, Mood and Feelings Questionnaire; RSE, Rosenberg Self Esteem Scale

Table 2. Descriptive characteristics of time-use compositions (min/day)

	Raw composition Median (IQR)		Imputed composition Compositional mean*	
	Weekday	**Weekend**	**Weekday**	**Weekend**
Sleep	550 (500, 610)	630 (550, 690)	779.8	800.8
Physical activity	40 (0, 110)	30 (0, 120)	42.2	23.0
School-related	370 (0, 420)	NA	135.3	NA
Hobbies	90 (20, 200)	180 (60, 320)	85.2	144.9
Electronic media	170 (70, 290)	240 (120, 390)	161.8	226.0
Domestic	180 (120, 250)	200 (130, 300)	235.6	245.2

Weekday n=3485; Weekend n=3468
IQR, inter-quartile range; NA, not applicable
*Geometric mean adjusted to sum to 1440 min/day

Table 3. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekday analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

		Predicted difference		
Add 15 min…	**Remove 15 min…**	**SDQ**	**MFQ**	**Rosenberg**
Sleep	Physical activity	**0.0786 (0.0305, 0.1268)**	**0.0823 (0.0302, 0.1344)**	**0.0407 (0.0148, 0.0666)**
Sleep	School-related	0.0039 (-0.0080, 0.0158)	**-0.0149 (-0.0278, -0.0020)**	-0.0028 (-0.0092, 0.0036)
Sleep	Hobbies	-0.0028 (-0.0263, 0.0208)	-0.0195 (-0.0450, 0.0060)	0.0016 (-0.0111, 0.0143)
Sleep	Electronic media	-0.0016 (-0.0179, 0.0147)	**-0.0289 (-0.0466, -0.0112)**	**-0.0153 (-0.0241, -0.0065)**
Sleep	Domestic	0.0080 (-0.0128, 0.0289)	-0.0003 (-0.0229, 0.0223)	-0.0019 (-0.0131, 0.0094)
Physical activity	Sleep	**-0.0549 (-0.0891, -0.0207)**	**-0.0553 (-0.0923, -0.0183)**	**-0.0277 (-0.0461, -0.0093)**
Physical activity	School-related	**-0.0510 (-0.0846, -0.0173)**	**-0.0702 (-0.1066, -0.0337)**	**-0.0305 (-0.0486, -0.0124)**
Physical activity	Hobbies	**-0.0576 (-0.0950, -0.0202)**	**-0.0748 (-0.1154, -0.0343)**	**-0.0261 (-0.0463, -0.0060)**
Physical activity	Electronic media	**-0.0564 (-0.0900, -0.0229)**	**-0.0841 (-0.1205, -0.0477)**	**-0.0430 (-0.0610, -0.0249)**
Physical activity	Domestic	**-0.0469 (-0.0835, -0.0103)**	**-0.0556 (-0.0953, -0.016)**	**-0.0296 (-0.0493, -0.0099)**
School-related	Sleep	-0.0039 (-0.0151, 0.0073)	**0.0141 (0.0020, 0.0262)**	0.0026 (-0.0034, 0.0087)
School-related	Physical activity	**0.0747 (0.0275, 0.1220)**	**0.0963 (0.0452, 0.1475)**	**0.0433 (0.0179, 0.0687)**
School-related	Hobbies	-0.0066 (-0.0273, 0.0141)	-0.0055 (-0.0280, 0.0169)	0.0042 (-0.0069, 0.0154)
School-related	Electronic media	-0.0054 (-0.0195, 0.0087)	-0.0149 (-0.0302, 0.0005)	**-0.0127 (-0.0203, -0.0051)**
School-related	Domestic	0.0042 (-0.0142, 0.0225)	0.0137 (-0.0062, 0.0336)	0.0008 (-0.0091, 0.0106)
Hobbies	Sleep	0.0017 (-0.0186, 0.0221)	0.0174 (-0.0047, 0.0394)	-0.0011 (-0.0121, 0.0099)
Hobbies	Physical activity	**0.0804 (0.0318, 0.1291)**	**0.0996 (0.0469, 0.1523)**	**0.0395 (0.0134, 0.0657)**
Hobbies	School-related	0.0057 (-0.0122, 0.0236)	0.0024 (-0.0170, 0.0218)	-0.0039 (-0.0136, 0.0057)
Hobbies	Electronic media	0.0002 (-0.0195, 0.0198)	-0.0116 (-0.0329, 0.0097)	**-0.0165 (-0.0271, -0.0058)**
Hobbies	Domestic	0.0098 (-0.0150, 0.0346)	0.0170 (-0.0100, 0.0439)	-0.0030 (-0.0164, 0.0104)
Electronic media	Sleep	0.0011 (-0.0142, 0.0164)	**0.0270 (0.0104, 0.0437)**	**0.0141 (0.0058, 0.0224)**
Electronic media	Physical activity	**0.0798 (0.0330, 0.1266)**	**0.1094 (0.0587, 0.1600)**	**0.0548 (0.0297, 0.0800)**
Electronic media	School-related	0.0051 (-0.0086, 0.0188)	0.0121 (-0.0028, 0.027)	**0.0113 (0.0039, 0.0187)**
Electronic media	Hobbies	-0.0016 (-0.0235, 0.0204)	0.0074 (-0.0164, 0.0312)	**0.0157 (0.0038, 0.0275)**
Electronic media	Domestic	0.0092 (-0.0103, 0.0287)	**0.0267 (0.0056, 0.0478)**	**0.0122 (0.0017, 0.0227)**
Domestic	Sleep	-0.0078 (-0.0278, 0.0122)	0.0009 (-0.0208, 0.0226)	0.0018 (-0.0090, 0.0126)
Domestic	Physical activity	**0.0708 (0.0215, 0.1202)**	**0.0831 (0.0297, 0.1366)**	**0.0425 (0.0160, 0.0690)**
Domestic	School-related	-0.0038 (-0.0217, 0.0141)	-0.0140 (-0.0335, 0.0054)	-0.0010 (-0.0106, 0.0087)
Domestic	Hobbies	-0.0105 (-0.0373, 0.0164)	-0.0187 (-0.0478, 0.0104)	0.0034 (-0.0111, 0.0179)
Domestic	Electronic media	-0.0093 (-0.0287, 0.0101)	**-0.0280 (-0.0490, -0.0071)**	**-0.0135 (-0.0239, -0.0031)**

Table 4. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekend analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

Add 15 min…	Remove 15 min…	Predicted difference SDQ	MFQ	Rosenberg
Sleep	Physical activity	**0.2006 (0.1152, 0.2860)**	**0.1021 (0.0093, 0.1949)**	**0.077 (0.0316, 0.1223)**
Sleep	Hobbies	0.0117 (-0.0035, 0.0270)	0.0060 (-0.0106, 0.0226)	0.0039 (-0.0042, 0.0121)
Sleep	Electronic media	0.0048 (-0.0088, 0.0184)	-0.0097 (-0.0244, 0.0050)	**-0.0087 (-0.0160, -0.0014)**
Sleep	Domestic	-0.0008 (-0.0196, 0.0179)	0.0027 (-0.0176, 0.0230)	0.0004 (-0.0095, 0.0103)
Physical activity	Sleep	**-0.0959 (-0.1376, -0.0541)**	**-0.0513 (-0.0967, -0.0060)**	**-0.0381 (-0.0602, -0.0159)**
Physical activity	Hobbies	**-0.0843 (-0.1262, -0.0423)**	-0.0439 (-0.0896, 0.0017)	**-0.0333 (-0.0556, -0.0110)**
Physical activity	Electronic media	**-0.0911 (-0.1315, -0.0507)**	**-0.0596 (-0.1036, -0.0156)**	**-0.0459 (-0.0674, -0.0244)**
Physical activity	Domestic	**-0.0966 (-0.1419, -0.0513)**	-0.0473 (-0.0966, 0.0020)	**-0.0368 (-0.0609, -0.0127)**
Hobbies	Sleep	-0.0110 (-0.0252, 0.0032)	-0.0081 (-0.0236, 0.0074)	-0.0052 (-0.0128, 0.0024)
Hobbies	Physical activity	**0.1894 (0.1046, 0.2741)**	**0.0953 (0.0031, 0.1875)**	**0.0726 (0.0275, 0.1176)**
Hobbies	Electronic media	-0.0061 (-0.0191, 0.0069)	**-0.0164 (-0.0306, -0.0023)**	**-0.0131 (-0.0200, -0.0061)**
Hobbies	Domestic	-0.0117 (-0.0305, 0.0070)	-0.0041 (-0.0245, 0.0163)	-0.0039 (-0.0139, 0.0060)
Electronic media	Sleep	-0.0048 (-0.0179, 0.0083)	0.0064 (-0.0078, 0.0206)	0.0065 (-0.0005, 0.0135)
Electronic media	Physical activity	**0.1958 (0.1120, 0.2795)**	**0.1099 (0.0188, 0.2009)**	**0.0844 (0.0398, 0.1289)**
Electronic media	Hobbies	0.0070 (-0.0066, 0.0206)	0.0138 (-0.0010, 0.0285)	**0.0113 (0.0040, 0.0185)**
Electronic media	Domestic	-0.0055 (-0.0220, 0.0109)	0.0104 (-0.0075, 0.0283)	0.0077 (-0.0010, 0.0165)
Domestic	Sleep	0.0005 (-0.0175, 0.0185)	-0.0052 (-0.0247, 0.0143)	-0.0021 (-0.0116, 0.0075)
Domestic	Physical activity	**0.2012 (0.1134, 0.2890)**	**0.0982 (0.0028, 0.1937)**	**0.0757 (0.0291, 0.1224)**
Domestic	Hobbies	0.0123 (-0.0066, 0.0312)	0.0022 (-0.0184, 0.0227)	0.0027 (-0.0073, 0.0128)
Domestic	Electronic media	0.0053 (-0.0107, 0.0214)	-0.0135 (-0.0310, 0.0039)	**-0.0099 (-0.0184, -0.0014)**

Figure titles

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.

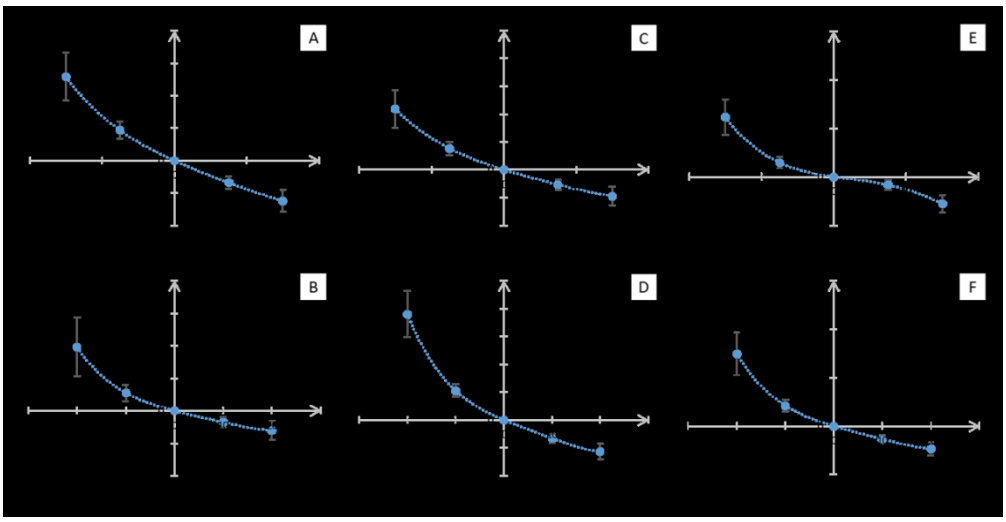

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.
Weekday data: panels A, C, E. Weekend data: panels B, D, F.
Models adjusted for age, sex, body mass index and family income. Data points are predicted differences in the outcome ± standard error.
Interpretation: Points plotted to the left of the Y-axis denote predicted differences in the outcome for a specified reduction in physical activity. Points plotted to the right of the Y-axis denote predicted differences in the outcome for a specified increase in physical activity.

550x280mm (59 x 59 DPI)

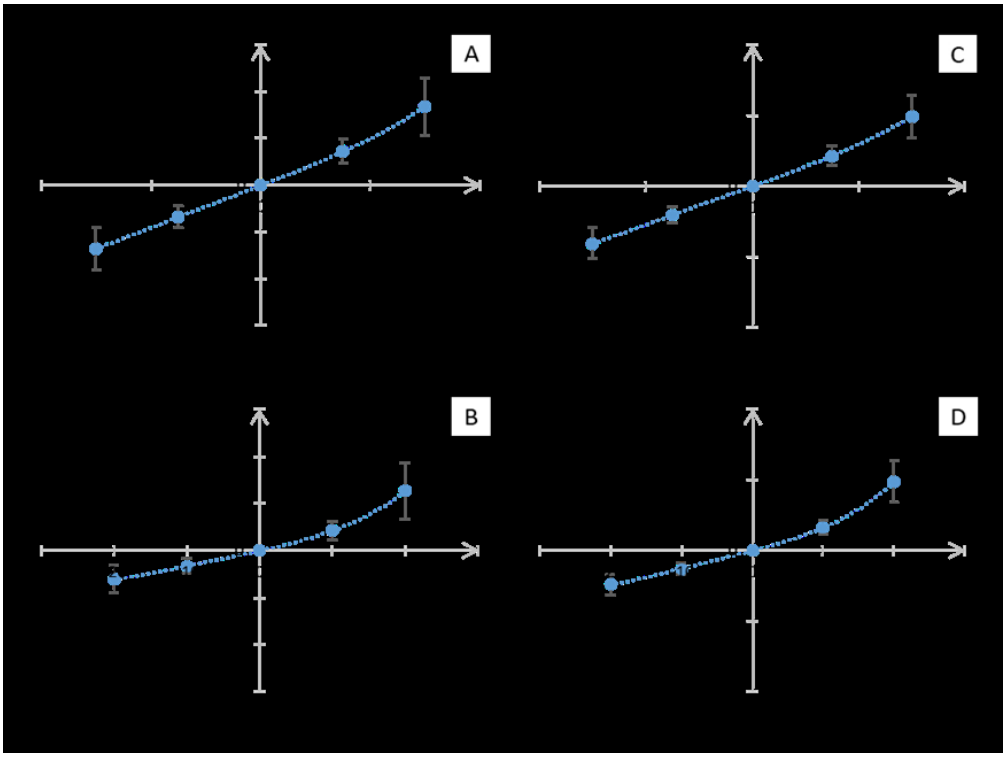

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.
Weekday data: panels A, C. Weekend data: panels B, D
Models adjusted for age, sex, body mass index and family income. Data points are predicted differences in the outcome ± standard error.
Interpretation: Points plotted to the left of the Y-axis denote predicted differences in the outcome for a specified reduction in electronic media. Points plotted to the right of the Y-axis denote predicted differences in the outcome for a specified increase in electronic media.

374x280mm (59 x 59 DPI)

Supplementary material

Table S1. Recoding of time-use diary entries into behavioural categories

Category name	Time-use diary: recorded activity
Sleep	Sleeping and resting
Physical activity	Cycling; Individual ball games and training (e.g. tennis, badminton); Jogging, running, walking, hiking; Team ball games and training (e.g. football, hockey); Swimming and other water sports; Other exercise and sports, dancing, keeping fit, skiing, gymnastics; Travel by physically active means (walk, bike etc.)
School-related activities	Homework; In class; School breaks; School clubs; Detention
Hobbies and socialising	Attending live sporting events; Cinema, theatre, performance, gig etc.; Exhibition, museum, library, other cultural events; Shopping (including window shopping, hanging out at shopping centre); Speaking, socialising face-to-face; Volunteering; Religious activities (including going to places of worship, praying etc.); Did nothing, just relaxing, bored, waiting; Hobbies, arts and crafts, musical activities, writing stories, poetry etc.; Reading (not for school); Other activities not listed
Electronic media	Speaking on the phone (including Skype, video calls); Answering emails, instant messaging, texting; Browsing and updating social networking sites (e.g. Twitter, Facebook, BBM, Snapchat); General internet browsing, programming (not time on social networking sites); Listening to music, radio, iPod, other audio content; Playing electronic games and Apps; Watch TV, DVDs, downloaded videos
Domestic, personal care and work-related activities	Personal care (including taking a shower/bath, grooming, getting dressed etc.); Paid work (including paid babysitting and paid work for the family); Unpaid work for family or other non-household members (e.g. help in family business); Cooking, cleaning, and shopping for the household; Fixing things around the house, fixing bike, gardening; Looking after brothers, sisters, other children in the household; Looking after parent or other adult in the households (medical or personal care); Pet care; Eating or drinking in a restaurant or café; Eating a meal; Eating a snack or having a drink; Travel by bus, taxi, tube, plane; Travel by car, van (including vehicles owned by friends and family)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6-9*
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	na
		(*c*) Explain how missing data were addressed	na
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	na
		(*e*) Describe any sensitivity analyses	na
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	na
		(c) Consider use of a flow diagram	na
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	11
Outcome data	15*	Report numbers of outcome events or summary measures	27

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	29-30
		(*b*) Report category boundaries when continuous variables were categorized	na
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	na
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10/figures
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Adolescent time-use and mental health: A cross-sectional, compositional analysis in the Millennium Cohort Study

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Abstract

Objectives

To examine the association of 24-hour time-use compositions with mental health in a large, geographically diverse sample of UK adolescents.

Design

Cross-sectional, secondary data analysis.

Setting

Millennium Cohort Study (sixth survey), a UK-based prospective birth cohort.

Participants

Data were available from 4642 adolescents aged 14 years. Analytical samples for weekday and weekend analyses were n=3485 and n=3468, respectively (45% boys, 85% White ethnicity).

Primary and secondary outcome measures

Primary outcome measures were the Strengths and Difficulties Questionnaire (SDQ; socioemotional behaviour), Mood and Feelings Questionnaire (MFQ; depressive symptoms) and Rosenberg Self-Esteem Scale (RSE; self-esteem). Behavioural exposure data was derived from 24-hour time use diaries.

Results

On weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Predicted differences in SDQ, MFQ and RSE were statistically significant for all models (weekday and weekend) that simulated the addition or removal of 15 minutes physical activity, with an increase in activity being associated with improved mental health and vice versa. Predicted differences in RSE were also significant for simulated changes

in electronic media use; an increase in electronic media use was associated with reduced self-esteem.

Conclusions

Small, but consistent, associations were observed between physical activity, electronic media use and selected markers of mental health. Findings support the delivery of physical activity interventions to promote mental health during adolescence, without the need to specifically target or protect time spent in other activities.

Keywords

Adolescence; Time-use; Physical activity; Sleep; Depression; Mental health; CoDA

Article summary: Strengths and limitations of the study

Strengths of this study:

- The large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments.
- Use of compositional data analysis of multiple behavioural exposures, which reflects that behaviour change inherently entails the reallocation of time between different domains of behaviour.

Limitations of this study:

- The cross-sectional design which precludes causal inference.
- The susceptibility of time-use diaries to recall and social desirability bias.
- Analyses were based upon a single day of assessment, which may not have been representative of typical behaviour patterns.

Introduction

The global adolescent population, estimated at 1.2 billion, is now larger than at any point in our history and represents approximately 16% of the global population.(1) Accordingly, research and policy activity to support the biological, social, emotional and behavioural development of this population has grown substantially in recent years.(2–4) Part of this wider movement has been a particular focus on mental health during adolescence, consistent with evidence that first diagnosis of a mental disorder often occurs during this period.(5–7) Surveillance data on adolescent mental health remains limited, but there is evidence of increasing prevalence of some conditions in recent years and substantial growth in demand for counselling and specialist mental health services.(8–11) Recent data from the Mental Health of Children and Young People survey, for example, indicated that between 1999-2017 the prevalence of having an emotional disorder (including anxiety and depression) increased from 4.3% to 5.5% in children aged 5-15 years.(12) From the same survey, cross-sectional data collected in 2017 showed that just over 10% of children in this age group had low self-esteem.(12) Interpretation of secular trend data on the prevalence of mental disorders in young people is complicated by a host of methodological, diagnostic and social factors, but it remains clear that a considerable proportion of the child and adolescent population experience mental ill health. A clearer understanding of factors that might predispose or protect children from mental health disorders will help in the development of preventative policies and practice.

A growing body of evidence indicates a role for health behaviours, such as sleep and physical activity, in the prevention of mental health disorders.(13–18) A recent US study, for example, found that over 1 year, sleep duration of less than 6 hours a night was associated with increased risk of anxiety disorders in adolescents aged 11-17 years.(16) This study adjusted for selected social and demographic covariates, but did not account for other health behaviours, such as

physical activity or sedentary behaviour. Given the finite time available each day, an increase in any behaviour (e.g. sleep) can only be achieved through a concomitant reduction in time allocated to one or more other activities (e.g. TV viewing). The nature of such reallocations has potentially important implications for health. The mental health benefits of increasing sleep duration, for example, may not be realised if they come at the expense of reduced physical activity, which is also positively associated with some mental health outcomes. Greater recognition of the complex inter-play between multiple behaviours and health has led to the adoption of sophisticated, and more appropriate, statistical methods and the establishment of new research networks to take the field forward.(19–24) This movement is reflected in new public health recommendations that provide guidance on the optimal composition of the entire (24h) day, rather than focussing on a single behaviour, such as physical activity or sleep.(25,26)

Previous research into the association of time-use composition with mental health in young people has focussed predominantly on health-related quality of life, captured within global measures or social / emotional health sub-scales.(27–29) Studies using cluster analysis to identify subgroups with distinct behavioural profiles have indicated that a lifestyle characterised by low physical activity and/or moderate to high sedentary behaviour was associated with poorer quality of life.(28,30) In contrast, Fairclough et al. (29) observed no differences in psychosocial quality of life for simulated substitutions between accelerometer-assessed sitting, light and moderate to vigorous intensity physical activity (MVPA) during the school day. One study to date has examined the association of time use with proxy-reported Strengths and Difficulties Questionnaire scores, observing that substituting time into MVPA from sleep, light intensity activity or sedentary time was associated with better mental health.(31) The relative lack of previous research on this topic, combined with the conflicting findings of what little evidence does exist, highlights the need for further research in this field.

Therefore, the objective of this study was to examine the cross-sectional associations between adolescents' time-use composition and selected markers of mental health and well-being.

Method

Sample and data collection

Data are from the Millennium Cohort Study (MCS), an observational cohort study of the social, economic, and health related circumstances of children born in the UK between September 2000 and January 2002.(32) The MCS is nationally representative and 18 552 families (18 818 children) were recruited in the first sweep. The sample was augmented with a further 701 children (692 families) born in the same period who had been missed previously, taking the total sample to 19,519. To date, there have been six waves of assessment (age nine months, three, five, seven, eleven, and fourteen years). This cross-sectional analysis uses data from the sixth wave of assessment (MCS6; data collection: January 2015-April 2016), conducted when participants were aged 14 years. 15 415 families were contacted for participation in MCS6; 11 884 participants from 11 726 families provided partial or complete data. MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786). The current study uses anonymised, publicly available data, obtained from the UK Data Service: https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

Patient and public involvement

The research question for this analysis was formulated by the authors (no patient involved). The content and methodology of the sixth sweep of MCS was informed by extensive development work to ensure relevance, participation and engagement amongst participants and their families. Full details are provided in the MCS sixth sweep technical report.(33)

Assessment of time-use

All participants from Wales, Scotland and Northern Ireland and approximately 80% of participants from England were invited to complete time-use diaries for two 24-hour periods (One week day and one weekend day. Days were selected at random by computer assisted personal interview (CAPI) software). The English sample was restricted due to limitations on the number of activity monitors available, which were deployed alongside the time-use diary. Only diary data are used for the current analysis. The diary was available in three formats: online (for completion on a desktop, laptop or netbook); using an App (for completion on a mobile phone or tablet); or on paper. Sixty-four percent of participants selected the App diary format, 29% used the online version and 7% the paper diary.(33)

For each day of assessment, participants recorded what they did from 4am to 4am the following day in 10-min timeslots. Participants also recorded where they were, who they were with and how much they liked each activity but these data are not considered here. The primary activity for each time-slot was selected from a list of 44 pre-defined activity codes, nested within 12 categories. Categories included 'sleep and personal care', 'school, homework and education', 'social time and family time' and 'Internet, TV and digital media'.(34) Due to the differing demands / opportunities afforded by being at school during the week, weekday and weekend data were analysed separately. For the weekday data, activity codes were collapsed into six mutually exclusive activity sets (see supplementary material): (1) Sleep; (2) Physical activity; (3) School-related activities; (4) Hobbies and socialising; (5) Electronic media; (6) Domestic, personal care and work-related activities. Weekend data were collapsed into five sets, omitting the school-related activities group. The five / six sets capture the entirety of participant's daily time use (24 h or 1440 min). Note that the sleep component represented all sleep occurring

between 4am and 4am. Therefore, it does not necessarily represent a full overnight sleep and may incorporate naps taken during the day.

Diaries with missing data (10 min slots with no activity indicated) were excluded from the analysis, as were those with no entries for 'sleep' or 'Domestic, personal care and work-related activities' (which included eating and getting dressed); these were deemed to be unreliable accounts of a complete day's activity. Zero values in any of the activity sets would preclude the use of compositional analysis, as log ratio coordinates cannot be applied to zero values.(35) Consistent with previous work using time-use data, zeros were replaced with small values of less than 10 min, drawing time from the other activity sets.(35,36)

Mental health

Three outcomes related to adolescent mental health were used in the analysis. Socioemotional behaviour was assessed using the Strengths and Difficulties Questionnaire (SDQ, version P4-17), completed by the parent or guardian.(37) The SDQ comprises 25-items relating to five subscales of five items each (Difficulties subscales: emotional problems, conduct problems, hyperactivity/inattention, peer relationship problems. Strengths subscale: prosocial behaviour). Answers are provided with reference to the previous six months and response options are 'Not true', 'Somewhat true' and 'Certainly true'. Example items: 'Often has temper tantrums or hot tempers'; 'Often unhappy, down-hearted or tearful'. A total difficulties score, derived as the sum of responses on the four difficulties subscales, was used in the analysis, consistent with previous research.(38,39) Higher scores indicate greater socioemotional difficulty. Depressive symptomology was assessed using the short-version (13-item) Mood and Feelings questionnaire (MFQ), completed by the participant.(40) Answers are given with reference to the previous two weeks. Response options are 'Not true', 'Sometimes' and 'True'.

Example items: 'I felt miserable or unhappy'; 'I didn't enjoy anything at all'. MFQ is scored as the sum of responses to all items, with higher scores suggesting more severe depressive symptoms. Global self-worth was self-reported using the five positive items from the Rosenberg Self Esteem Scale (RSE).(41) Response options are 'Strongly agree', 'Agree', 'Disagree' and 'Strongly disagree'. Example item: 'On the whole, I am satisfied with myself'. A total score, derived as the sum of responses to all items, was used in the analysis. For consistency with other outcomes, responses were recoded such that higher scores were indicative of lower self-esteem.

Covariates

Covariates were selected on the basis of previous research indicating that they may confound associations between exposure and outcome variables used in the current study.(15,16,31) The following constructs were selected: age, sex, adiposity (measured height and weight used to derive body mass index (BMI) category (42): underweight / normal, overweight, or obese) and equivalised family income (parent reported: <£20,800 annually, £20,800 to £31,300 annually, >£31,200 annually, missing or do not know).

Statistical analysis

Analyses were conducted using R open-source software (www.r-project.org) and the compositions and zCompositions packages for the analysis of compositional data (version 1.40-2).(43) Demographic and anthropometric characteristics of the analytical sample are presented as frequencies and percentages, means with standard deviation or medians with interquartile range as appropriate. Characteristics of those included / excluded from the analytical sample were compared using Student's t tests or chi-squared tests. Time (min/day) spent in each behavioural set is summarised for the raw time-use data (that which retained zero

values) using median and interquartile range. For the imputed time-use compositions (those in which zeros were replaced with small non-zero values, as described above), time in each behavioural set is presented as compositional means (geometric mean of each behaviour, linearly adjusted to collectively sum to 1440 minutes). Summary statistics are presented separately for week and weekend days. Due to the distribution of the health outcome data, associations between time use composition and mental health markers were examined using negative binomial regression.(44) Time-use compositions were expressed as sets of isometric log ratio (ILR) coordinates (R compositions, default ilr() transformation). The five and six part compositions for weekend and weekday time-use were expressed via four and five sets of ILR coordinates respectively. All models were adjusted for age, sex, weight status and family income. In preliminary analyses, models were additionally adjusted for ethnicity and maternal education. However, these variables demonstrated weak, non-significant associations with the outcomes and were subsequently dropped in the interests of model parsimony. Models were checked to ensure assumptions were not violated. Following procedures outlined in Dumuid et al. (19), we subsequently conducted compositional isotemporal substitution analyses to model the influence of reallocating fixed time durations (15 min) between pairs of behaviour sets on each of our mental health outcomes. Models were adjusted for the same covariates as described above and assessed for compliance with relevant statistical assumptions. When this model is subsequently used (in time reallocation of diary activities) to predict new values of the outcome, the predicted data are in log units, which makes it incompatible for mathematical operators such as subtraction to be used for estimation of differences. It is therefore necessary to transform the predicted values back into the original units (by taking the exponential) before estimating the differences in outcome due to time reallocation. In post-hoc analyses, we explored the shape of the association between behaviour reallocations of differing duration and selected outcomes. Specifically, we modelled predicted differences in SDQ, MFQ and

Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between physical activity and the mean of all remaining behavioural sets. In addition, we modelled predicted differences in MFQ and Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between electronic media and the mean of all remaining behavioural sets. Sets were combined for this analysis as the associations observed for paired reallocations between physical activity/electronic media and individual sets were highly consistent in direction and magnitude. The Generalised Linear Models that are used in the analysis, take the log of the outcome data before performing a regression with the explanatory variables. Regression estimates (and associated standard errors) are presented graphically for ease of interpretation.

Results

Data were available from 8625 diaries (person-days), obtained from 4642 participants. Of these, 1679 diaries were excluded due to missing data or non-reporting of sleep or domestic/personal care activities. The analytical samples for weekday and weekend analyses were n=3485 (29.3% of MCS6 participants) and n=3468 (29.2% of MCS6 participants) respectively. Characteristics of participants included in the weekday analyses are presented in Table 1. Overall, the weekday sample was 13.8 (0.5) years of age, 45% male and predominantly White ethnicity (85%). There were no differences in the demographic or anthropometric characteristics of the weekday and weekend analytical samples. Compared to those whose diaries did not meet our inclusion criteria (1679 diaries from n=1238 participants) the analytical sample on average had a lower BMI (Inc: 21.2, Exc: 21.6; P=0.014), were more likely to be White ethnicity (Inc: 85% White, Exc: 76% White; P<0.001) and come from families with higher income (Inc: 31% highest quintile, Exc: 19% highest quintile; P<0.001).

TABLE 1 HERE

Time spent in each of the behavioural sets is presented in Table 2. Compositional means indicated that on weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Corresponding figures for the weekend were: 56% (sleep), 2% (physical activity), 10% (hobbies), 16% (electronic media) and 17% (domestic).

TABLE 2 HERE

Preliminary analyses indicated that after adjustment for age, sex, weight status and family income, the isometric log ratio coordinates for time-use composition were significantly associated with each of the outcome variables (P for isometric log ratio coordinates: SDQ, weekday $P=0.018$, weekend $P<0.001$; MFQ, weekday $P<0.001$, weekend $P=0.023$; RSE weekday $P<0.001$, weekend $P<0.001$). Compositional isotemporal substitution analyses were conducted to simulate the association with each outcome of reallocating 15 min between pairs of behavioural sets; results are presented in Table 3 (weekdays) and Table 4 (weekend) respectively.

For all three outcomes, models that simulated the addition or removal of time from physical activity were statistically significant, with the addition of physical activity being associated with improved mental health and vice versa. The only exception to this trend was for MFQ and the substitution of time from domestic activities or hobbies into physical activity at the weekend, wherein the upper bound of the 95% confidence interval marginally overlapped zero

in both cases. Predicted differences were generally larger for the weekend analysis than the weekday analysis, but remained small at less than 0.3 of a unit of the outcome in all instances.

For the SDQ outcome, there were no statistically significant predicted differences for reallocations that did not include physical activity. For the Rosenberg outcome, all reallocations that included electronic media were statistically significant in the weekday data, with a reduction in time spent using electronic media associated with better mental health. This pattern was partially repeated in the weekend data, except that models simulating the reallocation of time from sleep and domestic activities into electronic media were non-significant. All predicted differences were less than 0.1 units. For MFQ, and in the weekday data only, reallocations between electronic media/sleep and electronic media/domestic activities were statistically significant, with a reduction in time spent using electronic media associated with better mental health.

TABLES 3 AND 4 HERE

Predicted differences in SDQ, MFQ and Rosenberg scores for a range of time reallocations to / from physical activity are presented in Figure 1. Consistent with the main analysis, figures show that simulated increases in physical activity were associated with reduced scores (negative predicted difference; better health) on each of the outcomes, whilst simulated reductions in physical activity were associated with higher outcome scores (positive predicted difference; worse health). In all scenarios, there was evidence of a curvilinear association, such that a modelled reduction in physical activity produced larger predicted differences in the outcomes than a modelled increase in physical activity of comparable duration. Predicted differences in MFQ and Rosenberg scores for a range of time reallocations to / from electronic

media use are presented in Figure 2. Simulated increases in electronic media use were associated with increased scores (positive predicted difference; worse health) on each of the outcomes, whilst simulated reductions in electronic media use were associated with lower outcome scores (negative predicted difference; better health). In the weekday data (Figure 2, panels A and C), the shape of the association appeared approximately linear throughout the range of reallocations tested. In the weekend data (Figure 2, panels B and D), there was evidence of slight deviation from linearity, wherein a modelled increase in electronic media use produced larger predicted differences in the outcomes than a modelled reduction in electronic media use of comparable duration.

FIGURES 1 AND 2 HERE

Discussion

In this large sample of UK adolescents, we found that simulated increases in physical activity were beneficially associated with socioemotional health, whilst comparable increases in electronic media use were adversely associated with depressive symptoms and self-esteem. Associations were largely consistent between week and weekend days, but remained small in magnitude across all behaviours and outcomes. Findings highlight a potential role for physical activity in supporting the socioemotional health of adolescents and provide insight into the possible content and timing of behaviour change interventions.

A simulated reallocation of 15 min from sleep, hobbies, electronic media use, school-related or domestic activities to physical activity was associated with better socioemotional health, reduced depression symptomology and improved self-esteem. This is consistent with previous

research by Carson et al (31) who modelled the impact on SDQ scores of substituting time between sleep, sedentary time, light and moderate to vigorous intensity physical activity measured by accelerometry. More broadly, our findings corroborate existing evidence, both observational and experimental, that physical activity may have a role in the prevention and treatment of mental ill health in young people.(45) The association of physical activity with all outcomes studied here was consistent in direction and magnitude for reallocations across all other behavioural domains, suggesting that the benefit of physical activity is universal and not dependent upon a reduction in any specific behaviour or group of behaviours. It should be acknowledged, nonetheless, that the associations were small in magnitude, perhaps indicating that physical activity alone may not be sufficient to bring about clinically meaningful benefits in the specific health markers examined here. Further research that incorporates other domains of physical activity, such as intensity or activity type, alongside duration, will be beneficial in establishing the direction and magnitude of the association with mental health. This point notwithstanding, and given the plethora of other known benefits of physical activity, our findings support the promotion of physical activity as part of a wider package of measures for the benefit of emotional and behavioural health during adolescence.

Across the range of behavioural substitutions examined, simulated increases in electronic media use were consistently associated with lower self-esteem (higher Rosenberg scores), with only a small number of non-significant predicted differences. We also observed an association between electronic media use and increased depression symptomology but this was confined to a small number of specific behavioural substitutions. Our findings align with a previous analysis in this sweep of the MCS, which reported adverse associations of social media, internet use, TV viewing and video gaming with depressive symptomology and self-esteem.(46) These studies add to a growing body of research examining the link between mental health and

electronic media use, both traditional (eg TV viewing) and contemporary (eg social media).(47–50) At present, the evidence appears equivocal, with findings sensitive to variations in measurement methodology and analysis.(48) Given the cross-sectional nature of this analysis, findings should be interpreted with caution due to the possibility of reverse causality or bi-directional associations. Nonetheless, this study adds to the evidence on this topic by making explicit the inter-connectedness of behaviours within the daily time-budget and adopting an analytical framework that can accommodate this complexity. As the evidence evolves, this approach may become increasingly valuable as we move beyond the largely exploratory nature of existing studies towards research that can explicitly inform the targeting and content of public health policy and behaviour change interventions.

In our post-hoc analyses, we examined the shape of the association between physical activity, electronic media use and selected mental health markers, informed by the findings from our primary analysis (Figures 1 and 2). The size of the association between physical activity and MFQ, SDQ or Rosenberg scores varied according to whether our simulation added or removed time spent active. Specifically, predicted differences for a reduction in physical activity were approximately twice as large as those for an increase in physical activity; this was the case for all outcomes. This asymmetrical phenomenon has also been reported in other studies that have used compositional isotemporal substitution modelling, though it is not observed across all health outcomes (29,31) and was not evident in our models simulating multiple time reallocations for electronic media use. The reason for the disparity in effect sizes in our study is unclear, though it is appropriate to note that effect sizes remained small in all instances. It may reflect a plateau effect in the health benefits of physical activity, such that most benefit is gained from a moderate amount of activity and further increases above this level bring diminishing returns. This is consistent with the wider physical activity literature, particularly

in adults, but the median activity level in the current sample was approx. 40 min / day, well below the recommended 60 min / day for this population.(51) As more research using compositional analytical techniques emerges, it will be possible to describe and investigate this trend in greater depth and establish whether it is a reflection of biological, statistical or some other underlying process.

A key limitation of the current study is the cross-sectional design, which precludes any conclusions about the direction of the associations observed. The isotemporal substitution model mimics within-person time reallocations, but remains a between-person comparison due to there being only 1 observation (point of assessment) per person. The findings are most appropriately interpreted as showing small differences in mental health status across durations of daily time allocated to physical activity and/or electronic media use. Numerous mental health conditions have lethargy or lack of engagement or energy within their diagnostic criteria (52), therefore reverse causality remains a highly plausible explanation for the associations observed in this study. In general, predicted differences in the weekend analysis were greater than those in the weekday analysis, which may also support this interpretation. Specifically with regard to physical activity, a larger proportion of weekday activity is non-volitional in nature, shaped by the more structured nature of the school day and associated routines.(45) This is reflected in evidence that the age-related decline in physical activity is smaller for weekdays than at the weekend and that weekday activity is less susceptible to seasonal variation.(53,54) It follows that a reduction in physical activity associated with mental ill health is likely to be greater at the weekend than during the week. This may account, in part, for our observation of a stronger association between physical activity and socioemotional health at weekends versus during the week.

Strengths and limitations

Keys strengths of this study include the large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments. In addition, daily activity was characterised in detail using 24-h time-use diaries. Concurrent analysis of multiple behavioural exposures is appropriate given that behaviour change inherently entails the reallocation of time between different domains of behaviour. The following limitations are acknowledged. The cross-sectional design precludes causal inference and the possibility of reverse causality or bidirectional associations is acknowledged, as discussed above. The analytical sample differed in its social and anthropometric characteristics compared to those who did not provide sufficient data to be included in the analysis, which may limit generalisability of our findings. Statistical models were adjusted for known demographic and anthropometric confounders, but residual confounding is possible due to measurement error or omission of unknown confounding variables. In addition, we did not explore non-linear associations in the current analysis; this would be valuable in future research, particularly with regard to the sleep dimension of time use. Time-use diaries, like other self-report instruments, are susceptible to recall and social desirability bias. Lastly, our analysis is based upon a single day of assessment, which may not be representative of typical behaviour patterns. However, measurement days were selected at random and short periods of assessment are typical in studies that employ time-use diaries in order to limit participant burden.(36)

Conclusion

This study adds to existing evidence on the association between lifestyle behaviours and mental health in adolescents. Our finding that substituting time from behaviours representing a number of different domains into physical activity was associated with better socioemotional

health has important implications for intervention design, and should be examined further in longitudinal and experimental studies.

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Competing interests

None declared.

Author contributions

AJA conceived the research question, contributed to the statistical analysis and led on manuscript preparation. JRD conducted the statistical analysis, generated the figures and contributed to drafting segments of the methods and results. DD contributed to development of the research question and advised on the statistical analysis and interpretation of the results. EK contributed to preparation of the introduction and discussion sections and interpretation of results. LS contributed to development of the research question, the analytical approach and interpretation of results. RT contributed to development of the research question and interpretation of results. CR contributed to development of the research question, the analytical approach and interpretation of results. RJN contributed to development of the research question, the analytical approach and interpretation of results. SJF contributed to development of the research question, the analytical approach and interpretation of results. All authors provided critical feedback on drafts of the manuscript and approved the final manuscript.

Data sharing statement

The datasets analysed during the current study are available from the UK Data Service: beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

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Ethics Statement

MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786).

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Tables

Table 1. Participant characteristics (Weekday sample; values are mean (SD) unless stated otherwise).

	Weekdays (n=3485)
Demographics	
Sex (n (% male))	1561 (45)
Age (years)	13.8 (0.5)
BMI (kg/m^2)	21.2 (4.0)
Ethnicity (white, n (%))	2951 (85)
Family income (quintile, n (%))	
First (lowest)	327 (9)
Second	436 (13)
Third	686 (20)
Fourth	958 (28)
Fifth (highest)	1075 (31)
Country (n (%))	
England	2119 (61)
Scotland	506 (15)
Wales	486 (14)
Northern Ireland	374 (11)
Outcomes (median (IQR))	
SDQ	6.0 (3.0, 9.0)
MFQ	17.0 (14.0, 21.0)
RSE	10.0 (7.0, 10.0)

Weekend analysis, n=3468.

SD, standard deviation; BMI, body mass index; IQR, inter-quartile range; SDQ, Strengths and Difficulties Questionnaire; MFQ, Mood and Feelings Questionnaire; RSE, Rosenberg Self Esteem Scale

Table 2. Descriptive characteristics of time-use compositions (min/day)

	Raw composition Median (IQR)		Imputed composition Compositional mean*	
	Weekday	**Weekend**	**Weekday**	**Weekend**
Sleep	550 (500, 610)	630 (550, 690)	779.8	800.8
Physical activity	40 (0, 110)	30 (0, 120)	42.2	23.0
School-related	370 (0, 420)	NA	135.3	NA
Hobbies	90 (20, 200)	180 (60, 320)	85.2	144.9
Electronic media	170 (70, 290)	240 (120, 390)	161.8	226.0
Domestic	180 (120, 250)	200 (130, 300)	235.6	245.2

Weekday n=3485; Weekend n=3468
IQR, inter-quartile range; NA, not applicable
*Geometric mean adjusted to sum to 1440 min/day

Table 3. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekday analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

		Predicted difference		
Add 15 min…	**Remove 15 min…**	**SDQ**	**MFQ**	**Rosenberg**
Sleep	Physical activity	**0.0786 (0.0305, 0.1268)**	**0.0823 (0.0302, 0.1344)**	**0.0407 (0.0148, 0.0666)**
Sleep	School-related	0.0039 (-0.0080, 0.0158)	**-0.0149 (-0.0278, -0.0020)**	-0.0028 (-0.0092, 0.0036)
Sleep	Hobbies	-0.0028 (-0.0263, 0.0208)	-0.0195 (-0.0450, 0.0060)	0.0016 (-0.0111, 0.0143)
Sleep	Electronic media	-0.0016 (-0.0179, 0.0147)	**-0.0289 (-0.0466, -0.0112)**	**-0.0153 (-0.0241, -0.0065)**
Sleep	Domestic	0.0080 (-0.0128, 0.0289)	-0.0003 (-0.0229, 0.0223)	-0.0019 (-0.0131, 0.0094)
Physical activity	Sleep	**-0.0549 (-0.0891, -0.0207)**	**-0.0553 (-0.0923, -0.0183)**	**-0.0277 (-0.0461, -0.0093)**
Physical activity	School-related	**-0.0510 (-0.0846, -0.0173)**	**-0.0702 (-0.1066, -0.0337)**	**-0.0305 (-0.0486, -0.0124)**
Physical activity	Hobbies	**-0.0576 (-0.0950, -0.0202)**	**-0.0748 (-0.1154, -0.0343)**	**-0.0261 (-0.0463, -0.0060)**
Physical activity	Electronic media	**-0.0564 (-0.0900, -0.0229)**	**-0.0841 (-0.1205, -0.0477)**	**-0.0430 (-0.0610, -0.0249)**
Physical activity	Domestic	**-0.0469 (-0.0835, -0.0103)**	**-0.0556 (-0.0953, -0.016)**	**-0.0296 (-0.0493, -0.0099)**
School-related	Sleep	-0.0039 (-0.0151, 0.0073)	**0.0141 (0.0020, 0.0262)**	0.0026 (-0.0034, 0.0087)
School-related	Physical activity	**0.0747 (0.0275, 0.1220)**	**0.0963 (0.0452, 0.1475)**	**0.0433 (0.0179, 0.0687)**
School-related	Hobbies	-0.0066 (-0.0273, 0.0141)	-0.0055 (-0.0280, 0.0169)	0.0042 (-0.0069, 0.0154)
School-related	Electronic media	-0.0054 (-0.0195, 0.0087)	-0.0149 (-0.0302, 0.0005)	**-0.0127 (-0.0203, -0.0051)**
School-related	Domestic	0.0042 (-0.0142, 0.0225)	0.0137 (-0.0062, 0.0336)	0.0008 (-0.0091, 0.0106)
Hobbies	Sleep	0.0017 (-0.0186, 0.0221)	0.0174 (-0.0047, 0.0394)	-0.0011 (-0.0121, 0.0099)
Hobbies	Physical activity	**0.0804 (0.0318, 0.1291)**	**0.0996 (0.0469, 0.1523)**	**0.0395 (0.0134, 0.0657)**
Hobbies	School-related	0.0057 (-0.0122, 0.0236)	0.0024 (-0.0170, 0.0218)	-0.0039 (-0.0136, 0.0057)
Hobbies	Electronic media	0.0002 (-0.0195, 0.0198)	-0.0116 (-0.0329, 0.0097)	**-0.0165 (-0.0271, -0.0058)**
Hobbies	Domestic	0.0098 (-0.0150, 0.0346)	0.0170 (-0.0100, 0.0439)	-0.0030 (-0.0164, 0.0104)
Electronic media	Sleep	0.0011 (-0.0142, 0.0164)	**0.0270 (0.0104, 0.0437)**	**0.0141 (0.0058, 0.0224)**
Electronic media	Physical activity	**0.0798 (0.0330, 0.1266)**	**0.1094 (0.0587, 0.1600)**	**0.0548 (0.0297, 0.0800)**
Electronic media	School-related	0.0051 (-0.0086, 0.0188)	0.0121 (-0.0028, 0.027)	**0.0113 (0.0039, 0.0187)**
Electronic media	Hobbies	-0.0016 (-0.0235, 0.0204)	0.0074 (-0.0164, 0.0312)	**0.0157 (0.0038, 0.0275)**
Electronic media	Domestic	0.0092 (-0.0103, 0.0287)	**0.0267 (0.0056, 0.0478)**	**0.0122 (0.0017, 0.0227)**
Domestic	Sleep	-0.0078 (-0.0278, 0.0122)	0.0009 (-0.0208, 0.0226)	0.0018 (-0.0090, 0.0126)
Domestic	Physical activity	**0.0708 (0.0215, 0.1202)**	**0.0831 (0.0297, 0.1366)**	**0.0425 (0.0160, 0.0690)**
Domestic	School-related	-0.0038 (-0.0217, 0.0141)	-0.0140 (-0.0335, 0.0054)	-0.0010 (-0.0106, 0.0087)
Domestic	Hobbies	-0.0105 (-0.0373, 0.0164)	-0.0187 (-0.0478, 0.0104)	0.0034 (-0.0111, 0.0179)
Domestic	Electronic media	-0.0093 (-0.0287, 0.0101)	**-0.0280 (-0.0490, -0.0071)**	**-0.0135 (-0.0239, -0.0031)**

Table 4. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekend analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

Add 15 min…	Remove 15 min…	Predicted difference SDQ	MFQ	Rosenberg
Sleep	Physical activity	**0.2006 (0.1152, 0.2860)**	**0.1021 (0.0093, 0.1949)**	**0.077 (0.0316, 0.1223)**
Sleep	Hobbies	0.0117 (-0.0035, 0.0270)	0.0060 (-0.0106, 0.0226)	0.0039 (-0.0042, 0.0121)
Sleep	Electronic media	0.0048 (-0.0088, 0.0184)	-0.0097 (-0.0244, 0.0050)	**-0.0087 (-0.0160, -0.0014)**
Sleep	Domestic	-0.0008 (-0.0196, 0.0179)	0.0027 (-0.0176, 0.0230)	0.0004 (-0.0095, 0.0103)
Physical activity	Sleep	**-0.0959 (-0.1376, -0.0541)**	**-0.0513 (-0.0967, -0.0060)**	**-0.0381 (-0.0602, -0.0159)**
Physical activity	Hobbies	**-0.0843 (-0.1262, -0.0423)**	-0.0439 (-0.0896, 0.0017)	**-0.0333 (-0.0556, -0.0110)**
Physical activity	Electronic media	**-0.0911 (-0.1315, -0.0507)**	**-0.0596 (-0.1036, -0.0156)**	**-0.0459 (-0.0674, -0.0244)**
Physical activity	Domestic	**-0.0966 (-0.1419, -0.0513)**	-0.0473 (-0.0966, 0.0020)	**-0.0368 (-0.0609, -0.0127)**
Hobbies	Sleep	-0.0110 (-0.0252, 0.0032)	-0.0081 (-0.0236, 0.0074)	-0.0052 (-0.0128, 0.0024)
Hobbies	Physical activity	**0.1894 (0.1046, 0.2741)**	**0.0953 (0.0031, 0.1875)**	**0.0726 (0.0275, 0.1176)**
Hobbies	Electronic media	-0.0061 (-0.0191, 0.0069)	**-0.0164 (-0.0306, -0.0023)**	**-0.0131 (-0.0200, -0.0061)**
Hobbies	Domestic	-0.0117 (-0.0305, 0.0070)	-0.0041 (-0.0245, 0.0163)	-0.0039 (-0.0139, 0.0060)
Electronic media	Sleep	-0.0048 (-0.0179, 0.0083)	0.0064 (-0.0078, 0.0206)	0.0065 (-0.0005, 0.0135)
Electronic media	Physical activity	**0.1958 (0.1120, 0.2795)**	**0.1099 (0.0188, 0.2009)**	**0.0844 (0.0398, 0.1289)**
Electronic media	Hobbies	0.0070 (-0.0066, 0.0206)	0.0138 (-0.0010, 0.0285)	**0.0113 (0.0040, 0.0185)**
Electronic media	Domestic	-0.0055 (-0.0220, 0.0109)	0.0104 (-0.0075, 0.0283)	0.0077 (-0.0010, 0.0165)
Domestic	Sleep	0.0005 (-0.0175, 0.0185)	-0.0052 (-0.0247, 0.0143)	-0.0021 (-0.0116, 0.0075)
Domestic	Physical activity	**0.2012 (0.1134, 0.2890)**	**0.0982 (0.0028, 0.1937)**	**0.0757 (0.0291, 0.1224)**
Domestic	Hobbies	0.0123 (-0.0066, 0.0312)	0.0022 (-0.0184, 0.0227)	0.0027 (-0.0073, 0.0128)
Domestic	Electronic media	0.0053 (-0.0107, 0.0214)	-0.0135 (-0.0310, 0.0039)	**-0.0099 (-0.0184, -0.0014)**

Figure titles

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.

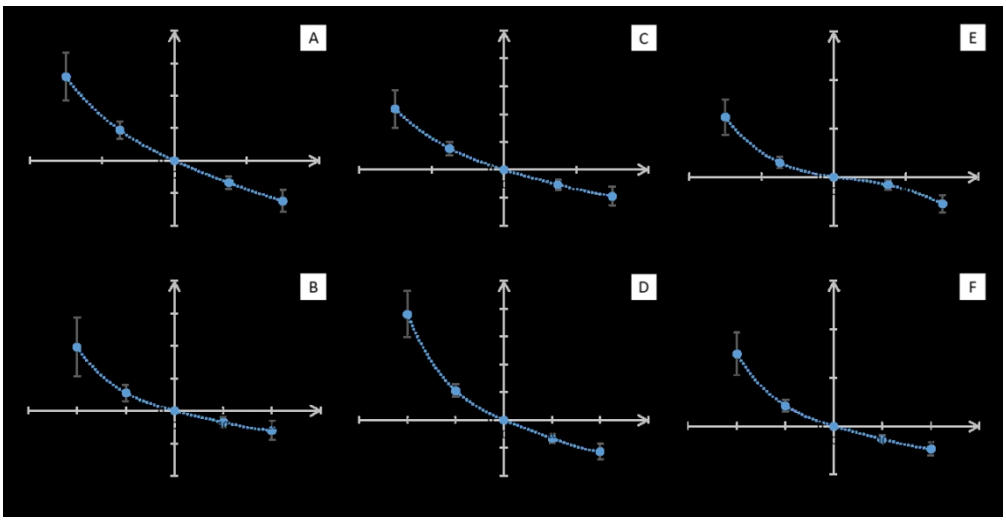

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.
Weekday data: panels A, C, E. Weekend data: panels B, D, F.
Descriptive statistics (median (inter-quartile range)): MFQ: 17.0 (14.0, 21.0); SDQ: 6.0 (3.0, 9.0); Rosenberg: 10.0 (7.0, 10.0)
Models adjusted for age, sex, body mass index and family income. Data points are predicted differences in the outcome ± standard error.
Interpretation: Points plotted to the left of the Y-axis denote predicted differences in the outcome for a specified reduction in physical activity. Points plotted to the right of the Y-axis denote predicted differences in the outcome for a specified increase in physical activity.

550x280mm (59 x 59 DPI)

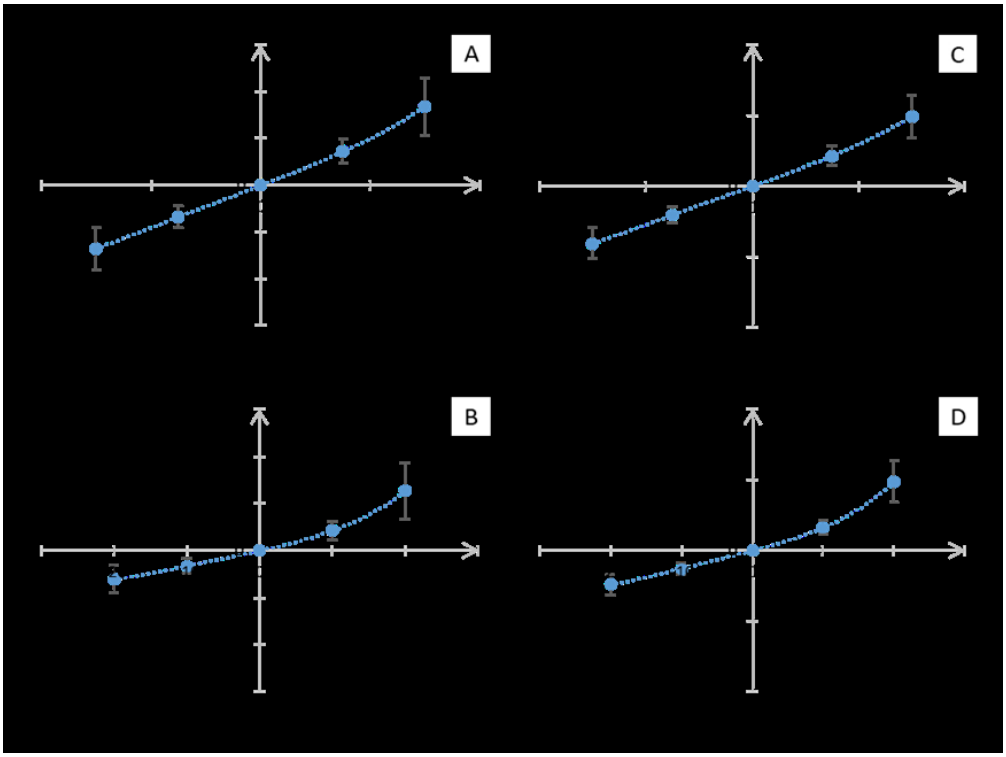

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.
Weekday data: panels A, C. Weekend data: panels B, D
Descriptive statistics (median (inter-quartile range)): MFQ: 17.0 (14.0, 21.0); RSE: 10.0 (7.0, 10.0)
Models adjusted for age, sex, body mass index and family income. Data points are predicted differences in the outcome ± standard error.
Interpretation: Points plotted to the left of the Y-axis denote predicted differences in the outcome for a specified reduction in electronic media. Points plotted to the right of the Y-axis denote predicted differences in the outcome for a specified increase in electronic media.

374x280mm (59 x 59 DPI)

Supplementary material

Table S1. Recoding of time-use diary entries into behavioural categories

Category name	Time-use diary: recorded activity
Sleep	Sleeping and resting
Physical activity	Cycling; Individual ball games and training (e.g. tennis, badminton); Jogging, running, walking, hiking; Team ball games and training (e.g. football, hockey); Swimming and other water sports; Other exercise and sports, dancing, keeping fit, skiing, gymnastics; Travel by physically active means (walk, bike etc.)
School-related activities	Homework; In class; School breaks; School clubs; Detention
Hobbies and socialising	Attending live sporting events; Cinema, theatre, performance, gig etc.; Exhibition, museum, library, other cultural events; Shopping (including window shopping, hanging out at shopping centre); Speaking, socialising face-to-face; Volunteering; Religious activities (including going to places of worship, praying etc.); Did nothing, just relaxing, bored, waiting; Hobbies, arts and crafts, musical activities, writing stories, poetry etc.; Reading (not for school); Other activities not listed
Electronic media	Speaking on the phone (including Skype, video calls); Answering emails, instant messaging, texting; Browsing and updating social networking sites (e.g. Twitter, Facebook, BBM, Snapchat); General internet browsing, programming (not time on social networking sites); Listening to music, radio, iPod, other audio content; Playing electronic games and Apps; Watch TV, DVDs, downloaded videos
Domestic, personal care and work-related activities	Personal care (including taking a shower/bath, grooming, getting dressed etc.); Paid work (including paid babysitting and paid work for the family); Unpaid work for family or other non-household members (e.g. help in family business); Cooking, cleaning, and shopping for the household; Fixing things around the house, fixing bike, gardening; Looking after brothers, sisters, other children in the household; Looking after parent or other adult in the households (medical or personal care); Pet care; Eating or drinking in a restaurant or café; Eating a meal; Eating a snack or having a drink; Travel by bus, taxi, tube, plane; Travel by car, van (including vehicles owned by friends and family)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6-9*
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	na
		(*c*) Explain how missing data were addressed	na
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	na
		(*e*) Describe any sensitivity analyses	na
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	na
		(c) Consider use of a flow diagram	na
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	11
Outcome data	15*	Report numbers of outcome events or summary measures	27

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	29-30
		(*b*) Report category boundaries when continuous variables were categorized	na
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	na
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10/figures
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Adolescent time-use and mental health: A cross-sectional, compositional analysis in the Millennium Cohort Study

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Word count: 4366

Abstract

Objectives

To examine the association of 24-hour time-use compositions with mental health in a large, geographically diverse sample of UK adolescents.

Design

Cross-sectional, secondary data analysis.

Setting

Millennium Cohort Study (sixth survey), a UK-based prospective birth cohort.

Participants

Data were available from 4642 adolescents aged 14 years. Analytical samples for weekday and weekend analyses were n=3485 and n=3468, respectively (45% boys, 85% White ethnicity).

Primary and secondary outcome measures

Primary outcome measures were the Strengths and Difficulties Questionnaire (SDQ; socioemotional behaviour), Mood and Feelings Questionnaire (MFQ; depressive symptoms) and Rosenberg Self-Esteem Scale (RSE; self-esteem). Behavioural exposure data was derived from 24-hour time use diaries.

Results

On weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Predicted differences in SDQ, MFQ and RSE were statistically significant for all models (weekday and weekend) that simulated the addition or removal of 15 minutes physical activity, with an increase in activity being associated with improved mental health and vice versa. Predicted differences in RSE were also significant for simulated changes

in electronic media use; an increase in electronic media use was associated with reduced self-esteem.

Conclusions

Small, but consistent, associations were observed between physical activity, electronic media use and selected markers of mental health. Findings support the delivery of physical activity interventions to promote mental health during adolescence, without the need to specifically target or protect time spent in other activities.

Keywords

Adolescence; Time-use; Physical activity; Sleep; Depression; Mental health; CoDA

Article summary: Strengths and limitations of the study

Strengths of this study:

- The large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments.
- Use of compositional data analysis of multiple behavioural exposures, which reflects that behaviour change inherently entails the reallocation of time between different domains of behaviour.

Limitations of this study:

- The cross-sectional design which precludes causal inference.
- The susceptibility of time-use diaries to recall and social desirability bias.
- Analyses were based upon a single day of assessment, which may not have been representative of typical behaviour patterns.

Introduction

The global adolescent population, estimated at 1.2 billion, is now larger than at any point in our history and represents approximately 16% of the global population.(1) Accordingly, research and policy activity to support the biological, social, emotional and behavioural development of this population has grown substantially in recent years.(2–4) Part of this wider movement has been a particular focus on mental health during adolescence, consistent with evidence that first diagnosis of a mental disorder often occurs during this period.(5–7) Surveillance data on adolescent mental health remains limited, but there is evidence of increasing prevalence of some conditions in recent years and substantial growth in demand for counselling and specialist mental health services.(8–11) Recent data from the Mental Health of Children and Young People survey, for example, indicated that between 1999-2017 the prevalence of having an emotional disorder (including anxiety and depression) increased from 4.3% to 5.5% in children aged 5-15 years.(12) From the same survey, cross-sectional data collected in 2017 showed that just over 10% of children in this age group had low self-esteem.(12) Interpretation of secular trend data on the prevalence of mental disorders in young people is complicated by a host of methodological, diagnostic and social factors, but it remains clear that a considerable proportion of the child and adolescent population experience mental ill health. A clearer understanding of factors that might predispose or protect children from mental health disorders will help in the development of preventative policies and practice.

A growing body of evidence indicates a role for health behaviours, such as sleep and physical activity, in the prevention of mental health disorders.(13–18) A recent US study, for example, found that over 1 year, sleep duration of less than 6 hours a night was associated with increased risk of anxiety disorders in adolescents aged 11-17 years.(16) This study adjusted for selected social and demographic covariates, but did not account for other health behaviours, such as

physical activity or sedentary behaviour. Given the finite time available each day, an increase in any behaviour (e.g. sleep) can only be achieved through a concomitant reduction in time allocated to one or more other activities (e.g. TV viewing). The nature of such reallocations has potentially important implications for health. The mental health benefits of increasing sleep duration, for example, may not be realised if they come at the expense of reduced physical activity, which is also positively associated with some mental health outcomes. Greater recognition of the complex inter-play between multiple behaviours and health has led to the adoption of sophisticated, and more appropriate, statistical methods and the establishment of new research networks to take the field forward.(19–24) This movement is reflected in new public health recommendations that provide guidance on the optimal composition of the entire (24h) day, rather than focussing on a single behaviour, such as physical activity or sleep.(25,26)

Previous research into the association of time-use composition with mental health in young people has focussed predominantly on health-related quality of life, captured within global measures or social / emotional health sub-scales.(27–29) Studies using cluster analysis to identify subgroups with distinct behavioural profiles have indicated that a lifestyle characterised by low physical activity and/or moderate to high sedentary behaviour was associated with poorer quality of life.(28,30) In contrast, Fairclough et al. (29) observed no differences in psychosocial quality of life for simulated substitutions between accelerometer-assessed sitting, light and moderate to vigorous intensity physical activity (MVPA) during the school day. One study to date has examined the association of time use with proxy-reported Strengths and Difficulties Questionnaire scores, observing that substituting time into MVPA from sleep, light intensity activity or sedentary time was associated with better mental health.(31) The relative lack of previous research on this topic, combined with the conflicting findings of what little evidence does exist, highlights the need for further research in this field.

Therefore, the objective of this study was to examine the cross-sectional associations between adolescents' time-use composition and selected markers of mental health and well-being.

Method

Sample and data collection

Data are from the Millennium Cohort Study (MCS), an observational cohort study of the social, economic, and health related circumstances of children born in the UK between September 2000 and January 2002.(32) The MCS is nationally representative and 18 552 families (18 818 children) were recruited in the first sweep. The sample was augmented with a further 701 children (692 families) born in the same period who had been missed previously, taking the total sample to 19,519. To date, there have been six waves of assessment (age nine months, three, five, seven, eleven, and fourteen years). This cross-sectional analysis uses data from the sixth wave of assessment (MCS6; data collection: January 2015-April 2016), conducted when participants were aged 14 years. 15 415 families were contacted for participation in MCS6; 11 884 participants from 11 726 families provided partial or complete data. MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786). The current study uses anonymised, publicly available data, obtained from the UK Data Service: https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

Patient and public involvement

The research question for this analysis was formulated by the authors (no patient involved). The content and methodology of the sixth sweep of MCS was informed by extensive development work to ensure relevance, participation and engagement amongst participants and their families. Full details are provided in the MCS sixth sweep technical report.(33)

Assessment of time-use

All participants from Wales, Scotland and Northern Ireland and approximately 80% of participants from England were invited to complete time-use diaries for two 24-hour periods (One week day and one weekend day. Days were selected at random by computer assisted personal interview (CAPI) software). The English sample was restricted due to limitations on the number of activity monitors available, which were deployed alongside the time-use diary. Only diary data are used for the current analysis. The diary was available in three formats: online (for completion on a desktop, laptop or netbook); using an App (for completion on a mobile phone or tablet); or on paper. Sixty-four percent of participants selected the App diary format, 29% used the online version and 7% the paper diary.(33)

For each day of assessment, participants recorded what they did from 4am to 4am the following day in 10-min timeslots. Participants also recorded where they were, who they were with and how much they liked each activity but these data are not considered here. The primary activity for each time-slot was selected from a list of 44 pre-defined activity codes, nested within 12 categories. Categories included 'sleep and personal care', 'school, homework and education', 'social time and family time' and 'Internet, TV and digital media'.(34) Due to the differing demands / opportunities afforded by being at school during the week, weekday and weekend data were analysed separately. For the weekday data, activity codes were collapsed into six mutually exclusive activity sets (see supplementary material): (1) Sleep; (2) Physical activity; (3) School-related activities; (4) Hobbies and socialising; (5) Electronic media; (6) Domestic, personal care and work-related activities. Weekend data were collapsed into five sets, omitting the school-related activities group. The five / six sets capture the entirety of participant's daily time use (24 h or 1440 min). Note that the sleep component represented all sleep occurring

between 4am and 4am. Therefore, it does not necessarily represent a full overnight sleep and may incorporate naps taken during the day.

Diaries with missing data (10 min slots with no activity indicated) were excluded from the analysis, as were those with no entries for 'sleep' or 'Domestic, personal care and work-related activities' (which included eating and getting dressed); these were deemed to be unreliable accounts of a complete day's activity. Zero values in any of the activity sets would preclude the use of compositional analysis, as log ratio coordinates cannot be applied to zero values.(35) Consistent with previous work using time-use data, zeros were replaced with small values of less than 10 min, drawing time from the other activity sets.(35,36)

Mental health

Three outcomes related to adolescent mental health were used in the analysis. Socioemotional behaviour was assessed using the Strengths and Difficulties Questionnaire (SDQ, version P4-17), completed by the parent or guardian.(37) The SDQ comprises 25-items relating to five subscales of five items each (Difficulties subscales: emotional problems, conduct problems, hyperactivity/inattention, peer relationship problems. Strengths subscale: prosocial behaviour). Answers are provided with reference to the previous six months and response options are 'Not true', 'Somewhat true' and 'Certainly true'. Example items: 'Often has temper tantrums or hot tempers'; 'Often unhappy, down-hearted or tearful'. A total difficulties score, derived as the sum of responses on the four difficulties subscales, was used in the analysis, consistent with previous research.(38,39) Higher scores indicate greater socioemotional difficulty. Depressive symptomology was assessed using the short-version (13-item) Mood and Feelings questionnaire (MFQ), completed by the participant.(40) Answers are given with reference to the previous two weeks. Response options are 'Not true', 'Sometimes' and 'True'.

Example items: 'I felt miserable or unhappy'; 'I didn't enjoy anything at all'. MFQ is scored as the sum of responses to all items, with higher scores suggesting more severe depressive symptoms. Global self-worth was self-reported using the five positive items from the Rosenberg Self Esteem Scale (RSE).(41) Response options are 'Strongly agree', 'Agree', 'Disagree' and 'Strongly disagree'. Example item: 'On the whole, I am satisfied with myself'. A total score, derived as the sum of responses to all items, was used in the analysis. For consistency with other outcomes, responses were recoded such that higher scores were indicative of lower self-esteem.

Covariates

Covariates were selected on the basis of previous research indicating that they may confound associations between exposure and outcome variables used in the current study.(15,16,31) The following constructs were selected: age, sex, adiposity (measured height and weight used to derive body mass index (BMI) category (42): underweight / normal, overweight, or obese) and equivalised family income (parent reported: <£20,800 annually, £20,800 to £31,300 annually, >£31,200 annually, missing or do not know).

Statistical analysis

Analyses were conducted using R open-source software (www.r-project.org) and the compositions and zCompositions packages for the analysis of compositional data (version 1.40-2).(43) Demographic and anthropometric characteristics of the analytical sample are presented as frequencies and percentages, means with standard deviation or medians with interquartile range as appropriate. Characteristics of those included / excluded from the analytical sample were compared using Student's t tests or chi-squared tests. Time (min/day) spent in each behavioural set is summarised for the raw time-use data (that which retained zero

values) using median and interquartile range. For the imputed time-use compositions (those in which zeros were replaced with small non-zero values, as described above), time in each behavioural set is presented as compositional means (geometric mean of each behaviour, linearly adjusted to collectively sum to 1440 minutes). Summary statistics are presented separately for week and weekend days. Due to the distribution of the health outcome data, associations between time use composition and mental health markers were examined using negative binomial regression.(44) Time-use compositions were expressed as sets of isometric log ratio (ILR) coordinates (R compositions, default ilr() transformation). The five and six part compositions for weekend and weekday time-use were expressed via four and five sets of ILR coordinates respectively. All models were adjusted for age, sex, weight status and family income. In preliminary analyses, models were additionally adjusted for ethnicity and maternal education. However, these variables demonstrated weak, non-significant associations with the outcomes and were subsequently dropped in the interests of model parsimony. Models were checked to ensure assumptions were not violated. Following procedures outlined in Dumuid et al. (19), we subsequently conducted compositional isotemporal substitution analyses to model the influence of reallocating fixed time durations (15 min) between pairs of behaviour sets on each of our mental health outcomes. Models were adjusted for the same covariates as described above and assessed for compliance with relevant statistical assumptions. When this model is subsequently used (in time reallocation of diary activities) to predict new values of the outcome, the predicted data are in log units, which makes it incompatible for mathematical operators such as subtraction to be used for estimation of differences. It is therefore necessary to transform the predicted values back into the original units (by taking the exponential) before estimating the differences in outcome due to time reallocation. In post-hoc analyses, we explored the shape of the association between behaviour reallocations of differing duration and selected outcomes. Specifically, we modelled predicted differences in SDQ, MFQ and

Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between physical activity and the mean of all remaining behavioural sets. In addition, we modelled predicted differences in MFQ and Rosenberg scores for reallocations of -30 to +30 min (15 min increments; weekday data) or -20 to +20 min (10 min increments; weekend data) between electronic media and the mean of all remaining behavioural sets. Sets were combined for this analysis as the associations observed for paired reallocations between physical activity/electronic media and individual sets were highly consistent in direction and magnitude. The Generalised Linear Models that are used in the analysis, take the log of the outcome data before performing a regression with the explanatory variables. Regression estimates (and associated standard errors) are presented graphically for ease of interpretation.

Results

Data were available from 8625 diaries (person-days), obtained from 4642 participants. Of these, 1679 diaries were excluded due to missing data or non-reporting of sleep or domestic/personal care activities. The analytical samples for weekday and weekend analyses were n=3485 (29.3% of MCS6 participants) and n=3468 (29.2% of MCS6 participants) respectively. Characteristics of participants included in the weekday analyses are presented in Table 1. Overall, the weekday sample was 13.8 (0.5) years of age, 45% male and predominantly White ethnicity (85%). There were no differences in the demographic or anthropometric characteristics of the weekday and weekend analytical samples. Compared to those whose diaries did not meet our inclusion criteria (1679 diaries from n=1238 participants) the analytical sample on average had a lower BMI (Inc: 21.2, Exc: 21.6; P=0.014), were more likely to be White ethnicity (Inc: 85% White, Exc: 76% White; P<0.001) and come from families with higher income (Inc: 31% highest quintile, Exc: 19% highest quintile; P<0.001).

TABLE 1 HERE

Time spent in each of the behavioural sets is presented in Table 2. Compositional means indicated that on weekdays, participants spent approximately 54% of their time in sleep, 3% in physical activity, 9% in school-related activities, 6% in hobbies, 11% using electronic media and 16% in domestic activities. Corresponding figures for the weekend were: 56% (sleep), 2% (physical activity), 10% (hobbies), 16% (electronic media) and 17% (domestic).

TABLE 2 HERE

Preliminary analyses indicated that after adjustment for age, sex, weight status and family income, the isometric log ratio coordinates for time-use composition were significantly associated with each of the outcome variables (P for isometric log ratio coordinates: SDQ, weekday $P=0.018$, weekend $P<0.001$; MFQ, weekday $P<0.001$, weekend $P=0.023$; RSE weekday $P<0.001$, weekend $P<0.001$). Compositional isotemporal substitution analyses were conducted to simulate the association with each outcome of reallocating 15 min between pairs of behavioural sets; results are presented in Table 3 (weekdays) and Table 4 (weekend) respectively.

For all three outcomes, models that simulated the addition or removal of time from physical activity were statistically significant, with the addition of physical activity being associated with improved mental health and vice versa. The only exception to this trend was for MFQ and the substitution of time from domestic activities or hobbies into physical activity at the weekend, wherein the upper bound of the 95% confidence interval marginally overlapped zero

in both cases. Predicted differences were generally larger for the weekend analysis than the weekday analysis, but remained small at less than 0.3 of a unit of the outcome in all instances.

For the SDQ outcome, there were no statistically significant predicted differences for reallocations that did not include physical activity. For the Rosenberg outcome, all reallocations that included electronic media were statistically significant in the weekday data, with a reduction in time spent using electronic media associated with better mental health. This pattern was partially repeated in the weekend data, except that models simulating the reallocation of time from sleep and domestic activities into electronic media were non-significant. All predicted differences were less than 0.1 units. For MFQ, and in the weekday data only, reallocations between electronic media/sleep and electronic media/domestic activities were statistically significant, with a reduction in time spent using electronic media associated with better mental health.

TABLES 3 AND 4 HERE

Predicted differences in SDQ, MFQ and Rosenberg scores for a range of time reallocations to / from physical activity are presented in Figure 1. Consistent with the main analysis, figures show that simulated increases in physical activity were associated with reduced scores (negative predicted difference; better health) on each of the outcomes, whilst simulated reductions in physical activity were associated with higher outcome scores (positive predicted difference; worse health). In all scenarios, there was evidence of a curvilinear association, such that a modelled reduction in physical activity produced larger predicted differences in the outcomes than a modelled increase in physical activity of comparable duration. Predicted differences in MFQ and Rosenberg scores for a range of time reallocations to / from electronic

media use are presented in Figure 2. Simulated increases in electronic media use were associated with increased scores (positive predicted difference; worse health) on each of the outcomes, whilst simulated reductions in electronic media use were associated with lower outcome scores (negative predicted difference; better health). In the weekday data (Figure 2, panels A and C), the shape of the association appeared approximately linear throughout the range of reallocations tested. In the weekend data (Figure 2, panels B and D), there was evidence of slight deviation from linearity, wherein a modelled increase in electronic media use produced larger predicted differences in the outcomes than a modelled reduction in electronic media use of comparable duration.

FIGURES 1 AND 2 HERE

Discussion

In this large sample of UK adolescents, we found that simulated increases in physical activity were beneficially associated with socioemotional health, whilst comparable increases in electronic media use were adversely associated with depressive symptoms and self-esteem. Associations were largely consistent between week and weekend days, but remained small in magnitude across all behaviours and outcomes. Findings highlight a potential role for physical activity in supporting the socioemotional health of adolescents and provide insight into the possible content and timing of behaviour change interventions.

A simulated reallocation of 15 min from sleep, hobbies, electronic media use, school-related or domestic activities to physical activity was associated with better socioemotional health, reduced depression symptomology and improved self-esteem. This is consistent with previous

research by Carson et al (31) who modelled the impact on SDQ scores of substituting time between sleep, sedentary time, light and moderate to vigorous intensity physical activity measured by accelerometry. More broadly, our findings corroborate existing evidence, both observational and experimental, that physical activity may have a role in the prevention and treatment of mental ill health in young people.(45) The association of physical activity with all outcomes studied here was consistent in direction and magnitude for reallocations across all other behavioural domains, suggesting that the benefit of physical activity is universal and not dependent upon a reduction in any specific behaviour or group of behaviours. It should be acknowledged, nonetheless, that the associations were small in magnitude, perhaps indicating that physical activity alone may not be sufficient to bring about clinically meaningful benefits in the specific health markers examined here. Further research that incorporates other domains of physical activity, such as intensity or activity type, alongside duration, will be beneficial in establishing the direction and magnitude of the association with mental health. This point notwithstanding, and given the plethora of other known benefits of physical activity, our findings support the promotion of physical activity as part of a wider package of measures for the benefit of emotional and behavioural health during adolescence.

Across the range of behavioural substitutions examined, simulated increases in electronic media use were consistently associated with lower self-esteem (higher Rosenberg scores), with only a small number of non-significant predicted differences. We also observed an association between electronic media use and increased depression symptomology but this was confined to a small number of specific behavioural substitutions. Our findings align with a previous analysis in this sweep of the MCS, which reported adverse associations of social media, internet use, TV viewing and video gaming with depressive symptomology and self-esteem.(46) These studies add to a growing body of research examining the link between mental health and

electronic media use, both traditional (eg TV viewing) and contemporary (eg social media).(47–50) At present, the evidence appears equivocal, with findings sensitive to variations in measurement methodology and analysis.(48) Given the cross-sectional nature of this analysis, findings should be interpreted with caution due to the possibility of reverse causality or bi-directional associations. Nonetheless, this study adds to the evidence on this topic by making explicit the inter-connectedness of behaviours within the daily time-budget and adopting an analytical framework that can accommodate this complexity. As the evidence evolves, this approach may become increasingly valuable as we move beyond the largely exploratory nature of existing studies towards research that can explicitly inform the targeting and content of public health policy and behaviour change interventions.

In our post-hoc analyses, we examined the shape of the association between physical activity, electronic media use and selected mental health markers, informed by the findings from our primary analysis (Figures 1 and 2). The size of the association between physical activity and MFQ, SDQ or Rosenberg scores varied according to whether our simulation added or removed time spent active. Specifically, predicted differences for a reduction in physical activity were approximately twice as large as those for an increase in physical activity; this was the case for all outcomes. This asymmetrical phenomenon has also been reported in other studies that have used compositional isotemporal substitution modelling, though it is not observed across all health outcomes (29,31) and was not evident in our models simulating multiple time reallocations for electronic media use. The reason for the disparity in effect sizes in our study is unclear, though it is appropriate to note that effect sizes remained small in all instances. It may reflect a plateau effect in the health benefits of physical activity, such that most benefit is gained from a moderate amount of activity and further increases above this level bring diminishing returns. This is consistent with the wider physical activity literature, particularly

in adults, but the median activity level in the current sample was approx. 40 min / day, well below the recommended 60 min / day for this population.(51) As more research using compositional analytical techniques emerges, it will be possible to describe and investigate this trend in greater depth and establish whether it is a reflection of biological, statistical or some other underlying process.

A key limitation of the current study is the cross-sectional design, which precludes any conclusions about the direction of the associations observed. The isotemporal substitution model mimics within-person time reallocations, but remains a between-person comparison due to there being only 1 observation (point of assessment) per person. The findings are most appropriately interpreted as showing small differences in mental health status across durations of daily time allocated to physical activity and/or electronic media use. Numerous mental health conditions have lethargy or lack of engagement or energy within their diagnostic criteria (52), therefore reverse causality remains a highly plausible explanation for the associations observed in this study. In general, predicted differences in the weekend analysis were greater than those in the weekday analysis, which may also support this interpretation. Specifically with regard to physical activity, a larger proportion of weekday activity is non-volitional in nature, shaped by the more structured nature of the school day and associated routines.(45) This is reflected in evidence that the age-related decline in physical activity is smaller for weekdays than at the weekend and that weekday activity is less susceptible to seasonal variation.(53,54) It follows that a reduction in physical activity associated with mental ill health is likely to be greater at the weekend than during the week. This may account, in part, for our observation of a stronger association between physical activity and socioemotional health at weekends versus during the week.

Strengths and limitations

Keys strengths of this study include the large, geographically and demographically diverse sample and the assessment of multiple mental health outcomes using well-established, widely tested instruments. In addition, daily activity was characterised in detail using 24-h time-use diaries. Concurrent analysis of multiple behavioural exposures is appropriate given that behaviour change inherently entails the reallocation of time between different domains of behaviour. The following limitations are acknowledged. The cross-sectional design precludes causal inference and the possibility of reverse causality or bidirectional associations is acknowledged, as discussed above. The analytical sample differed in its social and anthropometric characteristics compared to those who did not provide sufficient data to be included in the analysis, which may limit generalisability of our findings. Statistical models were adjusted for known demographic and anthropometric confounders, but residual confounding is possible due to measurement error or omission of unknown confounding variables. In addition, we did not explore non-linear associations in the current analysis; this would be valuable in future research, particularly with regard to the sleep dimension of time use. Time-use diaries, like other self-report instruments, are susceptible to recall and social desirability bias. Lastly, our analysis is based upon a single day of assessment, which may not be representative of typical behaviour patterns. However, measurement days were selected at random and short periods of assessment are typical in studies that employ time-use diaries in order to limit participant burden.(36)

Conclusion

This study adds to existing evidence on the association between lifestyle behaviours and mental health in adolescents. Our finding that substituting time from behaviours representing a number of different domains into physical activity was associated with better socioemotional

health has important implications for intervention design, and should be examined further in longitudinal and experimental studies.

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Competing interests

None declared.

Author contributions

AJA conceived the research question, contributed to the statistical analysis and led on manuscript preparation. JRD conducted the statistical analysis, generated the figures and contributed to drafting segments of the methods and results. DD contributed to development of the research question and advised on the statistical analysis and interpretation of the results. EK contributed to preparation of the introduction and discussion sections and interpretation of results. LS contributed to development of the research question, the analytical approach and interpretation of results. RT contributed to development of the research question and interpretation of results. CR contributed to development of the research question, the analytical approach and interpretation of results. RJN contributed to development of the research question, the analytical approach and interpretation of results. SJF contributed to development of the research question, the analytical approach and interpretation of results. All authors provided critical feedback on drafts of the manuscript and approved the final manuscript.

Data sharing statement

The datasets analysed during the current study are available from the UK Data Service: beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000031

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Ethics Statement

MCS6 was approved by the National Research Ethics Service (NRES) Research Ethics Committee (REC) London – Central (REC ref: 13/LO/1786).

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Tables

Table 1. Participant characteristics (Weekday sample; values are mean (SD) unless stated otherwise).

	Weekdays (n=3485)
Demographics	
Sex (n (% male))	1561 (45)
Age (years)	13.8 (0.5)
BMI (kg/m^2)	21.2 (4.0)
Ethnicity (white, n (%))	2951 (85)
Family income (quintile, n (%))	
First (lowest)	327 (9)
Second	436 (13)
Third	686 (20)
Fourth	958 (28)
Fifth (highest)	1075 (31)
Country (n (%))	
England	2119 (61)
Scotland	506 (15)
Wales	486 (14)
Northern Ireland	374 (11)
Outcomes (median (IQR))	
SDQ	6.0 (3.0, 9.0)
MFQ	17.0 (14.0, 21.0)
RSE	10.0 (7.0, 10.0)

Weekend analysis, n=3468.

SD, standard deviation; BMI, body mass index; IQR, inter-quartile range; SDQ, Strengths and Difficulties Questionnaire; MFQ, Mood and Feelings Questionnaire; RSE, Rosenberg Self Esteem Scale

Table 2. Descriptive characteristics of time-use compositions (min/day)

	Raw composition Median (IQR)		Imputed composition Compositional mean*	
	Weekday	**Weekend**	**Weekday**	**Weekend**
Sleep	550 (500, 610)	630 (550, 690)	779.8	800.8
Physical activity	40 (0, 110)	30 (0, 120)	42.2	23.0
School-related	370 (0, 420)	NA	135.3	NA
Hobbies	90 (20, 200)	180 (60, 320)	85.2	144.9
Electronic media	170 (70, 290)	240 (120, 390)	161.8	226.0
Domestic	180 (120, 250)	200 (130, 300)	235.6	245.2

Weekday n=3485; Weekend n=3468
IQR, inter-quartile range; NA, not applicable
*Geometric mean adjusted to sum to 1440 min/day

Table 3. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekday analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

		Predicted difference		
Add 15 min…	**Remove 15 min…**	**SDQ**	**MFQ**	**Rosenberg**
Sleep	Physical activity	**0.0786 (0.0305, 0.1268)**	**0.0823 (0.0302, 0.1344)**	**0.0407 (0.0148, 0.0666)**
Sleep	School-related	0.0039 (-0.0080, 0.0158)	**-0.0149 (-0.0278, -0.0020)**	-0.0028 (-0.0092, 0.0036)
Sleep	Hobbies	-0.0028 (-0.0263, 0.0208)	-0.0195 (-0.0450, 0.0060)	0.0016 (-0.0111, 0.0143)
Sleep	Electronic media	-0.0016 (-0.0179, 0.0147)	**-0.0289 (-0.0466, -0.0112)**	**-0.0153 (-0.0241, -0.0065)**
Sleep	Domestic	0.0080 (-0.0128, 0.0289)	-0.0003 (-0.0229, 0.0223)	-0.0019 (-0.0131, 0.0094)
Physical activity	Sleep	**-0.0549 (-0.0891, -0.0207)**	**-0.0553 (-0.0923, -0.0183)**	**-0.0277 (-0.0461, -0.0093)**
Physical activity	School-related	**-0.0510 (-0.0846, -0.0173)**	**-0.0702 (-0.1066, -0.0337)**	**-0.0305 (-0.0486, -0.0124)**
Physical activity	Hobbies	**-0.0576 (-0.0950, -0.0202)**	**-0.0748 (-0.1154, -0.0343)**	**-0.0261 (-0.0463, -0.0060)**
Physical activity	Electronic media	**-0.0564 (-0.0900, -0.0229)**	**-0.0841 (-0.1205, -0.0477)**	**-0.0430 (-0.0610, -0.0249)**
Physical activity	Domestic	**-0.0469 (-0.0835, -0.0103)**	**-0.0556 (-0.0953, -0.016)**	**-0.0296 (-0.0493, -0.0099)**
School-related	Sleep	-0.0039 (-0.0151, 0.0073)	**0.0141 (0.0020, 0.0262)**	0.0026 (-0.0034, 0.0087)
School-related	Physical activity	**0.0747 (0.0275, 0.1220)**	**0.0963 (0.0452, 0.1475)**	**0.0433 (0.0179, 0.0687)**
School-related	Hobbies	-0.0066 (-0.0273, 0.0141)	-0.0055 (-0.0280, 0.0169)	0.0042 (-0.0069, 0.0154)
School-related	Electronic media	-0.0054 (-0.0195, 0.0087)	-0.0149 (-0.0302, 0.0005)	**-0.0127 (-0.0203, -0.0051)**
School-related	Domestic	0.0042 (-0.0142, 0.0225)	0.0137 (-0.0062, 0.0336)	0.0008 (-0.0091, 0.0106)
Hobbies	Sleep	0.0017 (-0.0186, 0.0221)	0.0174 (-0.0047, 0.0394)	-0.0011 (-0.0121, 0.0099)
Hobbies	Physical activity	**0.0804 (0.0318, 0.1291)**	**0.0996 (0.0469, 0.1523)**	**0.0395 (0.0134, 0.0657)**
Hobbies	School-related	0.0057 (-0.0122, 0.0236)	0.0024 (-0.0170, 0.0218)	-0.0039 (-0.0136, 0.0057)
Hobbies	Electronic media	0.0002 (-0.0195, 0.0198)	-0.0116 (-0.0329, 0.0097)	**-0.0165 (-0.0271, -0.0058)**
Hobbies	Domestic	0.0098 (-0.0150, 0.0346)	0.0170 (-0.0100, 0.0439)	-0.0030 (-0.0164, 0.0104)
Electronic media	Sleep	0.0011 (-0.0142, 0.0164)	**0.0270 (0.0104, 0.0437)**	**0.0141 (0.0058, 0.0224)**
Electronic media	Physical activity	**0.0798 (0.0330, 0.1266)**	**0.1094 (0.0587, 0.1600)**	**0.0548 (0.0297, 0.0800)**
Electronic media	School-related	0.0051 (-0.0086, 0.0188)	0.0121 (-0.0028, 0.027)	**0.0113 (0.0039, 0.0187)**
Electronic media	Hobbies	-0.0016 (-0.0235, 0.0204)	0.0074 (-0.0164, 0.0312)	**0.0157 (0.0038, 0.0275)**
Electronic media	Domestic	0.0092 (-0.0103, 0.0287)	**0.0267 (0.0056, 0.0478)**	**0.0122 (0.0017, 0.0227)**
Domestic	Sleep	-0.0078 (-0.0278, 0.0122)	0.0009 (-0.0208, 0.0226)	0.0018 (-0.0090, 0.0126)
Domestic	Physical activity	**0.0708 (0.0215, 0.1202)**	**0.0831 (0.0297, 0.1366)**	**0.0425 (0.0160, 0.0690)**
Domestic	School-related	-0.0038 (-0.0217, 0.0141)	-0.0140 (-0.0335, 0.0054)	-0.0010 (-0.0106, 0.0087)
Domestic	Hobbies	-0.0105 (-0.0373, 0.0164)	-0.0187 (-0.0478, 0.0104)	0.0034 (-0.0111, 0.0179)
Domestic	Electronic media	-0.0093 (-0.0287, 0.0101)	**-0.0280 (-0.0490, -0.0071)**	**-0.0135 (-0.0239, -0.0031)**

Table 4. Predicted difference in outcome variables following reallocation of 15 min between behaviour groups – weekend analysis (predicted difference (95% CI); Associations significant at P<0.05 in bold)

Add 15 min…	Remove 15 min…	Predicted difference SDQ	MFQ	Rosenberg
Sleep	Physical activity	**0.2006 (0.1152, 0.2860)**	**0.1021 (0.0093, 0.1949)**	**0.077 (0.0316, 0.1223)**
Sleep	Hobbies	0.0117 (-0.0035, 0.0270)	0.0060 (-0.0106, 0.0226)	0.0039 (-0.0042, 0.0121)
Sleep	Electronic media	0.0048 (-0.0088, 0.0184)	-0.0097 (-0.0244, 0.0050)	**-0.0087 (-0.0160, -0.0014)**
Sleep	Domestic	-0.0008 (-0.0196, 0.0179)	0.0027 (-0.0176, 0.0230)	0.0004 (-0.0095, 0.0103)
Physical activity	Sleep	**-0.0959 (-0.1376, -0.0541)**	**-0.0513 (-0.0967, -0.0060)**	**-0.0381 (-0.0602, -0.0159)**
Physical activity	Hobbies	**-0.0843 (-0.1262, -0.0423)**	-0.0439 (-0.0896, 0.0017)	**-0.0333 (-0.0556, -0.0110)**
Physical activity	Electronic media	**-0.0911 (-0.1315, -0.0507)**	**-0.0596 (-0.1036, -0.0156)**	**-0.0459 (-0.0674, -0.0244)**
Physical activity	Domestic	**-0.0966 (-0.1419, -0.0513)**	-0.0473 (-0.0966, 0.0020)	**-0.0368 (-0.0609, -0.0127)**
Hobbies	Sleep	-0.0110 (-0.0252, 0.0032)	-0.0081 (-0.0236, 0.0074)	-0.0052 (-0.0128, 0.0024)
Hobbies	Physical activity	**0.1894 (0.1046, 0.2741)**	**0.0953 (0.0031, 0.1875)**	**0.0726 (0.0275, 0.1176)**
Hobbies	Electronic media	-0.0061 (-0.0191, 0.0069)	**-0.0164 (-0.0306, -0.0023)**	**-0.0131 (-0.0200, -0.0061)**
Hobbies	Domestic	-0.0117 (-0.0305, 0.0070)	-0.0041 (-0.0245, 0.0163)	-0.0039 (-0.0139, 0.0060)
Electronic media	Sleep	-0.0048 (-0.0179, 0.0083)	0.0064 (-0.0078, 0.0206)	0.0065 (-0.0005, 0.0135)
Electronic media	Physical activity	**0.1958 (0.1120, 0.2795)**	**0.1099 (0.0188, 0.2009)**	**0.0844 (0.0398, 0.1289)**
Electronic media	Hobbies	0.0070 (-0.0066, 0.0206)	0.0138 (-0.0010, 0.0285)	**0.0113 (0.0040, 0.0185)**
Electronic media	Domestic	-0.0055 (-0.0220, 0.0109)	0.0104 (-0.0075, 0.0283)	0.0077 (-0.0010, 0.0165)
Domestic	Sleep	0.0005 (-0.0175, 0.0185)	-0.0052 (-0.0247, 0.0143)	-0.0021 (-0.0116, 0.0075)
Domestic	Physical activity	**0.2012 (0.1134, 0.2890)**	**0.0982 (0.0028, 0.1937)**	**0.0757 (0.0291, 0.1224)**
Domestic	Hobbies	0.0123 (-0.0066, 0.0312)	0.0022 (-0.0184, 0.0227)	0.0027 (-0.0073, 0.0128)
Domestic	Electronic media	0.0053 (-0.0107, 0.0214)	-0.0135 (-0.0310, 0.0039)	**-0.0099 (-0.0184, -0.0014)**

Figure titles

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.

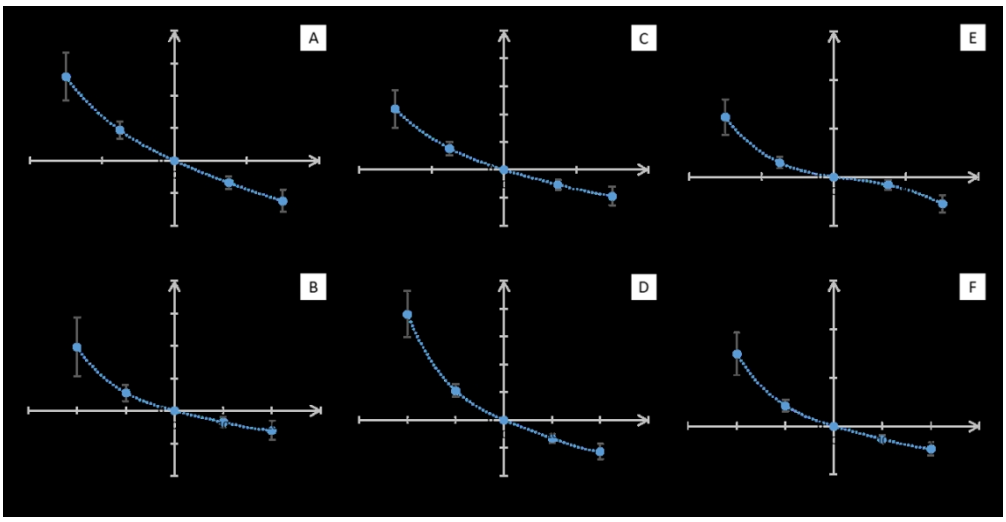

Figure 1. Predicted difference in Strengths and Difficulties Questionnaire, Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from physical activity.
Weekday data: panels A, C, E. Weekend data: panels B, D, F.
Descriptive statistics (median (inter-quartile range)): MFQ: 17.0 (14.0, 21.0); SDQ: 6.0 (3.0, 9.0); Rosenberg: 10.0 (7.0, 10.0)
Models adjusted for age, sex, body mass index and family income. Data points are predicted differences in the outcome ± standard error.
Interpretation: Points plotted to the left of the Y-axis denote predicted differences in the outcome for a specified reduction in physical activity. Points plotted to the right of the Y-axis denote predicted differences in the outcome for a specified increase in physical activity.

550x280mm (59 x 59 DPI)

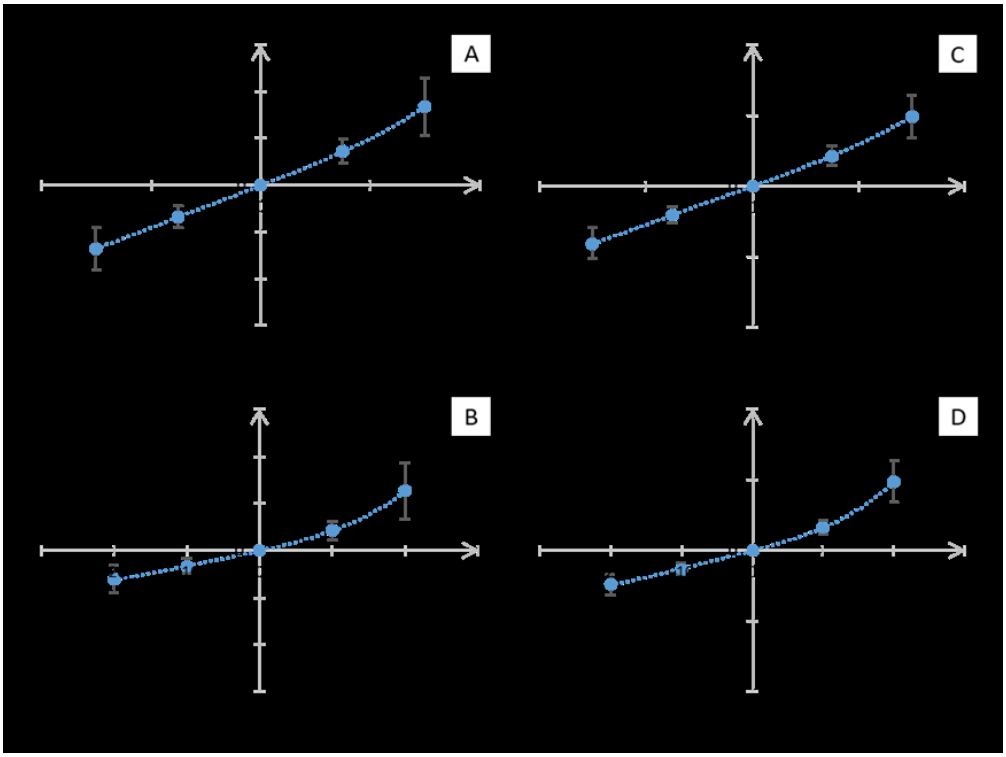

Figure 2. Predicted difference in Mood and Feelings Questionnaire and Rosenberg Self Esteem Questionnaire scores with selected time reallocations to/from electronic media use.
Weekday data: panels A, C. Weekend data: panels B, D
Descriptive statistics (median (inter-quartile range)): MFQ: 17.0 (14.0, 21.0); RSE: 10.0 (7.0, 10.0)
Models adjusted for age, sex, body mass index and family income. Data points are predicted differences in the outcome ± standard error.
Interpretation: Points plotted to the left of the Y-axis denote predicted differences in the outcome for a specified reduction in electronic media. Points plotted to the right of the Y-axis denote predicted differences in the outcome for a specified increase in electronic media.

374x280mm (59 x 59 DPI)

Supplementary material

Table S1. Recoding of time-use diary entries into behavioural categories

Category name	Time-use diary: recorded activity
Sleep	Sleeping and resting
Physical activity	Cycling; Individual ball games and training (e.g. tennis, badminton); Jogging, running, walking, hiking; Team ball games and training (e.g. football, hockey); Swimming and other water sports; Other exercise and sports, dancing, keeping fit, skiing, gymnastics; Travel by physically active means (walk, bike etc.)
School-related activities	Homework; In class; School breaks; School clubs; Detention
Hobbies and socialising	Attending live sporting events; Cinema, theatre, performance, gig etc.; Exhibition, museum, library, other cultural events; Shopping (including window shopping, hanging out at shopping centre); Speaking, socialising face-to-face; Volunteering; Religious activities (including going to places of worship, praying etc.); Did nothing, just relaxing, bored, waiting; Hobbies, arts and crafts, musical activities, writing stories, poetry etc.; Reading (not for school); Other activities not listed
Electronic media	Speaking on the phone (including Skype, video calls); Answering emails, instant messaging, texting; Browsing and updating social networking sites (e.g. Twitter, Facebook, BBM, Snapchat); General internet browsing, programming (not time on social networking sites); Listening to music, radio, iPod, other audio content; Playing electronic games and Apps; Watch TV, DVDs, downloaded videos
Domestic, personal care and work-related activities	Personal care (including taking a shower/bath, grooming, getting dressed etc.); Paid work (including paid babysitting and paid work for the family); Unpaid work for family or other non-household members (e.g. help in family business); Cooking, cleaning, and shopping for the household; Fixing things around the house, fixing bike, gardening; Looking after brothers, sisters, other children in the household; Looking after parent or other adult in the households (medical or personal care); Pet care; Eating or drinking in a restaurant or café; Eating a meal; Eating a snack or having a drink; Travel by bus, taxi, tube, plane; Travel by car, van (including vehicles owned by friends and family)

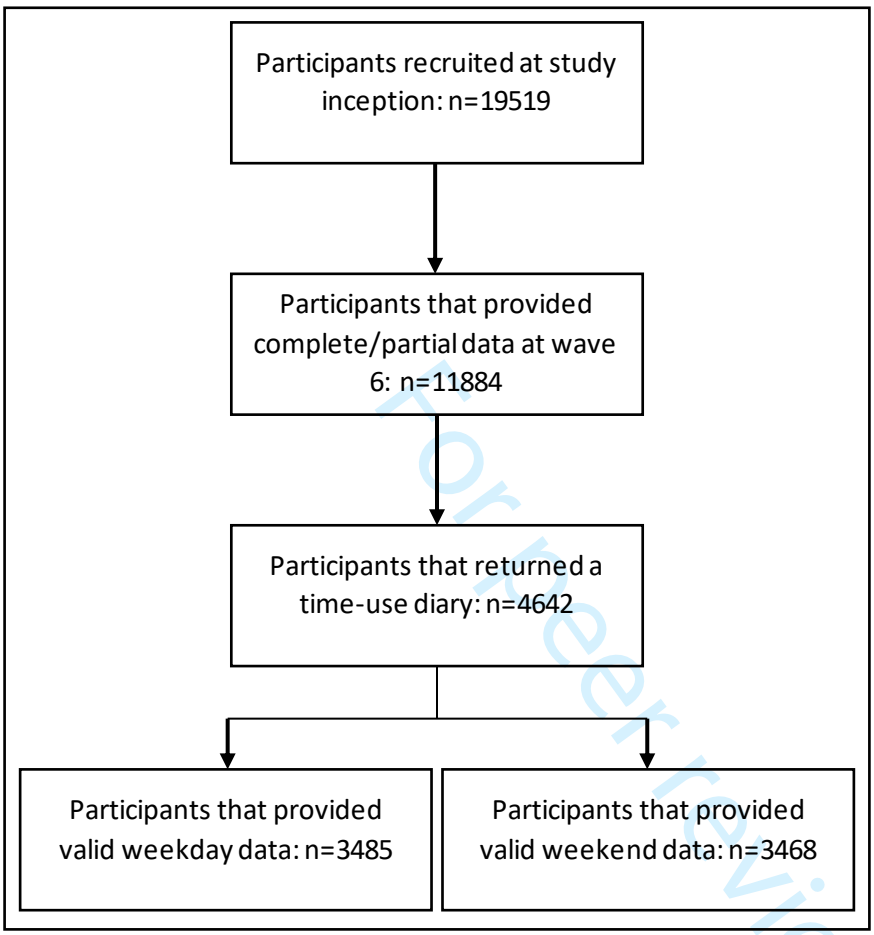

Figure S1. Flow diagram of participant selection process.

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6-9
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*6-9*
Bias	9	Describe any efforts to address potential sources of bias	9-10
Study size	10	Explain how the study size was arrived at	6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	9-10
		(*b*) Describe any methods used to examine subgroups and interactions	na
		(*c*) Explain how missing data were addressed	9-10
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	na
		(*e*) Describe any sensitivity analyses	na
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	na

		(c) Consider use of a flow diagram	See supplementary information
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	11
Outcome data	15*	Report numbers of outcome events or summary measures	27
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	29-30
		(*b*) Report category boundaries when continuous variables were categorized	na
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	na
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	10/figures
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	14-17
Generalisability	21	Discuss the generalisability (external validity) of the study results	14-17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.