The role of cyberbullying, sleep and physical activity in mediating the impact of social media use on mental health and wellbeing: findings from a national cohort of English young people

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Abstract

Background

There is growing concern about associations between social media use and mental health and wellbeing amongst young people. We explored links between frequency of social media use and later mental health and wellbeing in early adolescents, including mediation of effects through cyberbullying and displacement of sleep and physical activity.

Methods

Secondary analyses of *Our Futures*, a nationally-representative longitudinal study of young people in England from age 13 to 16 years. Exposures: frequency of social media use at waves 1 (age 13/14 years) through 3 (age 15/16y). Outcomes: a) mental health: General Health Questionnaire (GHQ) at wave 2; b) wellbeing scores (life satisfaction, life is worthwhile, happiness and anxiety) at wave 3. Analyses adjusted for minimal sufficient confounding structure. Mediation: assessed using khb commands in Stata 15.

Findings

Very frequent social media use (habitually multiple times daily) increased from 42.6% (95% CI: 41.2, 44.2) in wave 1 to 68.5%(67.3, 69.7) by wave 3. Very frequent social media use in wave 1 predicted GHQ high score at wave 2 amongst girls (odds ratio (OR) 1.31 (95% CI: 1.06, 1.63) p=0.01) and boys (1.67 (1.24, 2.26) p=0.001). Persistent very frequent social media use across waves 1 and 2 predicted lower wellbeing amongst girls only (happiness 0.80 (0.70, 0.92) p=0.001; anxiety 1.28 (1.11, 1.48) p=0.001). Associations of social media use with GHQ high score and wellbeing scores for girls were attenuated when adjusted for cyberbullying, sleep and physical activity, although associations amongst boys remained significant.

Interpretation

Mental health harms related to very frequent social media use amongst girls and appeared very largely due to exposure to cyberbullying and or displacement of sleep and physical activity. Interventions to promote mental health should include efforts to prevent or increase resilience to cyberbullying and ensure adequate sleep and physical activity amongst young people.

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Research in context

Evidence before this study

The literature on associations of digital screen use and social media with poorer mental health and wellbeing is limited, largely cross-sectional and contradictory. We drew upon two very recent systematic reviews to identify relevant literature. The first was a systematic review of reviews which searched Medline, EMBASe, PsycInfo and Cinahl in February 2018 using the search terms '(child OR teenager OR adolescent OR youth) AND (screen time OR television OR computer OR sedentary behaviour OR sedentary activity) AND health', with publication type limited to 'systematic review, with or without meta-analysis' (Stiglic & Viner, BMJ Open 2019; doi: 10.1136/bmjopen-2018-023191). We also drew upon a systematic review of 12 databases using a multiple search terms conducted in August 2018 and including publications from 2007 (Dickson et al. Screen-based activities and children and young people's mental health: A Systematic Map of Reviews, London: EPPI-Centre, 2019). These reviews identified some evidence for the association of screen use with depression in young people and found that there was a paucity of longitudinal studies of the impact of social media on later mental health and wellbeing amongst children and young people, and some suggest that prior mental health problems lead to greater social media use. We identified no longitudinal mediation studies which examined whether the impacts of social media were transmitted through cyberbullying or displacement of sleep and physical activity.

Added value of this study

We found that strong longitudinal associations between very frequent social media use and mental health and wellbeing in girls were very largely mediated by cyberbullying and the displacement of sleep and physical activity in girls. We found that the same factors mediated this relationship in boys, but to a much smaller degree.

Our paper is the first longitudinal mediation analysis on a nationally-representative cohort, and suggests that much of the harm attributed to social media is unlikely to be directly

related to social media use, but instead related to a) content watched (i.e. cyberbullying) or b) the displacement of healthy sleep and physical activity.

Implications of all the available evidence

Our data suggest that very frequent social media use in young people is unlikely to have directly harmful effects, but that harms appear to be related to watching harmful content or by displacement of healthy activities which promote wellbeing (e.g. sleep, physical activity). Interventions to reduce social media use in order to improve mental health may be misplaced. Prevention should consider interventions to prevent or increase resilience to cyberbullying and ensure adequate sleep and physical activity amongst today's young people.

Background

Our young people grow up in a media saturated world.[1] In the UK, over 90% of teenagers use the internet for social networking.[2] There is growing concern about the influence of social media use, on mental health and wellbeing amongst young people.[2] Yet the evidence remains contradictory,[3] particularly for social media use rather than other forms of digital screen use. [4]

Social media is a technology that enables online interactions between young people but maybe undertaken in solitary and sedentary environments.[5]. There is emerging evidence that online social media use including rejection and acceptance experiences and peer feedback (both prosocial and negative) may result in changes in brain activation documented in imaging studies.[1] Whilst it remains unclear whether these influences are positive, negative or neutral for adolescent brain development,[1] young people appear more sensitive to social media experiences than other age groups.[1]

There is some evidence that social media use can positively influence health, through increased interaction, reduction of social isolation and provision of information, particularly if use takes the form of active engagement rather than more passive monitoring of content.[6] However the literature has focused more strongly on health harms. A major limitation of current knowledge is the paucity of longitudinal studies.[3,7] Findings from the few longitudinal studies are contradictory,[8,9] and some suggest that prior mental health problems lead to greater social media use.[3,9]

A further limitation is that few studies have examined potential mechanisms by which social media may harm health. Potential mechanisms include: direct effects e.g. on brain development;[1] through content effects such as exposure to cyberbullying[10] and harmful content;[11] or indirect effects through displacement of healthy activities that are important for wellbeing such as sleep,[12] physical activity[13] and 'real-world' social interaction.[6,12,13]

We used longitudinal data from a contemporary population-based national survey of English young people and a causal epidemiological framework to examine whether frequency of social media use in early adolescence influenced later mental health and wellbeing. We

hypothesised that more frequent social media use would be associated with poorer mental health or wellbeing. We also examined whether associations between social media use and later poorer mental health or wellbeing were mediated by cyberbullying, sleep adequacy and physical activity.

Methods

We used data from the first 3 waves of *Our Futures*, the second cohort of the nationally-representative Longitudinal Study of Young People in England (LSYPE2). LSYPE2 began in 2013 and interviewed 12,866 young people in Year 9 (age 13/14 years) in 886 schools across England. Wave 2 (10,963 interviewed) was conducted in 2014 (Year 10; age 14/15 years) and wave 3 (9797 interviewed) in 2015 (Year 11; age 15/16 years) (see Appendix for further details). Data used were the publicly available dataset obtained from the UK Data Service.[14] No additional ethics permissions were sought for these secondary analyses.

Social media use

Young people reported the frequency with which they habitually accessed or checked social media networks in each wave. Social media was defined as any of the major social media networks, instant messaging or photo-sharing services or other social media networks, with example sites quoted and updated at each wave. Use was reported as never, weekly, every few days, daily, 2-3 times per day or multiple times daily. Hereafter we refer to multiple times daily as very frequent social media use. In analyses, never and weekly were collapsed due to small numbers. We created variables for persistence of use across waves. For persistent use across waves 1 and 2, young people were categorised as using social media daily or less often, 2-3 times per day or very frequent use at both waves, with those reporting differences in use between waves assigned to the less frequent category. For persistent use across all waves, we created a binary variable, assigning those who reported very frequent use at each wave as 1 and all others as 0.

Mental health and wellbeing

Self-report data on mental health and wellbeing were only available in waves 2 and 3.

In wave 2, young people completed the 12-item General Health Questionnaire (GHQ12), a widely used standard composite measure of psychological distress used in adolescents[15] as well as adults. Scale scores were added and dichotomised at a threshold of 3 to identify high scorers (≥3) indicative of psychological distress and likely psychiatric caseness.[16] To reduce misclassification bias those who responded don't know to 1 or more questions were assigned to a 'don't know' category.

In wave 3, young people completed 4 questions on personal wellbeing drawn from Office of National Statistics (ONS) Wellbeing Surveys.[17] These were:

1. Overall, how satisfied are you with your life nowadays?
2. Overall, to what extent do you feel the things you do in your life are worthwhile?
3. Overall, how happy did you feel yesterday?
4. Overall, how anxious did you feel yesterday?

Young people were asked to answer each question with a score from 0 (minimal) to 10 (high). For the first 3 questions, 10 represented high wellbeing. For the question on anxiety, 10 represented low wellbeing. Correlation between the four wellbeing questions was moderate (Appendix Table A1). We used each question as a separate outcome.

Potential mediators were chosen based upon the literature[10,12,13,18] and upon data availability in the cohort.

Cyberbullying Cyberbullying between waves 1 and 2 was assessed by a 3 questions in wave 2 asking young people whether they had experienced any cyberbullying through the internet, mobile phone use or other source since the last interview. These were combined before publication of the dataset to produce a composite cyberbullying variable with possible responses no, yes or don't know.

Sleep adequacy At wave 2 asking young people reported their usual weekday bed-time and wakening time during the last month, and duration of sleep was provided in the

dataset categorised as < 8 hours, 8 to 9.4 hours and 9.5 hours or more. We defined the <8 hours category as inadequate sleep.

Physical activity Physical activity was assessed at wave 2 with a question asking young people how often they participated in sports or physical activities such as football, aerobics, dance classes or swimming. We grouped responses as most days, weekly and less than weekly.

Confounding structure

We followed the causal inference literature[19,20] to identify a minimal sufficient confounder set for use in longitudinal analyses. First, we used the literature on associations of social media use and mental health and wellbeing in adolescence referenced above to construct a directed acyclic graph (DAG) including all variables likely to confound or mediate the relationship between social media use and later mental health and/or wellbeing. We then removed all variables that were descendants of the exposure. We used the software dagitty.net to build the DAG and identify which variables to condition upon to close all biasing paths. The variables remaining formed the minimal sufficient set:

1. Small-area measures of overall deprivation (Index of Multiple Deprivation (IMD)[21] quintiles were derived from the young person's postcode.
2. Ethnicity: young people self-reported their main ethnic group
3. Parental education: age at which the main interviewed parent left full-time education
4. Sex
5. School type: whether attending a state maintained or independent (e.g. private) school
6. Peer relationships: 2 proxy variables included:
    a. young person report of whether had friends over to their house in the past week (yes/no)
    b. Number of times young person went out with friends in the previous week (range 0-4 times)

The final DAG is shown in the Appendix, identifying variables in the minimal sufficient set.

Analyses

We first descriptively examined associations of social media use at wave 1 with later mental health and wellbeing, using multinomial logistic regression for GHQ score category and ordinal logistic regression for wellbeing (wave 3). Analyses used the survey (svy) commands in Stata 15 (StataCorp; College Station, TX USA) to account for survey design effects and weights. All analyses were conducted separately by sex as previous studies have reported different associations between social media use and mental health or wellbeing by sex.[5] No attempt was made to impute missing data.

Where associations were significant, mediation by cyberbullying, sleep and physical activity was explored by first assessing their association with the exposure and outcome and then examining whether associations were attenuated when the potential mediator was included in adjusted models. To estimate the proportion of the effect mediated in non-linear regression models, we used the *khb* command in Stata, which compares coefficients of nested, non-linear probability models to estimate direct and indirect effects.[22]

Role of the funding source

The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Data on frequency of social media use at wave 1 and GHQ scores at wave 2 were available for 9552 young people (74.2% of 12,866 respondents in wave 1). For the wellbeing analyses, data for persistence of frequency of social media across waves 1 and 2 and waves 1 to 3 were 7922 (72.3 % of 10,963 in wave 2) and 7805 (79.7% of 9797 of those interviewed in wave 3) respectively. 94.5% (10,361/10,960) of young people reported having their own mobile phone at wave 1, with internet access reported by 98.0% (10,739/10,963) at wave 2.

Table 1 shows the characteristics of all variables in the analytic sample for waves 1 to 3. Sample characteristics were highly similar across waves. Frequency of use of social media differed by sex and increased with age. Very frequent social media use increased from 42.6% (males 34.4 (95% CI: 32.4, 36.4); females 51.4 (49.5, 43.3)) in wave 1 to 59.4% (males 50.7 (48.8, 52.5); females 67.5 (65.7, 69.2)) in wave 2 and 68.5% (males 61.9 (60.3, 63.6); females 75.4 (73.8, 76.9)) by wave 3. Psychological distress (GHQ score 3+) was reported by 19.0% (18.0, 20.0) at wave 2.

Associations between social media use in wave 1 and GHQ score categories at wave 2 are shown in Table 2. There appeared to be a dose response relationship between frequency of social media use and GHQ high scorer category amongst girls, with 27.5% (25.6, 29.5) of very frequent users being high scorers on the GHQ compared with 19.9% (15.3, 25.5) of those using weekly or less. There was less evidence of a gradient amongst boys.

In logistic regression analyses, there were strong associations between very frequent social media use and risk of being a GHQ high scorer in both sexes, with little attenuation of these associations by adjustment for the confounding structure. In sensitivity analyses, the addition of further wave 1 variables to the confounding set, i.e. having a long-term condition, parental connection with school, substance use and truancy, made minimal difference to findings in either sex.

Persistent very frequent use of social media across waves 1 and 2 was found in 34.6% (33.2, 36.0) of young people, with persistent very frequent use across waves 1 through 3 in 29.6% (28.3, 31.0). The associations of persistent frequency use of social media across waves 1 and 2 with GHQ score were similar to those for wave 1 use alone; persistent very frequent use increased risk of GHQ high score amongst boys (1.74 (1.36, 2.21) p<0.0001) and amongst girls (1.50 (1.19, 1.76) p<0.0001) compared with use daily or less often. Table 3 shows the associations between social media use over waves 1 and 2 and wellbeing at wave 3. In adjusted analyses, the only significant associations were between persistent very frequent use and later life satisfaction, happiness and anxiety amongst girls. When persistent social media use across waves 1 through 3 was examined as the exposure, significant associations were again found in girls between persistent very frequent use and life satisfaction (OR 0.85 (0.75, 0.95) p=0.006), happiness (0.78 (0.69, 0.88) p<0.0001) and anxiety (1.17 (1.03, 1.32) p=0.01) with no significant associations in boys.

Mediation analyses

Each of the hypothesised mediators was strongly associated with earlier social media use and later mental health and wellbeing in both sexes (Appendix Table A2). We therefore proceeded to mediation analyses. Table 4 shows the association of social media use in wave 1 with GHQ category in wave 2 in the baseline (adjusted but unmediated) model and after the addition of each mediator to the models, together with the proportion of the association between social media use and GHQ score mediated by each variable. In models including all mediators, amongst boys each of very frequent social media use, cyberbullying, inadequate sleep and low (<weekly) physical activity remained highly significant predictors of GHQ high score with the overall proportion mediated by all variables 12.1%. The great majority of the indirect i.e. mediated effect was through cyberbullying (77%). Amongst girls, cyberbullying and inadequate sleep were highly significant predictors of GHQ high score while associations with very frequent social media use and with physical activity were attenuated and non-significant. The overall proportion mediated was 58.2%, again with the majority of this (57%) contributed by cyberbullying. Findings were highly similar when analyses were repeated using persistent frequency of social media use across waves 1 and 2, with the proportions mediated for very frequent use similar to that for wave 1 use (total mediation 11.8% in boys and 47.5% girls).

For the association of persistent social media use with later wellbeing (Table 5), mediation analyses were explored only where we previously identified significant relationships. Each of cyberbullying, inadequate sleep and physical activity appeared to mediate part of the association of very frequent social media use and each of the three wellbeing variables. In models including all 3 mediators, the association of very frequent social media use with later life satisfaction was fully attenuated, with the mediators estimated to account for 80.1% of the association. In contrast, the mediators together were estimated to explain 47.7% of the relationship with happiness and 32.4% of that of social media use with anxiety.

Discussion

We found that whilst very frequent social media use predicted poorer later mental health and wellbeing in both sexes independent of adjustment for carefully chosen confounders, amongst girls this relationship appeared to be very largely mediated through cyberbullying and inadequate sleep, with inadequate physical activity playing a more minor role. Indeed, inclusion of cyberbullying and inadequate sleep in models for girls entirely attenuated associations of frequent daily social media use with later psychological distress, life satisfaction and happiness scores. This suggests that the harmful impacts of frequent social media use on mental health and wellbeing in girls are driven very largely by the enablement of cyberbullying and by disruption of sleep. Moreover, the odds ratios for cyberbullying and inadequate sleep were notably larger than those for social media use in mediated models for psychological distress and models for wellbeing. This supports previous suggestions that sleep and cyberbullying are more powerful determinants of wellbeing in young people than digital screen use.[12]

In contrast, amongst boys we found that cyberbullying, sleep and physical activity were responsible for less (12%) of the impact of very frequent social media use on psychological distress, suggesting that the majority of the impact of social media on later mental health was through other mechanisms. We also found no impact of social media use frequency on wellbeing in boys. This may be partly explained by the positive association between frequency of social media use and frequency of physical activity observed in boys (in

contrast to an inverse association in girls) suggesting that social media use does not displace physical activity in boys in the way seen amongst girls. These findings together suggest that that there are other mechanisms by which frequent social media use impairs mental health in boys, but that these do not appear to affect aspects of wellbeing in this sample. Our data do not allow us to identify these other mechanisms. However, given that the great majority of the impact of social media on mental health and wellbeing amongst girls was indirect, it would be implausible to suggest that there may be a significant direct effect of social media on mental health amongst boys.

Comparison with the literature

Our finding that frequent social media use was predictive of later psychological distress is consistent with a small longitudinal literature[3,5,6] although others have reported no consistent relationship.[9] Our finding of clear sex differences in use of social media and associations of social media use and mental health and wellbeing is consistent with other reports.[5,23,24] The apparent sex differences may simply reflect higher use amongst girls than boys,[3] as was also found in our study. They may also reflect higher baseline levels of anxiety and psychological distress amongst adolescent girls than boys,[25] greater prevalence of cyberbullying amongst girls[26] and that cyberbullying is more associated with distress amongst girls than boys.[26] However, more detailed studies of the mechanisms of social media effects should be undertaken by gender.

We are aware of no similar longitudinal mediation studies which simultaneously examined cyberbullying, sleep and physical activity as potential mechanisms for the association of social media use with mental health or wellbeing. Our findings are consistent with a previous very large national cross-sectional study in which we showed that the association of high digital screen use with lower wellbeing was markedly attenuated in both sexes when adjusted for bullying, sleep and physical activity,[12] and a cross-sectional mediation analysis which reported that adjusting for online harassment, sleep, self-esteem and body image reduced coefficients for associations between social media use and depressive symptom.[23] Our findings for cyberbullying are consistent with a number of studies which have shown associations between social media use, cyberbullying and poor mental health.[10,27] Similarly, our findings that sleep plays a role in mediating associations between

social media use and mental health and wellbeing are consistent with a literature showing that inadequate sleep is associated with higher electronic media use amongst children and adolescents.[28] There is some evidence from cross-sectional studies that physical activity levels are lower amongst young people who are higher users of social media.[13]

Strengths and Limitations

We used a causal framework to study associations between potentially modifiable social media exposures and mediators and mental health and wellbeing in a large nationally-representative contemporary cohort, and used mediation methods appropriate to non-linear models. We conducted sensitivity analyses examining use of a different confounding structure and use of persistent social media frequency as the exposure, each of which did not materially change findings.

The main limitation of our study was the degree to which the exposure variable reflected the complexity of social media use. Our exposure was frequency of social media use, which is a proxy for both the attentional focus of young people on social media and for time spent in online social media. However we were unable to include other measures of social media use in our analyses, e.g. time spent in use, as these data were not collected. Such limitations are common to nearly all studies of social media in larger cohorts.

There are limitations to the GHQ as a measure of psychological distress in adolescence.[29] We included those who replied 'don't know' as an additional category to minimise misclassification bias. Analyses were limited by the data available. Mediator variables were used from wave 2, which meant that only associations using wave 1 through 3 data could be truly longitudinal. However note that the cyberbullying variable however specifically related to cyberbullying between waves 1 and 2. The cyberbullying variable did not allow examination of type or frequency of cyberbullying. Questions on social media use, cyberbullying, sleep and physical activity were direct questions in the survey and not previously validated. The lack of mental health or wellbeing data in wave 1 meant that we were unable to examine whether earlier psychological distress may have led to later social media use. However, whilst earlier mental health problems may be causally related to social

media use in wave 1 of our study, our findings strongly suggest there are causal links thereafter between social media use and mental health and wellbeing. The direction of bias from missing data for mental health and wellbeing outcomes is unclear. As proportions of missing data were low, and it is unlikely that data were missing at random and thus imputation was not undertaken. There was some excess attrition amongst boys between waves 1 and 3, which may have been a source of bias.

Conclusions

Mental health harms related to very frequent social media use amongst girls appear very largely due to exposure to cyberbullying and or displacement of sleep and physical activity. These same factors were operative amongst boys, although to a smaller degree. Further work is needed to examine which other mechanisms may be operative amongst boys, such as social exclusion, emotional engagement with social media[30] and effects related to content or type of site. Our data suggest that interventions to reduce social media use in order to improve mental health may be misplaced. Preventive efforts should consider interventions to prevent or increase resilience to cyberbullying and ensure adequate sleep and physical activity amongst today's young people.

Author contributions

RV and DN conceptualised the paper. RV downloaded and prepared the data and undertook all analyses. All authors contributed to preparation and editing of the manuscript.

Declaration of interests

RV is President of the Royal College of Paediatrics & Child Health. All other authors declare they have no conflicts of interest.

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Table 1. Characteristics of the sample at waves 1 to 3

		Wave 1			Wave 2			Wave 3		
		%	*95% CI*	*N*	*%*	*95% CI*	*N*	*%*	*95% CI*	*N*
Social media use										
Frequency social media use at each wave	weekly or less	10.5%	[9.3%,11.9%]	1,047	3.80%	[3.4%,4.2%]	374	1.50%	[1.2%,1.8%]	129
	every couple of days	9.3%	[8.7%,10.0%]	901	4.70%	[4.2%,5.1%]	437	2.90%	[2.5%,3.3%]	238
	daily but once	17.8%	[16.9%,18.7%]	1,594	10.70%	[10.0%,11.4%]	971	8.00%	[7.4%,8.7%]	621
	2-3 times a day	19.8%	[18.8%,20.7%]	1,806	21.50%	[20.5%,22.5%]	1,888	19.10%	[18.1%,20.1%]	1439
	regularly multiple times daily	42.6%	[41.2%,44.2%]	4,204	59.40%	[58.1%,60.7%]	5,589	68.50%	[67.3%,69.7%]	5437
	Total			*9552*			*9259*			*7864*
Persistent frequency of social media use wave 1 to 2	daily or less often				42.6%	[41.0%,44.3%]	3,923	42.4%	[40.9%,44.0%]	3,336
	2-3 times daily				22.8%	[21.8%,23.9%]	2,043	23.1%	[22.1%,24.1%]	1,789
	regularly multiple times daily				34.6%	[33.2%,36.0%]	3,298	34.5%	[33.1%,35.9%]	2,797
	Total						*9264*			*7922*
Mental health and Wellbeing outcomes										
GHQ categories wave 2	normal (0-2)				55.3%	[54.1%,56.6%]	5,092			
	don't know				25.7%	[24.4%,26.9%]	2,699			
	high scorer (3+)				19.0%	[18.0%,20.0%]	1,761			
	Total						*9552*			
Wave 3 wellbeing scores								mean	95% CI	N
Life satisfaction								7.86	[7.81, 7.91]	7,703
Life is worthwhile								7.79	[7.73, 7.84]	7,628
Happiness								7.69	[7.64, 7.74]	7,922
Anxiety								2.97	[2.89, 3.04]	7,601
Mediators measured at wave 2								*%*	*95% CI*	*N*
Cyberbullying experienced between wave 1 and 2	no				84.6%	[83.8%,85.4%]	8,012	84.9%	[84.0%,85.8%]	6,691
	yes				11.1%	[10.4%,11.8%]	1,095	11.0%	[10.3%,11.8%]	892
	refused or DK				4.3%	[3.9%,4.8%]	445	4.1%	[3.6%,4.6%]	339
	Total						*9552*			*7922*

Sleep: usual hours of sleep at night	< 8 hours				31.9%	[30.9%,33.1%]	3,107	32.5%	[31.3%,33.7%]	2,616
	8 to 9.49 hours				61.5%	[60.5%,62.6%]	5,688	61.3%	[60.1%,62.4%]	4,721
	9.5 hours or more				6.5%	[6.0%,7.1%]	665	6.2%	[5.7%,6.9%]	522
	Total						*9460*			*7859*
Physical activity: Usual frequency of sport or exercise	most days				31.8%	[30.4%,33.2%]	2,917	31.6%	[30.2%,33.0%]	2,403
	weekly				44.7%	[43.6%,45.9%]	4,222	45.1%	[43.9%,46.4%]	3,547
	<weekly				23.5%	[22.4%,24.7%]	2,401	23.3%	[22.1%,24.5%]	1,965
	Total						*9540*			*7915*
Demographic and confounding variables										
Gender	Male	50.0%	[48.4%,51.5%]	4,712	50.0%	[48.4%,51.5%]	4,712	48.7%	[47.0%,50.4%]	3,764
	Female	50.0%	[48.5%,51.6%]	4,840	50.0%	[48.5%,51.6%]	4,840	51.3%	[49.6%,53.0%]	4,158
	Total			*9552*			*9552*			*7922*
Index of Multiple Deprivation quartile, wave 1	1(least deprived)	26.9%	[24.7%,29.1%]	2,163	26.9%	[24.7%,29.1%]	2,163	27.3%	[25.1%,29.5%]	1,895
	2	25.2%	[23.8%,26.7%]	2,097	25.2%	[23.8%,26.7%]	2,097	25.6%	[24.1%,27.1%]	1,794
	3	24.2%	[22.8%,25.6%]	2,383	24.2%	[22.8%,25.6%]	2,383	24.3%	[22.9%,25.8%]	1,970
	4 (most deprived)	23.7%	[21.8%,25.7%]	2,901	23.7%	[21.8%,25.7%]	2,901	22.9%	[21.0%,24.9%]	2,255
	Total			*9544*			*9544*			*7914*
Ethnicity, wave 1	white British	79.8%	[77.7%,81.9%]	7,165	79.8%	[77.7%,81.9%]	7,165	80.6%	[78.7%,82.5%]	6,090
	white other	3.7%	[3.2%,4.3%]	298	3.7%	[3.2%,4.3%]	298	3.7%	[3.2%,4.3%]	239
	mixed ethnicity	3.8%	[3.4%,4.2%]	393	3.8%	[3.4%,4.2%]	393	4.0%	[3.6%,4.5%]	336
	south Asian	5.9%	[4.9%,7.1%]	656	5.9%	[4.9%,7.1%]	656	5.2%	[4.3%,6.2%]	482
	black	4.3%	[3.7%,4.9%]	748	4.3%	[3.7%,4.9%]	748	4.2%	[3.7%,4.9%]	574
	other	2.5%	[2.0%,3.1%]	219	2.5%	[2.0%,3.1%]	219	2.2%	[1.8%,2.7%]	160
	Total			*9479*			*9479*			*7881*
Age main parent left full-time education, wave 1	15 y or earlier	11.0%	[10.3%,11.7%]	1,249	11.0%	[10.3%,11.7%]	1,249	10.5%	[9.7%,11.3%]	957
	15-16y	35.1%	[33.7%,36.5%]	3,506	35.1%	[33.7%,36.5%]	3,506	35.4%	[33.9%,36.9%]	2,879
	17-18y	29.0%	[28.0%,30.1%]	2,651	29.0%	[28.0%,30.1%]	2,651	29.1%	[27.9%,30.3%]	2,258
	19-21y	13.6%	[12.7%,14.5%]	1,153	13.6%	[12.7%,14.5%]	1,153	13.6%	[12.7%,14.6%]	988
	22 plus	11.1%	[10.0%,12.3%]	890	11.1%	[10.0%,12.3%]	890	11.3%	[10.2%,12.5%]	780
	refused or don't know	0.2%	[0.1%,0.3%]	27	0.2%	[0.1%,0.3%]	27	0.2%	[0.1%,0.3%]	16

	Total			*9476*			*9476*			*7878*
Times out with friends in last week, wave 1	1	28.2%	[27.1%,29.4%]	2,694	28.2%	[27.1%,29.4%]	2,694	28.4%	[27.2%,29.7%]	2,253
	2	38.8%	[37.6%,40.0%]	3,567	38.8%	[37.6%,40.0%]	3,567	39.5%	[38.2%,40.7%]	3,042
	3	21.8%	[20.9%,22.8%]	2,051	21.8%	[20.9%,22.8%]	2,051	21.7%	[20.6%,22.8%]	1,706
	4	11.2%	[10.4%,12.0%]	1,152	11.2%	[10.4%,12.0%]	1,152	10.4%	[9.6%,11.3%]	862
	Total			*9464*			*9464*			*7863*
Had friends round to house in last week	No	81.2%	[80.2%,82.1%]	7,212	81.2%	[80.2%,82.1%]	7,212	81.2%	[80.2%,82.2%]	6,032
	Yes	18.8%	[17.9%,19.8%]	1,683	18.8%	[17.9%,19.8%]	1,683	18.8%	[17.8%,19.8%]	1,402
	Total			*8895*			*8895*			*7434*
School type	Independent	7.5%	[5.2%,10.7%]	393	7.5%	[5.2%,10.7%]	393	7.7%	[5.3%,11.0%]	348
	State maintained	92.5%	[89.3%,94.8%]	9,159	92.5%	[89.3%,94.8%]	9,159	92.3%	[89.0%,94.7%]	7,574
	Total			*9552*			*9552*			*7922*

Notes: The sample for wave 1 through 2 analyses was defined as those who had data on frequency of social media use at wave 1 and GHQ scores at wave 2, thus the characteristics of the sample are the same at wave 1 and 2. Proportions and 95% CI are shown weighted together with unweighted sample size (n).

Table 2. Associations between frequency of social media use at wave 1 (exposure) and later mental health (outcome) at wave 2

		Proportions			Unadjusted analyses				***Adjusted analyses			
	N*	Normal/low	Other scorers	GHQ high scorers	Other scorers		GHQ high scorers		Other scorers		GHQ high scorers	
Frequency social media use		**% (95% CI)**	**% (95% CI)**	**% (95% CI)**	**OR (95% CI)**	**p**	**OR (95% CI)**	**p**	**OR (95% CI)**	**P**	**OR (95% CI)**	**p**
Boys						N=4712				N=4379		
weekly or less	734	68.1 (64.5, 71.4)	21.7 (18.7, 25.0)	10.2 (8.0, 12.9)	1.16 (0.92, 1.47)	0.2	1.02 (0.73, 1.43)	0.9	0.89 (0.68, 1.17)	0.4	1.02 (0.69, 1.51)	0.9
every couple of days	569	73.2 (69.5, 76.6)	16.4 (13.7, 19.6)	10.4 (7.9, 13.6)	0.81 (0.61, 1.06)	0.13	1.06 (0.74, 1.50)	0.8	0.74 (0.56, 0.96)	0.03	0.99 (0.65, 1.51)	0.9
daily but once	854	69.8 (66.4, 72.9)	20.5 (17.7, 23.7)	9.7 (7.8, 12.1)	1		1		1		1	
2-3 times a day	887	68.3 (64.8, 71.5)	20.6 (17.8, 23.8)	11.1 (9.2, 13.4)	1.08 (0.86, 1.35)	0.5	1.13 (0.83, 1.55)	0.4	1.01 (0.78, 1.29)	0.9	1.18 (0.84, 1.65)	0.4
multiple times a day	1,668	60.1 (58.1, 63.1)	24.5 (22.4, 26.7)	14.9 (13.1, 16.8)	1.42 (1.16, 1.73)	0.001	1.63 (1.24, 2.14)	<0.001	1.17 (0.92, 1.49)	0.2	1.67 (1.24, 2.26)	0.000909 ~~0~~
GIRLS						N=4840				N=4429		
weekly or less	277	49.1 (42.8, 55.5)	31.0 (25.8, 36.7)	19.9 (15.3, 25.5)	1.21 (0.89, 1.64)	0.2	0.81 (0.57, 1.15)	0.2	1.06 (0.74, 1.52)	0.8	0.68 (0.43, 1.01)	0.10
every couple of days	332	52.0 (46.3, 57.6)	25.3 (20.7, 30.4)	22.8 (18.2, 38.1)	0.88 (0.64, 1.20)	0.4	0.90 (0.65, 1.24)	0.5	0.87 (0.61, 1.24)	0.5	0.87 (0.61, 1.24)	0.4
daily but once	740	48.9 (45.2, 52.7)	26.1 (22.8, 29.7)	25.0 (21.9, 28.3)	1		1		1		1	
2-3 times a day	919	48.0 (44.6, 51.4)	26.8 (23.9, 30.0)	25.2 (22.3, 28.3)	1.02 (0.81, 1.28)	0.9	1.03 (0.81, 1.32)	0.8	1.01 (0.78, 1.30)	0.9	0.99 (0.77, 1.27)	0.9
multiple times a day	2536	38.3 (36.3, 40.4)	34.2 (32.1, 36.3)	27.5 (25.6, 29.5)	1.60 (1.32, 1.94)	<0.001	1.35 (1.10, 1.66)	0.004	1.43 (1.18, 1.79)	0.002	1.31 (1.06, 1.63)	0.014

*N are unweighted

***Adjusted for minimal sufficient confounder set.

Table 3. Associations between persistent frequency of social media use across waves 1 and 2 (exposure) and wellbeing at wave 3 (outcome)

	Boys			Girls		
Social media use frequency	Mean (95% CI)	Adjusted OR*** (95% CI)	p	Mean (95% CI)	Adjusted OR*** (95% CI)	p
Life satisfaction	N=3715	N=3498		N=4075	N=3753	
Daily or less	8.14 (8.07, 8.21)	1		7.61 (7.49, 7.73)	1	
2-3 times per day	8.21 (8.10, 8.33)	1.01 (0.87, 1.18)	0.9	7.64 (7.52, 7.76)	0.99 (0.84, 1.16)	0.9
Multiple times per day	8.06 (7.94, 8.18)	0.88 (0.75, 1.02)	0.10	7.48 (7.38, 7.58)	0.86 (0.74, 0.99)	0.039
Life is worthwhile	N=3648	N=3435		N=4023	N=3713	
Daily or less	7.96 (7.88, 8.04)	1		7.63 (7.52, 7.75)	1	
2-3 times per day	7.98 (7.84, 8.12)	1.02 (0.87, 1.19)	0.8	7.59 (7.46, 7.72)	0.96 (0.82, 1.11)	0.5
Multiple times per day	8.02 (7.888, 8.15)	1.06 (0.91, 1.25)	0.4	7.53 (7.43, 7.63)	0.91 (0.75, 1.05)	0.18
Happiness	N=3764	N=3544		N=4158	N=3831	
Daily or less	8.05 (7.96, 8.14)	1		7.48 (7.35, 7.61)	1	
2-3 times per day	8.05 (7.92, 8.19)	0.96 (0.83, 1.11)	0.6	7.50 (7.34, 7.65)	1.01 (0.87, 1.19)	0.9
Multiple times per day	7.98 (7.83, 8.13)	0.92 (0.78, 1.07)	0.3	7.23 (7.11, 7.34)	0.80 (0.70, 0.92)	0.0011
Anxiety	N=3575	N=3369		N=4060	N=3745	
Daily or less	2.28 (2.15, 2.41)	1		3.34 (3.17, 3.52)	1	
2-3 times per day	2.41 (2.18, 2.65)	1.10 (0.93, 1.30)	0.2	3.54 (3.33, 3.74)	1.16 (0.98, 1.36)	0.08
Multiple times per day	2.41 (2.20, 2.62)	1.10 (0.94, 1.30)	0.2	3.71 (3.56, 3.87)	1.28 (1.11, 1.48)	0.0010

***Adjusted for minimal sufficient confounder set

Table 4. Mediation of the association of social media use in wave 1 with GHQ high score in fully adjusted models in wave 2, by cyberbullying, sleep and physical activity

		Single mediator models						Model including all 3 mediators together	
		Cyberbullying		Sleep		Physical activity			
		OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p
Males		N=4379		N=4343		N=4375		N=4340	
Frequency of social media use	weekly or less	1.03 (0.69, 1.54)	9	1.03 (0.70, 1.52)	0.9	1.01 (0.68, 1.49)	0.9	1.02 (0.69, 1.53)	0.9
	every couple of days	1.04 (0.68, 1.59)	0.9	0.99 (0.65, 1.51)	0.9	0.98 (0.64, 1.49)	0.9	1.02 (0.67, 1.56)	0.9
	daily but once	1		1		1		1	
	2-3 times a day	1.14 (0.80, 1.61)	0.5	1.16 (0.82, 1.64)	0.4	1.20 (0.85, 1.68)	0.3	1.14 (0.80, 1.62)	0.5
	multiple times a day	1.58 (1.17, 2.16)	0.003	1.59 (1.18, 2.16)	0.003	1.68 (1.25, 2.27)	0.001	1.53 (1.13, 2.08)	0.006
Cyberbullying	No	1						1	
	Yes	3.92 (2.81, 5.49)	p<0.0001					3.86 (2.77, 5.39)	p<0.0001
	Don't know / refused	4.33 (2.61, 7.21)	p<0.0001					4.11 (2.46, 6.87)	p<0.0001
Sleep	<8 hours			1.45 91.17, 1.80)	0.001			1.36 (1.10, 1.70)	0.004
	8-9.49 hours			1				1	
	9.5 or more hours			0.85 (0.55, 1.33)	0.5			0.87 (0.55, 1.36)	0.5
Physical activity	most days					0.86 (0.70, 1.06)	0.16	0.86 (0.69, 1.06)	0.16
	around weekly					1		1	
	< weekly					1.42 (1.06, 1.90)	0.19	1.38 (1.03, 1.86)	0.03
Proportions mediated:	Cyberbullying	10.4%						9.4%	
	Sleep			4.8%				4.1%	
	Physical activity					-5.9%		-1.3%	
	Total							12.1%	
Females		N=4429		N=4388		N=4422		N=4384	
Frequency of social media use	weekly or less	0.67 (0.42, 1.06)	0.09	0.72 (0.45, 1.13)	0.16	0.68 (0.43, 1.07)	0.09	0.70 (0.44, 1.11)	0.13

	every couple of days	0.85 (0.60, 1.22)	0.4	0.89 (0.62, 1.29)	0.5	0.86 (0.60, 1.24)	0.4	0.87 (0.60, 1.25)	0.5
	daily but once	1		1		1		1	
	2-3 times a day	0.95 (0.74, 1.21)	0.7	0.97 (0.76, 1.25)	0.8	0.98 (0.76, 1.26)	0.9	0.92 (0.72, 1.18)	0.5
	multiple times a day	1.19 (0.96, 1/49)	0.11	1.26 (1.01, 1.57)	0.04	1.28 (1.03, 1.60)	0.025	1.12 (0.90, 1.40)	0.3
Cyberbullying	No	1						1	
	Yes	3.40 (2.70, 4.28)	p<0.0001					3.35 (2.65, 4.24)	p<0.0001
	Don't know / refused	2.81 (2.47, 5.88)	p<0.0001					3.72 (2.40, 5.76)	p<0.0001
Sleep	<8 hours			2.00 (1.68, 2.38)	<0.0001			1.96 (1.64, 2.34)	p<0.0001
	8-9.49 hours			1				1	
	9.5 plus hours			0.74 (0.61, 1.01)	0.06			0.74 (0.50, 1.08)	0.12
Physical activity	most days					0.85 (0.69, 1.06)	0.16	0.82 (0.66, 1.02)	0.08
	around weekly					1		1	
	< weekly					1.20 (0.99, 1.46)	0.06	1.20 (0.99, 1.47)	0.06
Proportions mediated:	Cyberbullying	35.7%						33.4%	
	Sleep			17.0%				15.8%	
	Physical activity					13.4%		9.0%	
	Total							58.2%	

All models are adjusted for the minimal sufficient confounder set.

Proportions mediated indicate the proportion of the total effect of social media use at time 2 on GHQ at wave 2 that is mediated through the specified mediator. The total proportion is the proportion mediated across all 3 mediators in the model including all mediators together.

Table 5. Mediation of the association in girls between persistent social media use across waves 1 and 2 and wellbeing at wave 3 by cyberbullying, sleep and physical activity

		Single mediator			All mediators together
		Cyberbullying	**Sleep**	**Physical activity**	
		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Life satisfaction		N=3753	N=3727	N=3750	N=3725
Social media use	Daily or less	1	1	1	1
	2-3 times per day	1.01 (0.86, 1.19)	1.01 (0.86, 1.18)	1.00 (0.85, 1.17)	1.04 (0.88, 1.22)
	Multiple times per day	0.90 (0.78, 1.04)	0.89 (0.77, 1.03)	0.89 (0.77, 1.03)	0.96 (0.83, 1.11)
Cyberbullying	No	1			1
	Yes	0.50*** (0.42, 0.60)			0.51*** (0.42, 0.61)
	Don't know / refused	0.54*** (0.42, 0.70)			0.56*** (0.43, 0.72)
Sleep	<8 hours		0.57*** (0.51, 0.65)		0.58*** (0.51, 0.66)
	8-9.49 hours		1		1
	9.5 plus hours		1.11 (0.86, 1.44)		1.10 (0.85, 1.43)
Physical activity	most days			1	1
	around weekly			0.72*** (0.62, 0.85)	1.40*** (1.19, 1.65)
	< weekly			0.55*** (0.46, 0.66)	0.77** (0.66, 0.89)
Proportions mediated	Cyberbullying	34.3%			29.7%
	Sleep		33.9%		31.2%
	Physical activity			23.8%	19.1%
	Total				80.1%
Happiness		N=3831	N=3801	N=3827	N=3798
Social media use	Daily or less	1	1	1	1
	2-3 times per day	1.03 (0.88, 1.21)	1.03 (0.88, 1.20)	1.02 (0.87, 1.19)	1.05 (0.90, 1.23)
	Multiple times per day	0.84** (0.73, 0.95)	0.84** (0.73, 0.95)	0.82** (0.72, 0.94)	0.88 (0.76, 1.01)
Cyberbullying	No	1			1
	Yes	0.59*** (0.49, 0.72)			0.59*** (0.49, 0.72)
	Don't know / refused	0.63** (0.48, 0.88)			0.65** (0.48, 0.88)
Sleep	<8 hours		0.66*** (0.58, 0.76)		0.67*** (0.59, 0.76)
	8-9.49 hours		1		1
	9.5 plus hours		1.24 (0.95, 1.63)		1.23 (0.94, 1.61)
Physical activity	most days			1	1
	around weekly			0.78** (0.66, 0.91)	1.29** (1.10, 1.52)
	< weekly			0.68*** (0.57, 0.82)	0.88 (0.76, 1.01)
Proportions mediated	Cyberbullying	18.1%			17.7%
	Sleep		22.3%		21.5%
	Physical activity			9.2%	8.5%

	Total				47.7%
Anxiety		N=3745	N=3717	N=3741	N=3714
Social media use	Daily or less	1	1	1	1
	2-3 times per day	1.14 (0.97, 1.34)	1.15 (0.98, 1.35)	1.15 (0.98, 1.35)	1.13 (0.97, 1.33)
	Multiple times per day	1.23** (1.07, 1.42)	1.25** (1.08, 1.45)	1.26** (1.09, 1.45)	1.19* (1.02, 1.37)
Cyberbullying	No	1			1
	Yes	1.62*** (1.36, 1.93)			1.61*** (1.35, 1.90)
	Don't know / refused	1.70*** (1.32, 2.18)			1.66*** (1.29, 2.14)
Sleep	<8 hours		1.35*** (1.18, 1.54)		1.33*** (1.17, 1.52)
	8-9.49 hours		1		1
	9.5 plus hours		1.01 (0.75, 1.35)		1.03 (0.76, 1.38)
Physical activity	most days			1	1
	around weekly			1.21* (1.02, 1.43)	0.82* (0.69, 0.97)
	< weekly			1.37**(1.13, 1.66)	1.12 (0.98, 1.28)
Proportions mediated	Cyberbullying	16.1%			15.3%
	Sleep		12.0%		11.0%
	Physical activity			7.0%	6.2%
	Total				32.4%

*p<0.05, **p<0.01, ***p<0.001