RESEARCH ARTICLE

Daily and average associations of physical activity, social media use, and sleep among adolescent girls during the COVID-19 pandemic

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Summary

Adolescents' daily lives have been disrupted during the Coronavirus disease 2019 (COVID-19) pandemic. It remains unclear how changes in adolescents' daily physical and social behaviours affect their sleep. The present study examined the daily and average effects of physical activity and social media use (i.e., video chatting, texting, and social networking sites) on adolescent girls' sleep during the COVID-19 pandemic. Adolescent girls aged 12–17 years ($N = 93$; 69% White) from a larger longitudinal study completed a 10-day daily diary protocol during state-mandated stay-at-home orders. Girls reported on daily sleep (duration, timing, quality), physical activity, and social media use during COVID-19. Multilevel modelling was used to examine the within- and between-person effects of physical activity and social media on sleep duration, timing, and quality during the 10-day period. Between-person associations indicate that youth with greater social media use (texting, video chatting, and social networking) and less physical activity had later sleep timing across the 10-day study period. Only video chatting was associated with shorter sleep duration. There were no within-person effects of physical activity or social media activities on sleep outcomes. Findings indicate that physical activity and social media use may impact later adolescent sleep timing during the COVID-19 pandemic. It will be critical for research to examine the potential long-term costs of delayed sleep timing, and whether targeting specific youth behaviours associated with sleep and circadian disruption improve mental and physical health during the COVID-19 pandemic and beyond.

KEYWORDS
physical activity, sleep duration, sleep quality, sleep timing, social media, social networking, texting, video chatting

The coronavirus disease 2019 (COVID-19) pandemic has drastically impacted the daily lives of adolescents worldwide through its effects on health, safety, and youth scholastic and social activities. These major changes in adolescents' lives have affected adolescents' behaviours (Francisco et al., 2020) and sleep and circadian rhythms (Becker & Gregory, 2020). Due to school closures and delayed school start times during the COVID-19 pandemic, adolescents had more autonomy over their sleep–wake schedules, resulting in more hours of

sleep per night (Francisco et al., 2020; Gruber et al., 2020; López-Bueno et al., 2020). While adolescents may have had more opportunity to sleep (Francisco et al., 2020), the absence of regular schedules and structured activities may impede daily sleep schedules, thereby contributing to later sleep start and wake times (Gruber et al., 2020). Results regarding sleep quality during the pandemic are mixed, with some studies indicating that youth have poorer sleep quality (Luijten et al., 2020; Zhou et al., 2020), whereas others suggest improved sleep quality and reduced daytime sleepiness (Gruber et al., 2020). These findings highlight the need to examine sleep both *between* and *within* adolescents (e.g., how sleep fluctuates on a day-to-day basis). Yet, few studies have examined factors affecting adolescent sleep on a daily basis or explored how adolescents' behaviours during the pandemic are associated with changes in sleep processes. Examining the daily and overall relationships between behavioural factors and adolescent sleep during COVID-19 may inform our understanding of modifiable factors for adolescents' sleep health during the pandemic and beyond.

Without school, extracurriculars, and in-person socialising (Carskadon, 2011), adolescents may engage in different behaviours during the day that disrupt sleep and circadian rhythms. Adolescents are more limited in their ability to leave the house for their usual activities due to physical distancing practices and safety concerns. Thus, it is not surprising that physical activity has been markedly reduced (Ellis et al., 2020; López-Bueno et al., 2020). While it is recommended for youth to have at least 60 min of physical activity per day (on multiple days per week) (Lobelo et al., 2020), research indicates that youth are engaging in 90 min of physical activity per week during the COVID-19 pandemic (López-Bueno et al., 2020). Prior research on physical activity and sleep suggests that adolescents with more physical activity experience better sleep quality (Lang et al., 2016), as well as earlier sleep timing and longer sleep duration (Master et al., 2019). Individual fluctuations in physical activity also affect daily sleep, such that on days youth are less physically active they reported later sleep timing and shorter sleep duration (Master et al., 2019). Recent research during COVID-19 in adults has similarly found that reduced physical activity during the pandemic is associated with poorer sleep quality and shorter duration (Chouchou et al., 2020; Diniz et al., 2020; Janssen et al., 2020). Yet, no known study has investigated these daily relationships during COVID-19 among adolescents.

In addition to changes in physical activity, adolescents are now turning to social media to stay socially connected during the physical isolation of the pandemic (Hamilton et al., 2021b; Munasinghe et al., 2020). Social media broadly encompasses digital tools used for social interaction, including social networking sites (SNS), text messaging apps, and video chatting. Given the importance of social relationships during adolescence, particularly for girls (Rose & Rudolph, 2006; Rudolph & Conley, 2005), teenagers are now engaged in social media activities at higher levels than before the pandemic (Ellis et al., 2020). Some teenagers are even spending between 3–5 h on social media per day (Ellis et al., 2020; Francisco et al., 2020), which is in sharp contrast to the current recommendations of 2 h/day (American Academy of Pediatrics, 2016). While more synchronous and active social media use can promote social connection and well-being during the

pandemic (Hamilton et al., 2021b), social media use also can displace and disrupt sleep (Scott & Woods, 2019). A growing body of research indicates that teenagers who spend more time on social media have later bedtimes, shorter sleep times, and poorer sleep quality (Carter et al., 2016; Scott & Woods, 2019). To date, few studies have evaluated social media use and sleep across multiple domains on a daily basis. One recent study found that adolescents who sent more messages than their peers had shorter actigraphy-derived sleep duration over a 3-day period (Burnell et al., 2021), but there were no within-person effects of daily social media use and sleep.

Adolescent girls may be particularly vulnerable to the potential negative effects of COVID-19 on sleep problems, including insomnia (Li et al., 2021), and mental health problems more generally (Hawes et al., 2021). Even beyond the pandemic, gender differences in insomnia and mental health disorders first emerge during adolescence (Marver & McGlinchey, 2020; Salk et al., 2017). Given that sleep is a major risk factor for depression and suicidal thoughts and behaviours (Liu et al., 2020), it is critical to identify modifiable risk factors for sleep among adolescent girls, especially during the high-stress period of the pandemic (Racine et al., 2021). The alterations in behaviours during the pandemic present a natural experiment in which to explore the between- and within-person differences in how physical activity and social media activities affect adolescent girls' sleep duration, timing, and quality. These behaviours also represent *modifiable* factors that are amenable to change, both directly and indirectly, and therefore can be targeted to promote sleep and well-being. Daily monitoring designs provide opportunities to examine these processes day-to-day, aggregate data to explore differences between adolescent girls using multiple assessments, and tease apart within-person fluctuations, thereby leading to a better understanding of behavioural factors that affect adolescent girls' sleep during a vulnerable period for mental health concerns (Racine et al., 2021).

1 | THE PRESENT STUDY

The present study used online subjective daily assessments to examine physical activity and social media use as predictors of daily and average sleep domains for 10 days during the COVID-19 pandemic (April–May 2020 in Pennsylvania, United States). Given increasing rates of depression and potential vulnerability to mental health effects from COVID-19 among adolescent girls (Hawes et al., 2021), the present study examined predictors of poor sleep health in a sample of girls selected to include two-thirds of participants at higher risk of future social anxiety and depression (Silk et al., 2021). It was hypothesised that girls who engaged in less physical activity and used more social media (social networking, video chatting, texting) on average during the 10-day period would have later sleep timing and poorer sleep quality overall. We also hypothesised that these relationships would be specific to sleep timing and sleep quality, but not sleep duration, given research indicating that teenagers had longer sleep duration during the initial phase of the pandemic due to school closures, the absence of regular schedules, and teenagers' increasing autonomy

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over their waketimes (e.g., Gruber et al., 2020). Limited research has examined the variability of day-to-day fluctuations of physical activity and social media use during the pandemic. Thus, we further explored whether daily associations of physical activity and social media use compared to girls' usual amount (over the 10-day period) would predict later sleep timing, poorer sleep quality, and shorter sleep duration. Given limited research comparing types of social media use, particularly on a day-to-day basis, there were no a priori hypotheses regarding which aspects of social media would be more strongly related to sleep outcomes in the present study.

2 | METHODS

2.1 | Participants and procedures

Participants included 93 adolescent girls aged 12–17 years (mean [SD] 15.06 [1.21] years) recruited from a larger longitudinal study ($N = 129$) to evaluate the development of depression and anxiety symptoms among adolescent girls. The larger study sample was enriched to have two-thirds of participants at temperamental risk of social anxiety and depression based on elevated scores (0.75 SD above the mean) on the Early Adolescent Temperament Questionnaire–Revised Version (EATQ-R; Ellis & Rothbart, 2001; Hamilton et al., 2021a). Adolescents were excluded from the larger study if they met criteria for current or past anxiety (except specific phobia), depressive, psychotic, or autism spectrum disorder at the time of recruitment. The present study included participants who consented for future contact ($n = 113$) and were sent information about the COVID-19 study ~20 days after the start of stay-at-home orders in the State of Pennsylvania.[1] Data were collected remotely between April and May 2020 for all participants, during which time all schools in the State of Pennsylvania were under State-mandated closures and provided only distance-learning options. Interested participants provided consent/assent online in accordance with the university's institutional review board. Participants completed the initial and follow-up study visits at the start and end of the daily diary assessments, respectively. On average, participants completed all procedures within a mean (SD) of 12 (3.17) days.

2.2 | Daily diary assessments

Participants completed online, smartphone-based subjective daily diary assessments over the course of 10 days using a link to the survey that was texted and emailed to participants at 7:00 p.m. each evening. All participants started the daily diary assessments on Friday and completed each diary between 7:00 and 11:00 p.m.

2.2.1 | Perceived sleep

Participants reported the time that they went to sleep the prior night ("What time did you go to sleep ['lights out'] last night?"), the time

they woke up that day ("What time did you wake up this morning?"), and quality of sleep ("How was the quality of your sleep last night?") on a sliding scale from 0 (very bad) to 100 (very good). Perceived sleep start times ("lights out") was used in the present study, and times were converted to a 24-h scale in which later times indicate later hours (i.e., 23 = 11:00 p.m.; 24 = 12:00 a.m., 25 = 1:00 a.m.). Sleep duration was estimated using only reported sleep start and wake times.

2.2.2 | Physical activity

Participants reported how much time they spent that day engaging in any exercise or physical activity (e.g., walking, yoga), with responses including "none (0)", "<15 min", "<30 min, "30 min–1 h", "1–3 h", "3–5 h", ">5 h (6)." Based on endorsed responses, physical activity was recoded with responses of 3–5 h or >5 h merged into one category of ≥3 h.

2.2.3 | Social media use

Participants indicated the time spent using social media and related social technologies that day using three items of video chatting, texting, and SNS. On the first item, participants reported approximately how much time they spent video chatting (e.g., Facetime) their friends outside of remote school using the following six response options of the following ranges: "<30 min", "30 min–1 h", "1–2 h", "2–4 h", "4–6 h", and ">6 h." For the last two items, participants reported approximately how much time they spent texting their friends and on SNS (e.g., TikTok, Snapchat, Instagram) using nine response options ("none", "<30 min", "0.5–1 h", "1–2 h", "2–4 h", "4–6 h", "6–8 h", "8–10 h", and ">10 h"). Based on low frequency of participant responses at the highest levels for each item, responses were collapsed into 2+ h for video chatting (revised scores ranged from 0 to 3), 4+ h for texting (revised scores ranged from 0 to 5), and 6+ h for social media (revised scores ranged from 0 to 6).

2.2.4 | Internalising symptoms

Participants reported daily depressive symptoms using six items adapted from the Patient Health Questionnaire (Allgaier et al., 2012) and daily anxiety symptoms using seven items from the adapted version of the Generalized Anxiety Disorder-7 (Spitzer et al., 2006). Participants rated each symptom that day on a 0–100 scale, which was averaged within and across days for between-person means of both depressive and anxiety symptoms. There was good internal reliability in the present study (all $\alpha = 0.93$). Internalising symptoms were included as covariates in the present study given known associations between symptoms of depression and anxiety and sleep.

2.3 | Statistical analyses

Multilevel modelling using R 3.6 was used to examine the within- and between-person effects of physical activity and social media use (social networking, texting, video chatting) on that night's sleep timing, duration, and quality. Given that sleep and behaviours were assessed simultaneously, a lead function was used in R to establish temporal associations between predictors and sleep outcomes. A random intercept and random slope of physical activity and social media on next-day sleep outcomes were included in all models to allow for individual variations from the intercept and slope. To disentangle the effects of between- and within-person effects, continuous predictors were both group-mean centred to create daily fluctuations from one's own typical mean within-person (e.g., how much a person varied from their own average on any given day), and grand-mean centred to create between-person means (e.g., individual means or averages compared to others over the 10 days). Both between-person means and person-centred daily fluctuations were included as primary predictors of that night's sleep in each model. Covariates included age- and person-means of both depression and anxiety symptoms over the study period to examine unique effects of predictors beyond that of internalising symptoms, which may affect sleep outcomes in adolescents (Marino et al., 2021).

3 | RESULTS

There was a total of 93 participants in the present study. Participants completed an average of 8.78 daily diaries (SD = 1.76; range = 1–10),

TABLE 1 Adolescent girls' daily behaviours across 10 days during the coronavirus disease 2019 (COVID-19) pandemic

Activity	Response options	Mean (SD)	% of participants who endorsed response item
Social networking sites	None	0.96 (2.13)	26.88
	<30 min	1.52 (2.48)	46.24
	30 min–1 h	1.42 (1.90)	59.14
	1–2 h	1.48 (1.96)	56.99
	2–4 h	1.62 (2.07)	54.84
	4–6 h	1.17 (2.06)	36.56
	6–8 h	0.42 (1.23)	16.13
	8–10 h	0.16 (0.58)	9.68
	>10 h	0.03 (0.23)	2.15
Texting	None	0.71 (1.70)	29.03
	<30 min	2.39 (2.77)	59.14
	30 min–1 h	2.16 (1.77)	75.27
	1–2 h	1.63 (1.97)	56.99
	2–4 h	0.98 (1.55)	39.78
	4–6 h	0.48 (1.12)	23.66
	6–8 h	0.28 (0.95)	11.83
	8–10 h	0.08 (0.45)	4.30
	> 10 h	0.08 (0.34)	5.38
Video chatting	<30 min	5.22 (2.94)	91.40
	30 min–1 h	1.28 (1.41)	61.30
	1–2 h	1.16 (1.44)	56.99
	2–4 h	0.77 (1.24)	43.01
	4–6 h	0.26 (0.67)	17.20
	> 6 h	0.08 (0.27)	7.53
Physical activity	none (0)	1.65 (2.25)	54.84
	<15 min	1.48 (1.83)	61.30
	<30 min	1.39 (1.52)	63.44
	30 min– h	2.56 (2.20)	80.65
	1–3 h	1.29 (1.60)	56.99
	3–5 h	0.32 (0.65)	25.81
	>5 h	0.10 (0.49)	5.38

Note: This table reports the mean (SD) of the number of days each response option was endorsed for each activity across participants. Percentages reflect the percentage of participants who endorsed this response item at any point over the 10-day daily diary period.

with 95% completing six or more diaries (out of 10). Adolescent girls self-reported their racial and ethnic identities and background. A total of 68.8% of the sample identified as White, non-Hispanic; 17.2% as Black, non-Hispanic; 8.6% as Biracial; 2.3% as Asian; and 2.2% as American Indian. On a categorical scale of perceived income from 0 (<$10,000) to 10 (≥$100,000), the mean (SD) was 7.48 (2.38). Correlations of perceived income and primary study variables indicated that higher incomes were correlated with more sleep ($r = 0.23$, $p < 0.05$) and earlier perceived sleep start times ($r = -0.30$, $p < 0.01$). Thus, income was added as a covariate in all study models. In the present study, 63% ($n = 59$) were determined to be at high risk of depression and anxiety based on temperamental risk (EATQ-R), and 37% ($n = 34$) were not high risk, thereby reflecting the larger study sample. Independent t tests indicated there were no differences on sleep outcomes, social media, or physical activity between those who

were classified as high risk and those who were not (all $t < 1.19$, all $p > 0.24$).

In general, adolescent girls received a mean (SD) 8.78 (1.18) h of sleep over the 10-day diary period, and girls reported going to sleep at ~1:30 a.m. (mean [SD] 25.41 [1.73]) and waking up at ~10:15 a.m. (mean [SD] 10.18 [1.54]). On average, sleep quality was 65% out of 100% (SD = 19.48%). A total of 5% of adolescents reported not using any SNS, one person did not report texting, and 15 (16%) did not engage in video chatting over the study period. See Table 1 for a summary of adolescents' daily behaviours. Correlations between mean-level primary study variables are presented in Table 2. Sleep duration and timing were negatively correlated ($r = -0.49$), such that later sleep timing was associated with shorter sleep. Sleep quality was not correlated with sleep timing or duration. All social media activities were positively correlated with one another.

TABLE 2 Correlation matrix of primary study variables

Variable	1	2	3	4	5	6	7	8
1. Sleep duration	–							
2. Sleep start times	−0.49**	–						
3. Sleep quality	0.15	−0.15	–					
4. Physical activity	0.17	−0.22*	0.09	–				
5. Social networking	−0.11	0.36**	0.04	0.12	–			
6. Video chat	−0.24*	0.38**	−0.04	0.06	0.22*	–		
7. Texting	−0.04	0.36**	0.06	0.11	0.56**	0.39**	–	
8. Anxiety symptoms	−0.01	−0.16	−0.40**	−0.04	−0.01	−0.02	−0.11	–
9. Depressive symptoms	0.00	−0.20	−0.50**	−0.10	−0.11	−0.09	−0.22*	0.84**

Note: Significant values are denoted by *$p < 0.05$ and **$p < 0.01$. All values reflect aggregated person-means across the 10-day ecological momentary assessment (EMA) period.

TABLE 3 Daily physical activity and sleep outcomes

	Sleep duration			Sleep timing			Sleep quality		
Predictors	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
Between-person									
(Intercept)	8.35	0.30	**<0.001**	26.08	0.38	**<0.001**	64.13	4.46	**<0.001**
Age	−0.06	0.10	0.52	0.21	0.13	0.10	0.28	1.49	0.80
Income	0.10	0.04	**0.03**	−0.15	0.06	**0.01**	0.37	0.66	0.57
Anxiety	−0.01	0.02	0.63	0.02	0.02	0.43	0.06	0.27	0.82
Depression	0.01	0.02	0.68	−0.05	0.03	0.10	−1.05	0.32	**<0.01**
Physical activity mean	0.16	0.13	0.22	−0.38	0.16	**0.02**	0.51	1.86	0.78
Within-person									
Physical activity	0.04	0.05	0.49	−0.02	0.04	0.63	0.66	0.65	0.31
Random effects									
Residual (σ^2)	**1.50**			**1.28**			**18.94**		
Intercept (τ_{00})	**0.98**			**1.35**			**15.09**		
Physical activity	**0.13**			**6.10**			**1.66**		

Note: Physical activity mean reflects the person-level means (averages) across the 10-day period of physical activity duration per day. Physical activity at the within-person level reflects the individual fluctuations within-person from their own individual means on a daily basis. Significant values denoted in bold.

Overall, there was considerable variability both between- and within-people in sleep over the study period (Figure S1), such that 69% of the variance in sleep duration, 40% of the variance in sleep timing, and 52% of the variance in sleep quality occurred at the between-person level compared to within-person. Thus, individuals varied considerably in perceptions of how much they slept, what time they fell asleep, and how well they slept during the daily diary period. Across the sample, most of the variability in social networking and texting occurred between people (73% and 63%, respectively), whereas much of the variability was within-person for video chatting (34% between) and physical activity (37% between) (Figure S2), which still provided sufficient variability to evaluate within- and between-person effects in these relationships.

Physical activity and sleep

There was no significant effect of daily changes in physical activity from an individual's mean on perceived sleep timing, duration, or quality (Table 3). However, there was a significant between-person effect of physical activity on sleep timing, such that girls who exercised less on average per day reported later sleep timing. There were no effects of physical activity on average sleep duration or quality.

Social media activities and sleep

Overall, there were no significant effects of individual fluctuations in the amount of social media use, including social networking, text, and video chatting, and that night's sleep duration, timing, or quality on a daily basis. However, on average, all social media activities were associated with later sleep timing across the study period (Table 4), indicating that individuals who engaged in more social media use on average were more likely to have later sleep timing. Interestingly, there were no effects of average social networking or texting on sleep duration, but there was an effect of average video chatting (Table 4), such that girls who video chatted more had shorter sleep per night on average. There was no effect of any type of social media use on sleep quality (Table 4), and only depressive symptoms significantly predicted lower sleep quality.

4 | DISCUSSION

Through the unique lens of the COVID-19 pandemic, the present study examined two potentially modifiable risk factors, physical activity and social media use, on a daily basis to disentangle their effects on self-reported sleep duration, timing, and quality among adolescent

TABLE 4 Daily social media use and sleep outcomes

Predictors	Sleep duration			Sleep timing			Sleep quality		
	Estimate	SE	*p*	Estimate	SE	*p*	Estimate	SE	*p*
Between-person									
(Intercept)	8.81	0.25	**<0.001**	24.30	0.30	**<0.001**	67.00	3.66	**<0.001**
Age	−0.04	0.08	0.64	0.18	0.20	0.12	0.31	1.45	0.83
Income	0.11	0.04	**0.02**	−0.18	0.05	**0.001**	0.46	0.64	0.48
Anxiety	0.00	0.02	0.93	0.01	0.02	0.73	0.10	0.26	0.70
Depression	0.001	0.02	0.94	−0.02	0.03	0.39	−1.11	0.32	**<0.001**
Social networking sites (SNS)									
SNS mean	−0.47	−0.08	0.58	0.34	0.10	**<0.001**	−0.64	1.16	0.58
SNS within	−0.06	0.08	0.49	0.08	0.08	0.32	−0.48	0.93	0.60
Text									
Text mean	−0.03	0.09	0.75	0.38	0.11	**0.001**	−1.25	1.37	0.36
Text within	−0.09	0.07	0.18	−0.04	0.06	0.44	−0.01	0.89	0.98
Video chat									
Video chat mean	−0.36	0.17	**0.04**	0.74	0.22	**<0.001**	−1.57	2.62	0.55
Video chat within	0.02	0.07	0.82	−0.03	0.06	0.60	0.58	1.01	0.57
Random effects									
Residual (σ^2)	**1.48**			**1.23**			**18.99**		
Intercept (τ_{00})	**0.99**			**1.30**			**15.18**		
SNS	**0.35**			0.39			2.41		
Text	<0.01			0.13			2.78		
Video chat	<0.001			0.004			3.74		

Note: SNS, social networking sites. SNS, text, and video chat multilevel models were conducted separately, with similar estimates for model covariates, intercept, and random effects. Mean levels of social media reflects the person-level means (averages) of duration per day across the 10-day period. Within-person level reflects the individual fluctuations within-person from their own individual means on a daily basis. Significant values denoted in bold.

girls over a 10-day period. Descriptively, our findings support research conducted during the earlier phases of the pandemic finding that adolescents report more sleep per night and are going to bed later than before the pandemic (Francisco et al., 2020). Our findings also indicate that girls are engaging in relatively high levels of social media use and low levels of physical activity per day compared to recommended ranges (American Academy of Pediatrics, 2016; Lobelo et al., 2020) and before the pandemic (Ellis et al., 2020; Munasinghe et al., 2020). The present study used daily diaries to examine these behaviours day-to-day rather than relying on a single assessment point, which may better capture daily variations and overall estimates of these behaviours.

Surprisingly, there were no within-person effects of individual fluctuations in social media use or physical activity compared to a person's usual amount on daily sleep outcomes over this short-term period, which is consistent with some prior studies (Das-Friebel et al., 2020; Youngstedt et al., 2003). However, our findings indicate that girls who use more social media and engage in less physical activity on average report going to sleep later than their peers, and those with higher levels of video chatting have shorter sleep duration. The absence of structured activities, such as school, physical activity, and social interactions, may result in irregular time cues for bedtime and other activities that lead adolescent girls to stay up later, especially because they are able to wake later. Limited space in one's home and reduced ability to be outside for regular physical activities may lead to spending more time in one's room and limit exposure to natural light, which can disrupt sleep and circadian rhythms (Wams et al., 2017). These findings highlight the importance of having regular cues throughout the day to keep routines and activities more structured during a time in which there are fewer social cues (e.g., school, extra-curricular activities, socialising) to promote healthy sleep and well-being. In particular, implementing time cues and monitoring these behaviours may be particularly important among adolescent girls, who are already at heightened risk of negative mental health consequences from the pandemic (Hawes et al., 2021).

This study is among the first to demonstrate the significant variability of daily social media use across modalities, including social networking, video chatting, and texting with peers, suggesting that social media use is not static but represents a more dynamic and potentially modifiable behaviour to target for sleep. Girls reported engaging in less video chatting than other forms of social media, which is concerning given that video chatting is more synchronous, has more similar features to in-person social communication (Nesi et al., 2018), and is associated with social connection and well-being (Hamilton et al., 2020). However, the present study did not distinguish specific behaviours within social networking, which includes both passive consumption (e.g., scrolling) and active engagement (e.g., messaging) with others, which may differentially affect sleep and well-being. Importantly, it is unclear how representative these behaviours are compared with other periods of time before, during, or post-pandemic; although our study provides preliminary evidence for the importance of examining these behaviours on a more fine-grained scale. Thus, it will be critical to examine the longer-term patterns of these behaviours to evaluate whether our findings reflect new or temporary patterns of behaviours during COVID-19 with potential health consequences, and the extent to which pandemic-related stress impacts observed associations.

There are several limitations to our study, including self-reported assessments of sleep. Perceptions of sleep timing may not accurately reflect sleep onset, but rather the start of the sleep attempt. Sleep duration also was calculated using reported sleep start and wake times, but did not include sleep onset latency or wake after sleep onset. Thus, sleep duration in the present study may be confounded with time in bed from the start of the sleep attempt to perceived wake time. Although the daily diary design is a strength, sleep was assessed in the evening rather than in the morning, which may influence the accuracy of reported sleep. Future studies should use both daily diaries and actigraphy to better capture multiple sleep domains. Further, our daily measures only ascertained duration of activities and not the quality, experiences, timing, or type of engagement, which is important in understanding their potential impact on sleep health (Scott & Woods, 2019). For instance, physical activity included any activity endorsed, and did not evaluate exercise by intensity level, which differently affects sleep and health (Ng et al., 2021). There also were different response options for social media behaviours and physical activity, which may have affected adolescents' responses and introduced measurement bias. Although treated continuously, these options also were categorical, which limits practical interpretation of their coefficients and effects in the present study. Our sample was predominantly White, which likely restricts generalisation to girls who are Black, Hispanic/Latinx, Asian, or Indigenous, particularly given the disproportionate impact of COVID-19 on these communities (Andrasfay & Goldman, 2021) and racial and ethnic sleep disparities (Guglielmo et al., 2018). Our sample also included only adolescent girls, two-thirds of whom were at high temperamental risk of depression and anxiety, which limits our ability to test gender differences in these relationships and to generalise these findings to all adolescent girls.

5 | CONCLUSIONS

Our study represents a valuable contribution to our understanding of adolescent girls' sleep patterns and associations with physical activity and social media use during the COVID-19 pandemic. Our findings that lower levels of physical activity and higher levels of social media use are associated with later sleep timing, point to the potential role of these modifiable behaviours in adolescent sleep health and potential circadian disruption, and the importance of time cues such as physical activity and social interactions in maintaining healthy sleep. Critically, these behaviours do not exist in isolation and likely influence one another to disrupt or promote sleep. Monitoring these behaviours, as well as maintaining and promoting regular routines and behaviours (Bates et al., 2020) are important in adolescent sleep health. Maintaining healthy sleep and circadian rhythms is critical to helping adolescents cope with the psychological toll of the ongoing COVID-19 pandemic and physically stay healthy.

AUTHOR CONTRIBUTIONS

Jessica L. Hamilton conceived of the present study, conducted analyses, and drafted manuscript. Emily Hutchinson assisted with study analyses and manuscript preparation. Maria R. Evankovich assisted with manuscript preparation. Cecile D. Ladouceur co-designed the original study design and provided critical review of the manuscript. Jennifer S. Silk co-designed the original study design, provided resources to conduct the study, and provided critical review of the manuscript.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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ENDNOTE

[1] Stay-at-home orders by the Pennsylvania Governor were as follows: All individuals are "ordered to stay at home except as needed to access, support, or provide life sustaining business, emergency, or government services."

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