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SCIENTIFIC INVESTIGATIONS

A sleep promotion program for insufficient sleep among adolescents: a pilot feasibility randomized controlled trial

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Study Objectives: We examined the feasibility, acceptability, and impact of a sleep promotion program (SPP).

Methods: This pilot trial randomly assigned adolescents (13–15 years of age) with insufficient sleep duration and irregular sleep timing to SPP-continuation (n = 24; SPP in month 1, continuation treatment in month 2) or monitoring-SPP (n = 20; monitoring in month 1, SPP in month 2). SPP included 1 clinician session and at-home delivery of web-based reports of each youth's sleep diary data with accompanying intervention questions that prompt youth to engage in sleep behavior change. Attrition rate primarily measured feasibility. Program satisfaction measured acceptability. Total sleep time, sleep timing, and sleep timing regularity were measured via sleep diary at baseline, Follow-up 1, and Follow-up 2 (each ∼1 month apart). Linear mixed-effects models compared treatment arms on changes in sleep from baseline to Follow-up 1 (month 1). We also compared changes in sleep during month 1 to changes in sleep during month 2 among SPP-continuation participants.

Results: Attrition rate was 8.5%, and 96.5% of participants rated the quality of care received as good or excellent. In month 1, SPP-continuation youth showed a significantly greater increase in mean total sleep time than monitoring-SPP youth (0.57 vs −0.38 hours; contrast = 0.95; confidence interval = 0.14, 1.76; $P = .024$). SPP-continuation participants showed an increase in total sleep time during month 1 (0.51 hours) but a decrease during month 2 (−0.74 hours; contrast = −1.24; confidence interval = −2.06, −0.42; $P = .005$). No other significant effects were observed.

Conclusions: SPP is highly feasible, acceptable, and associated with a significant increase in total sleep time early in treatment.

Clinical Trial Registration: Registry: ClinicalTrials.gov; Name: Targeted Intervention for Insufficient Sleep among Typically-Developing Adolescents; URL: https://clinicaltrials.gov/ct2/show/NCT04163003; Identifier: NCT04163003.

Keywords: youth, irregular sleep, sleep duration, behavioral treatment

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BRIEF SUMMARY

Current Knowledge/Study Rationale: There are very few brief, scalable sleep promotion programs for insufficient adolescent sleep.

Study Impact: During month 1, our sleep promotion program was associated with a greater increase in total sleep time, via a delay in wake-up time, relative to monitoring. Youth in both treatment arms delayed their sleep timing, but those in sleep promotion program did so to a greater degree. Future work should examine whether equivalent changes in total sleep time resulting from changes in sleep timing (advance or delay) are associated with differences in downstream benefits on subjective levels of alertness, health, and functioning, as a function of whether the change in sleep timing is more or less in line with the individual's preferred circadian phase.

INTRODUCTION

Insufficient sleep is highly prevalent during adolescence.[1–4] The normative delay in adolescent sleep timing, combined with the need to wake up early on weekday mornings to arrive on time to school, frequently results in insufficient sleep duration.[5–7] Adolescents often "catch up" on short weekday sleep by sleeping longer and later on the weekends, contributing to irregular weekday–weekend sleep–wake schedules.[4,8,9] Sleeping in on weekends can make it more difficult for adolescents to fall asleep on Sunday night, further contributing to short sleep duration at the start of the school week and a mini jetlag on Monday morning.[7,10] This pattern of short and irregular sleep is associated with numerous adverse consequences, such as increased risk of depression, substance use, suicidality, poorer academic performance, and poorer physical health.[1,11–16]

Several cognitive behavioral programs for adolescent sleep have been developed that significantly improve sleep behaviors.[17–19] For example, a 2017 review of behavioral sleep interventions for adolescents reported improved self-reported sleep onset latency, total sleep time (TST), wake after sleep onset, and sleep efficiency, among other outcomes.[18] Yet, most sleep-focused programs target insomnia symptoms and processes,[17,20] rather than the short sleep duration and irregular sleep timing that are highly pervasive and

problematic among adolescents. Further, most existing programs involve at least 6 face-to-face sessions, and some trials testing these programs did not include a controlled condition.[17–19]

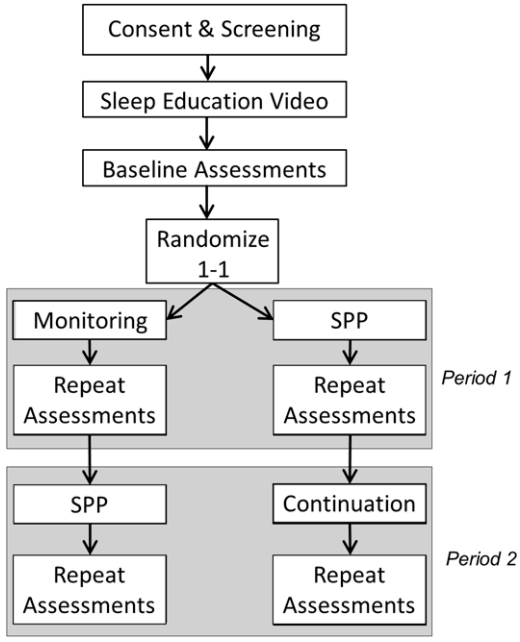
Other sleep promotion programs have been developed specifically to address insufficient sleep, which have been primarily implemented in the school setting.[21–26] Though these have been associated with improved *knowledge* about sleep, most have been limited in terms of clinical significance and sustained effectiveness.[21,24,25,27,28] These limitations may result from a focus on *all* students (some of whom may have good sleep with little room for improvement) rather than only those with poor sleep, limited focus on motivation, minimal involvement of parents and caregivers, and emphasis on psychoeducation alone to bring about behavior change.[23–25,29] Needed are sleep interventions that reach a large number of adolescents and effectively improve sleep behaviors.[22,24]

We developed a brief, scalable, behavioral sleep promotion program (SPP) for insufficient and irregular adolescent sleep that addresses these challenges by (1) targeting youth who report short sleep duration and irregular sleep timing; (2) delivering the program in a personalized, 1-on-1 format; (3) including parents in the program session; (4) leveraging automated smartphone technology to deliver some program components; and (5) increasing motivation for changing sleep by using a motivational interviewing framework.[30–32] As a health promotion program, our SPP intended to enable young people to improve their sleep duration and regularity via increased sleep-related knowledge and sleep behavior change. The SPP included personalized feedback on each participant's sleep to promote sleep behavior change,[33] which can increase an individual's awareness of their behavior and help identify a discrepancy between where one is and where one wants to be.[31,33] To develop a feasible and acceptable program, we worked collaboratively with adolescents and emerging adults, parents of adolescents, and health care providers working with adolescents, to inform program development prior to implementation and testing. Qualitative findings of this formative research have been reported previously.[34]

We subsequently conducted a 2-period pilot randomized controlled trial. Participants were randomized to SPP followed by a continuation phase (SPP-continuation) or to sleep monitoring followed by SPP (monitoring-SPP) (**Figure 1**). Here we report on the primary aims of the trial. Aim 1 examined the feasibility and acceptability of the SPP. We hypothesized that the SPP would be both feasible and acceptable (< 20% on attrition rate, satisfaction scores on program format and content, rate of attendance at clinician sessions, and response rate to electronic intervention prompts). Aim 2 examined the initial impact of the SPP program on sleep behavior (sleep diary–measured TST, sleep onset time, wake up time, and regularity of sleep timing [difference in weekday–weekend sleep onset and wake-up times]). We hypothesized that participants randomly assigned to SPP-continuation would demonstrate greater improvement in the primary sleep outcomes during Period 1 (from baseline to Follow-up 1) compared to participants randomly assigned to monitoring-SPP, who solely monitored their sleep during Period 1.

Among participants randomly assigned to SPP-continuation, we also examined whether any improvements in sleep observed during SPP (Period 1) remained during continuation (Period 2). Separately among participants randomly assigned to monitoring-SPP, we examined differences in sleep behavior observed during sleep monitoring (Period 1) and SPP (Period 2) to determine whether participants showed greater improvement in sleep behaviors during the intervention period compared with the preceding monitoring period. We did not directly compare the 2 groups during Period 2 because it consisted of SPP continuation treatment for the SPP-continuation group and an initial SPP program for the monitoring-SPP group; because these are different stages of treatment, their comparison was not a priority in this feasibility pilot study.

Figure 1—Study design.



SPP = sleep promotion program.

METHODS

Participants and eligibility

Youth were eligible if they were (1) ages 13 years, 0 months to 15 years, 11 months and (2) able and willing to give informed assent to participate (with informed consent from parent). They were further eligible if they reported (3) insufficient sleep (≤ 7.5 hours sleep on average weeknights) and (4) weekend–weekday sleep timing shift ≥ 1.5 hours, per youth or parent (School Sleep Habits Survey).[35] Youth were excluded if they (1) had unstable medical conditions; (2) used psychotropic medications or medications or supplements known to affect sleep; (3) were pregnant; (4) had clinical levels of psychopathology; (5) had evidence of intellectual disability, pervasive developmental disorder, or organic central nervous system disorder; (6) had current sleep disorders except for sleep-onset insomnia; (7) reported extreme evening preference on the School Sleep Habits Survey; or (8) lived more

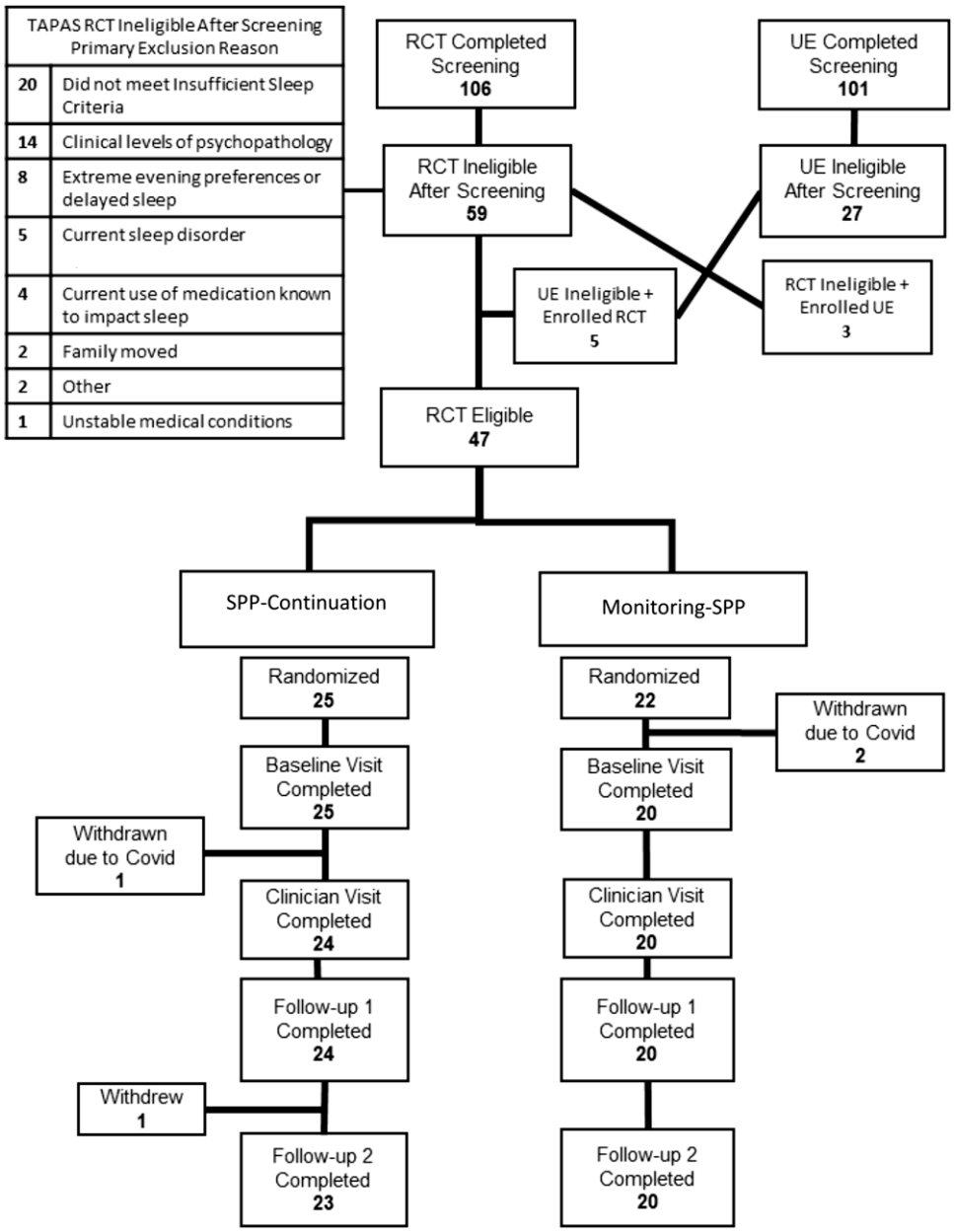
than an hour's drive from Pittsburgh, Pennsylvania. Original inclusion criteria included ≥ 2 hours of weekend–weekday sleep timing shift, but this was changed to ≥ 1.5 hours in February 2020 because many participants were just under the 2-hour shift criterion and they represented the youth we were interested in studying. Eligibility criteria were not applicable for parents.

A CONSORT diagram is illustrated in **Figure 2**. A total of 390 participants expressed interest in participating, of whom 207 completed screening and 47 met full eligibility criteria and were enrolled in the study. Three were withdrawn by investigators due to COVID-19–related changes in sleep affecting their eligibility (2 withdrawn prior to completing baseline, 1 withdrawn after baseline but before intervention). These individuals were not included in our final analytic sample. Our final sample included 44 youth participants recruited via the University of Pittsburgh Research Registry (Pitt+Me), through community and online advertisements, and by advertising our study with individuals who have previously participated in our colleagues' research studies at the University of Pittsburgh.

Study design and overview

This is a 2-period pilot randomized controlled trial that emphasized feasibility and acceptability. Accordingly, it was not designed to be a fully powered efficacy trial. All participants watched a 2-minute

Figure 2—CONSORT diagram.



RCT = randomized controlled trial, TAPAS = targeted approaches for promoting adolescent sleep, UE = universal education only (those who reported good sleep and were only eligible to view the sleep video).

sleep education video before being randomized, per the Screening, Brief Intervention and Referral to Treatment (SBIRT) model.[36] The goal of the video was to provide basic information about sleep to *all* study participants, including consequences of insufficient sleep, recommended sleep duration, contributors to insufficient sleep, and healthy sleep habits. Participants were then assigned to 1 of 2 pathways: SPP-continuation participants received SPP in Period 1 followed by continuation SPP treatment in Period 2. Monitoring-SPP participants monitored their sleep in Period 1 and then received SPP in Period 2 (**Figure 1**). SPP was intended to last 1 month (Period 1 for SPP-continuation or Period 2 for monitoring-SPP), including 1 clinician session followed by smartphone-based intervention prompts. Those receiving SPP first were meant to monitor their sleep only during Period 2. However, due to a computer programming error, for participants in SPP-continuation the smartphone-based intervention prompts were not turned off during Period 2, and thus they continued to receive the prompts during that month as well (ie, continuation SPP treatment).

Youth were enrolled in the study from November 2019 to June 2022. Nearly the entire trial (all except 4 months) was conducted during the COVID-19 pandemic, including the shelter-in-place period. In March 2020, we shifted all study procedures to occur remotely, including online assessments and conduct of study visits and clinician sessions via Health Insurance Portability and Accountability Act–compliant videoconference. The study was completed in August 2022. Youth were compensated for their participation. Parents were reimbursed for parking expenses only. The study was approved by the University of Pittsburgh Human Research Protection Office.

Randomization

Enrolled youth were randomly assigned using a permuted block randomization (block size of 4), stratified by sex at birth (male, female) and school level (middle school vs high school) in a 1:1 design. These strata were chosen given the known sex differences in sleep and the significant changes in sleep duration that occur during the middle-to-high school transition.[37–39] Participants, study staff, and study clinicians were not blinded to randomization. After a participant was enrolled a study data manager generated the randomization scheme using a computer-generated random number list, which was then shared with the study coordinator.

Procedures

Adolescents and parents completed preconsent screening online. Those who denied a history of psychopathology and who indicated insufficient sleep completed consent/assent, were asked to complete postconsent screening, and watched the 2-minute sleep education video. Those who remained eligible were enrolled and randomized and then completed their baseline assessment, which included questionnaires and 1 week of sleep diary and actigraphy. An actigraph is a wristwatch-sized device (Actiwatch 2; Philips Respironics, Murrysville, Pennsylvania) worn on the nondominant arm that captures movement and ambient light levels as a proxy for sleep. Youth were asked to complete a daily sleep diary for the duration of their study participation. Sleep diary data were used by the therapists to inform treatment and were analyzed as primary sleep outcome data. Actigraphy data were used by therapists to inform treatment if available (during the COVID-19 pandemic, watches were mailed back by participants, but some watches were not received in time for the clinician visit). Youth randomly assigned to SPP-continuation had their clinician session 1–2 weeks after their baseline visit, followed by 2 follow-up visits occurring 1 and 2 months after the clinician visit. Youth randomly assigned to monitoring-SPP completed their first follow-up visit approximately 1 month after baseline. Their clinician session occurred about 1 week after Follow-up 1, with their second follow-up occurring 1 month after their clinician session. We enrolled participants year-round. In this study, those receiving SPP-continuation continued to receive SPP smartphone-based prompts during Period 2, rather than the intervention prompts being turned off, and thus we labeled this *continuation* SPP treatment.

Intervention arms

SPP

The SPP aims to increase knowledge about healthy sleep practices, increase sleep duration and regularity in sleep timing over the week, and build motivation and efficacy for changing sleep behaviors. Based in the Theory of Planned Behavior and the Attitude, Social Influence, Self-Efficacy model,[40,41] SPP uses a motivational interviewing[30,31] framework to deliver evidence-based strategies for improving sleep. SPP includes 1 face-to-face session with a clinician, followed by automated web-based communication, including twice-weekly (Friday and Sunday) summary reports of each youth's sleep diary data with accompanying intervention questions that prompt youth to assess and update their sleep behavior change goals (see the supplemental material for smartphone-based intervention questions). Sessions lasted about 60 minutes and were recorded. Sessions were held in-person prior to the pandemic (n = 9) and via videoconference otherwise (n = 35). During the session, youth met with the clinician to discuss the findings of their sleep diary and actigraphy data, to discuss healthy sleep practices, to build motivation for improving sleep, and to set goals and discuss strategies for doing so. In addition to sleep education, evidence-based strategies included regularizing sleep and wake routines, resolving barriers to sleep (eg, improved time management), stimulus control, identifying and challenging sleep-interfering beliefs, establishing a wind-down routine, and managing technology use.[17,20,42–45] The clinician helped to build discrepancy between the youth's current sleep pattern and the pattern they would like to have and worked to link improved sleep with outcomes of interest to the adolescent. Specific goals were collaboratively set by the clinician and adolescent, with a discussion of possible strategies to use for achieving those goals. Parents were involved in the first ~10 minutes of the session to review session goals, discuss confidentiality, and discuss the role of parents, as well as the last ~10 minutes, when the youth and clinician collaboratively summarized the session and discussed strategies for how the parent could support the youth in pursuing the goals that were set.

Regarding the web-based intervention components, on Fridays and Sundays youth received a text message containing a link to a report showing the summary of their sleep diary data. Summary reports reflected the past week's sleep diary, as well as

week-by-week sleep timing for weekday and weekend, and a comparison of the participant's past-week sleep duration with established norms (**Figure 3**). After reviewing the report, youth were invited to answer questions prompting them to update their sleep behavior change goals, to describe their reasons for making changes to their sleep, and to report on their confidence in and importance of doing so (see supplemental material). Questions were tailored to each participant's past week sleep pattern. Reports and questions were viewed and completed online as home-based intervention components. Sunday prompts focused on reducing insufficient sleep duration during the coming school week. Friday prompts focused on reducing weekday–weekend sleep timing discrepancy during the upcoming weekend.

SPP therapists were clinical psychology graduate students, social workers embedded in an adolescent medicine clinic, and a licensed clinical psychologist (J.C.L.). Therapist training included review of the SPP manual, didactic instruction, and role play (about 4 hours). Clinicians attended weekly or biweekly supervision with the principal investigator. Sessions were delivered in the adolescent medicine clinic, in the principal investigator's research offices, and via videoconference.

Monitoring

Youth randomly assigned to monitoring-SPP received no intervention components during Period 1. They were only asked to complete a daily sleep diary, as was standard for all participants throughout the trial. Monitoring only was chosen as the control condition to allow us to offer participation in the active intervention to all participants, enhancing ethical acceptability of the study. Second, the design includes follow-up of the SPP-continuation group, allowing us to test whether improvements are sustained.

Measures

Feasibility was measured by attrition rate (expected < 20%; primary measure of feasibility), proportion of participants who attended the clinician session (expected ≥ 80%), and rate of

Figure 3—Sample sleep summary report.

TST = total sleep time.

response to mobile intervention prompts (expected ≥ 80%). Acceptability was measured by youth and parent satisfaction as reported on the Intervention Satisfaction Questionnaire (mean ratings ≥ 80% as acceptable), a locally developed measure of satisfaction with the intervention program and research study.

Screening measures

Youth and parents completed the School Sleep Habits Survey,[35] a self- and parent-report of youth sleep patterns. Youth completed a locally developed Sleep Disorders Screening Questionnaire to identify those at high risk of having a sleep disorder, as well as the Mood and Feelings Questionnaire,[46–48] the Self-Report for Childhood Anxiety Related Disorders,[49] and a brief demographic survey. Parents reported on the demographic information of themselves and their children, including the MacArthur Subjective Social Status Scale.[50] They also reported on child symptoms of attention deficit hyperactivity disorder via the Vanderbilt Assessment Scale.[51,52]

Sleep outcomes

Twice per day youth completed a web-based version of the Pittsburgh Sleep Diary,[53] consisting of items pertaining to daytime and nighttime sleep and wake behaviors. An a priori decision was made to focus on changes in TST, sleep onset time, sleep offset time, regularity of sleep onset timing, and regularity of sleep offset timing (differences in weekday–weekend sleep onset and offset) because those reflect the goals of the sleep program.

Calculation of sleep diary data

We used sleep diary data given the increased accuracy of reporting via prospective sleep diary compared to retrospective self-report.[54] Diary data were collected during the week following the baseline visit and the week leading up to the follow-up visits. To be included in our sleep diary analyses, participants had to have at least 4 days of diary data within those 7-day windows and at least 1 weekend day and 2 weekdays to have a reliable estimate of sleep.[55]

Analytic plan

For acceptability and feasibility, our strategy was to compute summary statistics (eg, mean and standard deviation for continuous measures, percent and frequency for categorical measures) of attrition rate, rate of response to electronic intervention prompts, rate of attendance at clinician sessions, and satisfaction scores on program format and content.

We used Cohen's d effect sizes to quantify and compare improvements in sleep during Period 1 between participants randomly assigned to each arm. To accommodate missing longitudinal data, we ran a generalized linear mixed-effects model regressing each of the sleep outcomes on time point (Baseline and Follow-up 1), treatment group, and treatment × time point interaction, adjusting for participant sex at birth, age, pubertal status, middle vs high school, and socioeconomic status. We subsequently ran a priori pairwise contrasts to compute effect sizes (95% confidence intervals) quantifying the within-person changes from Baseline to Follow-up 1 within each arm, as well as the differences in slopes between the arms.

To quantify maintenance of intervention effects in SPP-continuation, and the effect of the SPP intervention in monitoring-SPP, we quantified the amount of change from Baseline to Follow-up 1 (ie, during Period 1) and from Follow-up 1 to Follow-up 2 (ie, between Period 2) in each arm separately. Because our interest was not in the between-group comparison, we fit linear mixed effects in each treatment group separately. Specifically, within each treatment group we regressed each sleep outcome on time point (Baseline, Follow-up 1, Follow-up 2), adjusting for the covariates listed above. A priori pairwise contrasts assessed differences in slopes between each time point.

The trial will be reported according to CONSORT guidelines.[56]

RESULTS

Sample characteristics

Participant demographics by treatment arm are shown in **Table 1**. Though participants at high risk for insomnia or delayed sleep–wake phase disorder were eligible for the study, we did not enroll any participants at high risk for those disorders.

Feasibility

Forty-four participants (24 in SPP-continuation and 20 in monitoring-SPP) were included in our full sample and received the SPP. One participant who was randomized to SPP-continuation withdrew prior to study completion (just prior to the second follow-up visit due to being too busy) and 3 participants were withdrawn by investigators in April 2020 due to COVID-19–related changes in the eligibility, resulting in an attrition rate of 8.5%. When the COVID-19 pandemic began, the authors paused study activities for about a month while shifting to entirely remote procedures. Upon resuming, active participants were reassessed to ensure they still met our eligibility criteria, given changes to sleep and schedules that resulted from shelter in place orders. Three participants no longer met our eligibility criteria and thus were excluded. They were not included in data analyses. Two had not completed baseline assessments, and 1 had completed baseline but had not completed any intervention components.

We calculated response rates to the Sunday and Friday mobile intervention prompts in the month following the clinician session. The overall Sunday and Friday completion rates were 51.2% (standard deviation [SD] = 39.7%) and 53.4% (SD = 39.5%), respectively, with slightly decreasing trends over 8 weeks (**Figure 4**; a few participants completed more than 8 weeks of prompts due to scheduling delays, but only 8 weeks is depicted because this was the planned intervention duration and given small sample sizes in the outlying weeks). Participants tended to complete none (∼22%), some (∼45%), or all (∼27%) of their Sunday prompts and tended to complete none (∼22%), some (∼54%), or all (∼22%) of their Friday prompts.

Program session details

Per clinicians' reports, clinician sessions lasted an average of 52 minutes (SD = 9 minutes). Session duration was nearly

Table 1—Demographic, clinical, and sleep characteristics.

	Baseline SPP-Continuation	Baseline Monitoring-SPP	Baseline All
Age	14 (0.75)	13.85 (0.69)	14 (0.72)
Female sex, n (%)	10 (41.7)	7 (35.0)	17 (38.6)
Female gender identity, n (%)	10 (41.7)	7 (35.0)	17 (38.6)
Race, n (%)			
White	20 (83.3)	15 (75.0)	35 (79.6)
Black	2 (8.3)	4 (20.0)	6 (13.6)
More than 1 race	2 (8.3)	1 (5.0)	3 (6.8)
Education			
Private school	6 (25.0)	6 (30.0)	12 (27.3)
Public school	18 (75.0)	14 (70.0)	32 (72.7)
Living situation			
Adoptive parents	1 (4.2)	0 (0.0)	1 (2.3)
Both biological parents	17 (70.8)	15 (75.0)	32 (72.7)
Biological mother and stepfather	2 (8.3)	0 (0.0)	2 (4.6)
Biological mother only	4 (16.7)	5 (25.0)	9 (20.5)
Middle school, n (%)	10 (41.7)	9 (45.0)	19 (43.2)
Tanner stage, mean (SD)[a]	3.5 (0.75)	3.67 (0.77)	3.56 (0.75)
Subjective social status (range 1–10)[a]	4.57 (1.75)	4.17 (1.62)	4.38 (1.68)
School start time, mean clock time (SD in minutes)	7:58 (00:29)	7:52 (00:37)	7:55 (00:32)
MFQ	6.38 (6.30)	6.5 (6.5)	6.43 (6.32)
SCARED	11.50 (7.95)	9.85 (7.29)	10.75 (7.61)

	SPP-Continuation			Monitoring-SPP			All		
	Baseline Mean (SD)	FU 1 Mean (SD)	FU 2 Mean (SD)	Baseline Mean (SD)	FU 1 Mean (SD)	FU 2 Mean (SD)	Baseline Mean (SD)	FU 1 Mean (SD)	FU 2 Mean (SD)
Average difference in weekend–weekday sleep onset (hours)	1.19 (0.98)	0.57 (0.96)	0.41 (1.27)	0.9 (1.59)	0.44 (1.3)	0.85 (1.14)	1.06 (1.28)	0.51 (1.12)	0.59 (1.22)
Average difference in weekend–weekday sleep offset (hours)	1.79 (1.54)	1.43 (1.37)	1.39 (2.17)	1.22 (1.69)	1.07 (1.34)	1.78 (1.54)	1.53 (1.61)	1.26 (1.34)	1.55 (1.92)
Average weekday sleep onset	23:24 (0:57)	23:58 (1:23)	00:25 (1:29)	23:37 (1:08)	00:04 (1:57)	23:26 (1:31)	23:30 (1:02)	00:01 (1:38)	00:01 (1:33)
Average weekday sleep offset	7:01 (0:54)	7:58 (1:38)	7:53 (1:43)	7:28 (1:26)	7:45 (1:44)	7:16 (1:22)	7:13 (1:11)	7:52 (1:40)	7:38 (1:35)
Average weekend sleep onset	0:35 (1:13)	0:32 (1:20)	0:50 (0:57)	0:31 (1:09)	0:31 (1:24)	0:17 (1:16)	0:34 (1:10)	0:31 (1:20)	0:37 (1:06)
Average weekend sleep offset	8:49 (1:17)	9:24 (1:26)	9:17 (1:52)	8:42 (1:18)	8:49 (1:26)	9:02 (1:06)	8:46 (1:17)	9:08 (1:26)	9:11 (1:35)
Average total sleep time (hours)	8.05 (0.82)	8.47 (0.9)	8.16 (1.23)	8.25 (0.92)	8.17 (0.96)	8.33 (0.67)	8.14 (0.86)	8.33 (0.93)	8.23 (1.03)

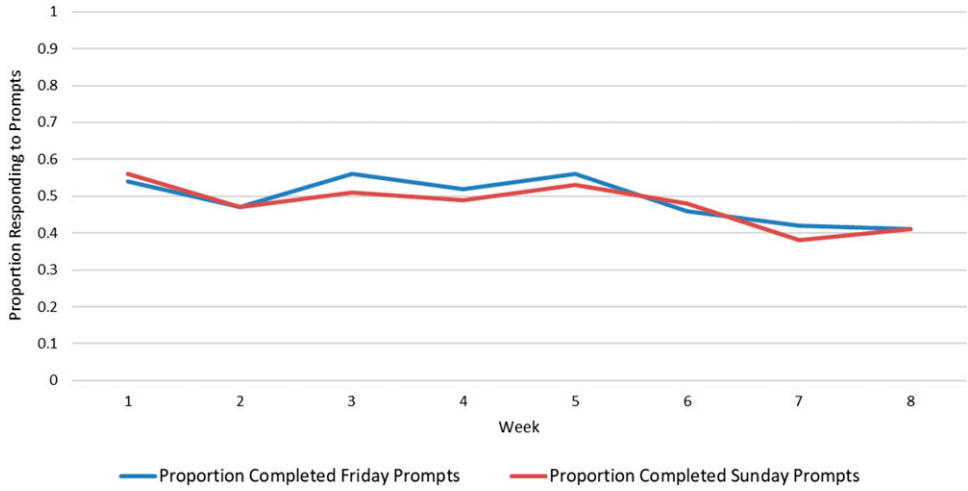
[a]n = 39. FU 1 = Follow-Up 1, FU 2 = Follow-Up 2, MFQ = Mood and Feelings Questionnaire, SCARED = Self-Report for Childhood Anxiety Related Disorders, SD = standard deviation, SPP = sleep promotion program.

identical across arms (SPP-continuation mean [SD] =52.0 minutes [8.9 minutes]; monitoring-SPP mean [SD] = 52.3 minutes [9.7 minutes]). Parents were present for all sessions. They were involved for an average of 11.6 (SD = 4 minutes) of the 52 minutes (SPP-continuation mean [SD] =11.9 minutes [4.0 minutes]; monitoring-SPP mean [SD] = 11.3 minutes [4.6 minutes]).

Acceptability

Youth and parents were highly satisfied with the program (Table 2 shows ratings for overall care; **Table S1** in the supplemental material shows all program satisfaction items), and 96.5% of participants rated the care quality as good or excellent. Forty-seven percent of youth and 35% of parents reported they

Figure 4—Proportion of completed intervention prompts.



did not have concerns about their child's sleep at the start of the program, though youth met our eligibility criteria for insufficient sleep and elected to participate in a sleep promotion study. Some participants provided qualitative feedback on the Intervention Satisfaction Questionnaire. Youth "liked most" learning about sleep and the ease and comfort of working with the study team. Parents also liked learning about sleep most. One youth stated, "I could track my sleep to see what i [*sic*] could do to improve my sleep based on what i [*sic*] got from the sleep summaries." The most common feature reportedly "disliked" by both groups was the length of study surveys, rather than the intervention itself, but few participants offered suggestions for improving the program.

Sleep outcomes

Sleep diary data were available for 42 participants at Baseline (95%; 23 SPP-continuation, 19 monitoring-SPP), 34 at Follow-up 1 (77%; 18 SPP-continuation, 16 monitoring-SPP), and 32 at Follow-up 2 (73%; 19 SPP-continuation, 13 monitoring-SPP).

Table 1 shows the observed sleep characteristics. **Table 3** provides the pairwise contrasts estimated from the mixed models. When comparing the initial intervention effect (ie, change in sleep from Baseline to Follow-up 1 in each arm), the largest group difference was observed for TST. The SPP-continuation mean TST increased by 0.57 hours and the monitoring-SPP mean TST decreased by 0.38 hours based on mixed-model estimates (**Figure 5**). This was primarily driven by later sleep offset time at Follow-up 1 for SPP-continuation. Additionally, SPP-continuation had a steeper shift toward earlier offset time relative to monitoring-SPP (**Figure 5**). Across all sleep timing variables, we observed a general trend for later sleep timing at Follow-up 1 vs Baseline, except for average weekend sleep onset (which remained steady).

Table 2—Program satisfaction.

Domain	Program Satisfaction Evaluation Item: Youth	% (n = 43)	Program Satisfaction Evaluation Item: Parent	% (n = 43)
Overall care	I would rate the overall quality of care I received as good or excellent	100%	I would rate the overall quality of care my child and I received as good or excellent	93%
	I would strongly recommend the care I received to a friend or relative	98%	I would strongly recommend the care I received to a friend or relative	88%
	Concerns that prompted me to start participating in this research study are now:	• Much better = 19% • A little bit better = 28% • I didn't have concerns = 47%	Concerns that prompted my child to start participating in this research study are now:	• Much better = 12% • A Little bit better = 35% • I didn't have concerns = 35%
	I would be very likely to accept another research opportunity if it was offered to me by this program	88%	I would be very likely to accept another research opportunity if it was offered to me by this program	93%
	The program was very relevant to me	77%	The program was very relevant to my child	84%

Table 3—Post hoc contrasts estimated from the linear mixed model.

Feature	Period 1 Change in SPP-Continuation – Period 1 Change in Monitoring-SPP* (95% CI)	SPP-Continuation: Period 1 Change – Period 2 Change**	Monitoring-SPP: Period 1 Change – Period 2 Change**
Average difference in weekend–weekday sleep onset (hours)	−0.29 (−1.27, 0.69)	0.62 (−0.95, 2.18)	0.99 (−0.55, 2.52)
Average difference in weekend–weekday sleep offset (hours)	−0.53 (−1.76, 0.71)	0.20 (−1.91, 2.31)	0.52 (−0.78, 1.81)
Average weekday sleep onset	0.09 (−1.17, 1.34)	−0.18 (−1.47, 1.11)	−1.34 (−2.89, 0.21)
Average weekend sleep offset	0.57 (−0.70, 1.85)	−0.94 (−3.03, 1.16)	−0.24 (−1.59, 1.11)
Average total sleep time (hours)	0.95 (0.14, 1.76)	−1.24 (−2.06, −0.42)	0.39 (−0.55, 1.33)

*Higher positive values indicate a greater increase in SPP-continuation relative to monitoring-SPP. More negative values indicate a greater decrease in SPP-continuation relative to monitoring-SPP. **Higher positive values indicating a greater increase from Follow-up 1 (FU1) to Follow-up 2 (FU2) relative to Baseline (BL) to Follow-up 1. More negative values indicate a greater decrease from FU1–FU2 relative to BL–FU1. CI = confidence interval, SPP = sleep promotion program.

Within SPP-continuation, average TST increased from Baseline to Follow-up 1 (change estimate = 0.51 hours) but decreased from Follow-up 1 to Follow-up 2 (change estimate = −0.74 hours), resulting in an overall shorter TST at Follow-up 2 than at Baseline. This was driven by both a sleep onset that delayed progressively across time points and a sleep offset that delayed more at Follow-up 1 than at Follow-up 2. The trajectories of other features were relatively stable across Periods 1 and 2 for SPP-continuation. In Monitoring-SPP, there were no differences in trajectories between Period 1 (monitoring) and Period 2 (SPP), indicating that SPP did not meaningfully affect the trajectory of the sleep characteristics.

We conducted sensitivity analyses excluding the 4 participants who completed baseline at the end of their school year (eg, in May) but completed the remainder of their participation during the summer, because changes in their schedule affecting sleep may have occurred from the school year to summer. The pattern of results was nearly identical to that described above.

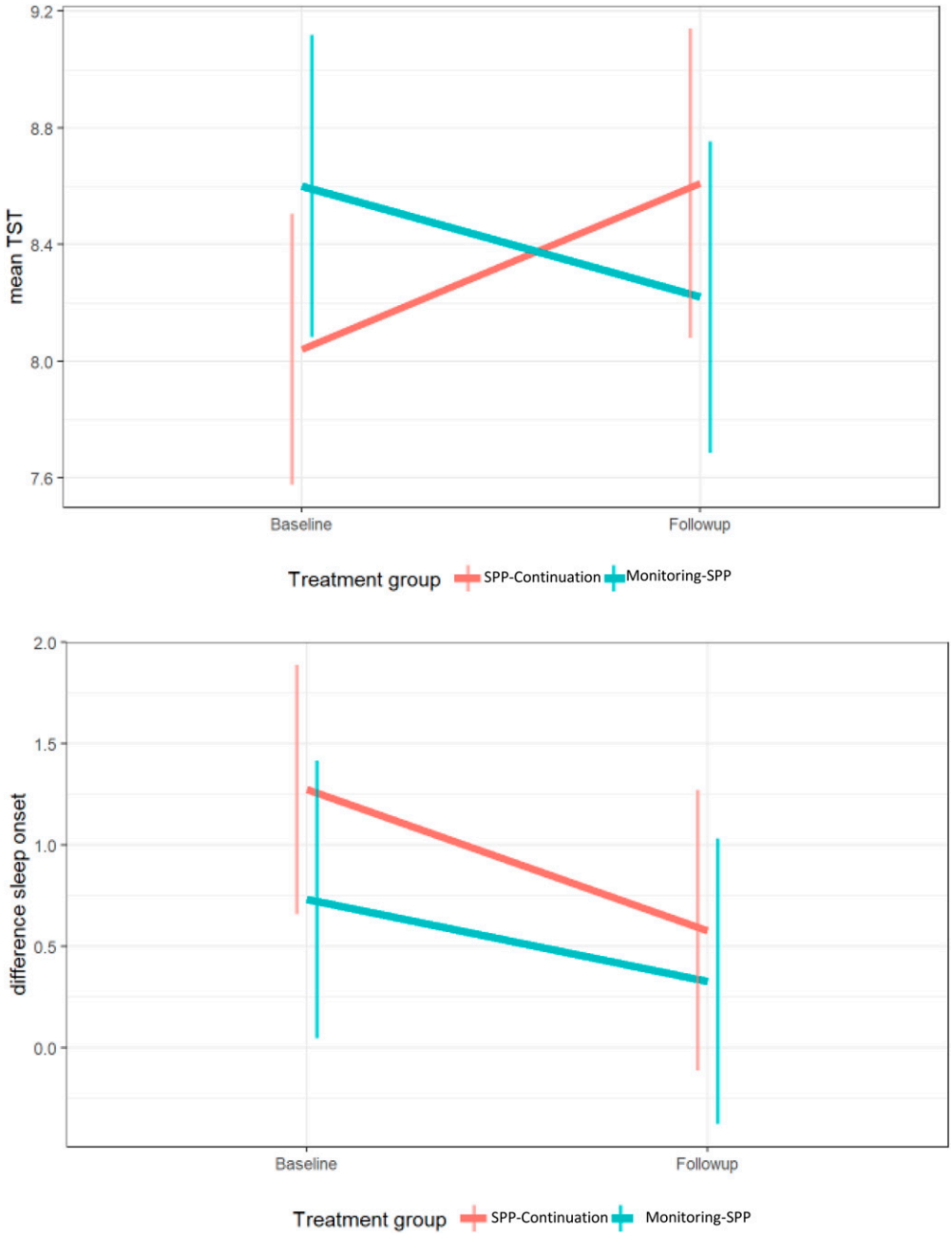
DISCUSSION

Our scalable, 1-session, behavioral SPP for adolescents with insufficient and irregular sleep showed good feasibility and acceptability. All youth and parent participants completed the SPP program session. Only 1 youth dropped out and 3 were withdrawn by investigators due to COVID-19–related changes in sleep patterns, resulting in an overall attrition rate of 8.5%. Youth and parents reported especially high acceptability ratings for skill of the clinician and overall rating of the quality of care.

Average rate of completing the mobile intervention prompts was just above 50% (peak of 56%) and declined over time. The distributions showed meaningful variability, with some youth consistently completing the prompts and others completing prompts very infrequently. Interestingly, 81% of youth reported that completing these prompts had a small burden or less, though perhaps a low rating on burden reflects that participants were not completing that component. Future work should focus on uncovering contributors to low adherence and evaluating whether increased prompt completion is associated with greater improvement in sleep. Future work could also focus on technology-based passive sensing methods of measuring sleep and rhythms.[57] Of the participants 35%–47% reported they did not have concerns related to the youth's sleep at the start of the program, even though youth met our sleep eligibility criteria, perhaps reflecting a need for greater understanding of sleep need among this age group. Future work could focus on increasing the perceived relevance of the program for some youth and parents by further emphasizing the critical role of sleep to adolescent health, functioning, and other outcomes of high priority to the youth. An alternative may be to assess the perceived importance of sleep and sleep treatment among the young person and their parent. If perceived importance is low, the clinician may spend more time building motivation for treatment before beginning sleep-specific work. Additionally, adding a second session to this program may facilitate this goal, because informal feedback from our study clinicians indicated that 2 sessions would be optimal to accomplish intervention goals. Session 1 could focus on education, building motivation, linking sleep with outcomes relevant to youth, and making an action plan. Session 2 could focus on refining the action plan and troubleshooting and could include a review of intervention prompts answered between sessions, which may further increase adherence to that intervention component. Additional information from families and clinicians about how to accomplish this while minimizing burden will be critical to future iterations of this intervention.

In terms of changes in sleep, youth randomly assigned to SPP-continuation reported an increase in TST of 34 minutes, and those assigned to monitoring-SPP reported a decrease of about 23 minutes in Period 1. An increase of this magnitude has been associated with clinically meaningful outcomes in adolescence.[43,58–60] Though we observed delays in weekday sleep onset *and* offset timing, the delay in sleep offset was greater, resulting in an increase in weekday TST. Similarly, we observed delays in weekend sleep offset timing (wake time), whereas weekend sleep onset timing remained steady, resulting in an increase in weekend TST of 38 minutes. Thus, SPP in Period 1 was associated with a

Figure 5—Predicted differences in sleep variables by timepoint and group.



TST = total sleep time.

greater increase in TST, via a delay in wake-up time, relative to monitoring. This study was conducted from November 2019 through June 2022, so most participants completed the sleep intervention during the COVID-19 pandemic, when many schools operated remotely. Accordingly, many participants attended school online via synchronous or asynchronous learning. Some participants reported delayed school start times during online learning, meaning they may have been able to delay their sleep timing to better match their preferred circadian phase.[61] For others, school start times did not change but students were able to wake up later because they did not need time to commute to school. Thus, when given the opportunity to delay wake-up time, students in both arms delayed their sleep timing, but those in SPP delayed their wake-up time to a greater degree, resulting in significantly greater TST. Some efforts have focused on *advancing* sleep onset as a means of increasing sleep duration.[62] Future work should examine whether equivalent changes in TST resulting from changes in sleep timing that are more or less consistent with preferred circadian phase (via advancing vs delaying sleep timing) are associated with differences in downstream benefits. Further,

substantial evidence supports the beneficial impact of delayed school start times on sleep and other health and functional outcomes.[63] Yet, even if delayed school start times are implemented more permanently in a postpandemic world, it is unlikely that this change alone would result in sufficiently improved sleep for all adolescents.[64] For example, a 2020 report showed a mean TST of 8 hours and 5 minutes among youth attending schools with delayed start times, indicating that a large proportion of students obtained *less* than the 8-hour minimum sleep duration recommended by the National Sleep Foundation[65] even with delayed start times. Even if a delay of school start times were to occur nationally, not all youth would necessarily delay their wake time to regularize sleep timing and increase TST. Rather, our data suggest that the SPP intervention is associated with a greater increase in TST as a result of delayed weekday wake-up times, even when participants in both arms experienced later school start times. Our results suggest that engaging in the SPP, even with delayed school start times, is an efficacious way to increase sleep duration.

We also found that the improvement in sleep duration observed over the first intervention period among the SPP group was not sustained during the second intervention period. A higher intervention dose (eg, a booster clinician session or more engaging mobile intervention prompts) may be needed to sustain the program's impact on sleep duration, consistent with informal clinician feedback regarding their desire for a second SPP session. Future work should also examine factors promoting sustained improvement in sleep, such as perceived behavioral control or unexpected and compelling schedule demands affecting sleep in the long term.

The present analyses have important limitations. Not all of our 44 participants completed sufficient sleep diary data to be included in the primary analyses, further restricting our sample. Future work should focus on larger samples to bolster power to detect effects. Our sample was limited in racial and ethnic diversity, which precluded subgroup comparisons focusing on these factors. Because youth minoritized by race and socioeconomic status experience worse sleep than their nonminoritized peers,[66–70] future investigations should include a more diverse sample, measure acceptability among minoritized youth, and collect data on the experiences of discrimination, community violence, and systemic racism that underlie these disparities.[67,71,72] The COVID-19 pandemic resulted in 3 adolescents no longer being eligible for the study due to externally imposed changes in their sleep that affected their eligibility. They were not included in our analyses. Still, only 1 participant chose to end their study participation. This study is more reflective of an efficacy study than an effectiveness study, given the strict eligibility criteria and conduct within an academic medical center. Nevertheless, youth were recruited from the community, and clinicians with varying levels of experience and a range of professional background delivered the intervention, including 2 social workers embedded in an adolescent medicine clinic. This speaks to the capacity for clinicians of various backgrounds to learn and deliver this program. Future work should focus on increasing generalizability and real-world relevance by broadening inclusion criteria and embedding the program in a community setting. Last, this report focuses on self-reported sleep outcomes via sleep diary. Future reports from this study will include objective measures of sleep via actigraphy. Even with these limitations, our study is innovative in testing an evidence-based SPP that optimizes patient and clinician acceptability and promotes broad dissemination.

CONCLUSIONS

Results of our study testing a personalized SPP for adolescents with insufficient and irregular sleep indicate that the program is highly feasible and acceptable with a low rate of participant drop-out. Our SPP was associated with a greater increase in TST, via a delay in wake-up time, than was observed among those in the monitoring condition. Engaging in the SPP is an acceptable and efficacious way to increase sleep duration. Increasing the relevance of the program for young people and their parents should be a focus of future work, as should increasing engagement in the mobile technology intervention components and identifying and testing strategies for sustaining the short-term improvement in sleep.

ABBREVIATIONS

SD, standard deviation
SPP, sleep promotion program
TST, total sleep time

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