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Feasibility of a Single-Subject Protocol to Shift Young Children's Sleep Schedules

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Abstract
The objective of this study is to describe children's adherence to changing sleep schedules within a small-scale, single-subject, at-home sleep manipulation experiment. Subjects were six healthy children (male = 4, ages 6–8). Children underwent: baseline, a 7-day self-selected sleep pattern; Condition A1, a 3- to 12-day stabilized sleep pattern (assigned time into/out of bed set at baseline averages); Condition B, a 3- to 12-day phase-delayed sleep pattern (time into/out of bed 2 h later than Condition A); and Condition A2, a 3- to 7-day return-to-stabilized sleep pattern (time into/out of bed at Baseline averages, identical to Condition A1). All children completed conditions. Per parent report, adherence to assigned time into/out of bed was good; sleep onset/offset adherence was variable. Within this small-scale, short-term sleep manipulation, children effectively got into/out of bed at assigned times despite manipulating sleep schedules by 2 h. However, they struggle to shift their sleep onset and offset times to match the time they were in bed.

Keywords Pediatric · Circadian · Bedtime · Methods · Experimental

Introduction

Although variable sleep schedules were formerly seen as a uniquely adolescent phenomenon, variability in sleep has become more commonplace in today's younger youth. Indeed, previous work has found that young children (ages 0–6) exhibit increasingly variable bed and wake times from week day to weekends as they age, likely to adapt to changing demands in schedules and activities as they enter school (Randler, Fontius, & Vollmer, 2012). This kind of delayed or variable sleep timing in youth is linked with negative health (Chaput, 2014; Thellman, Dmitrieva, Miller, Harsh, & LeBourgeois, 2017), behavioral (Biggs, Lushington, van den Heuvel, Martin, & Kennedy, 2011; Pesonen et al., 2010), cognitive (Kelly, Kelly, & Sacker, 2013), and academic (Tonetti, Natale, & Randler, 2015) consequences in school-aged children. Increasingly, studies suggest that sleep timing factors (e.g., bedtimes, wake times, sleep chronotype) may be as or more relevant to child biopsychosocial health as sleep duration (Golley, Maher, Matricciani, & Olds, 2013; Olds, Maher, & Matricciani, 2011; Short, Gradisar, Lack, & Wright, 2013).

Many of these studies explore the question of whether sleep timing is an independent predictor of poor outcomes by statistically controlling for shortened sleep duration (a frequent consequence of later bedtimes in youth). While these studies strongly suggest an independent effect of sleep timing, they are all correlational, and cannot establish the presence or direction of causation. A necessary step toward greater understanding of the consequences of delayed sleep timing in youth is the use of controlled experimental designs.

A number of established youth experimental sleep duration restriction and extension paradigms exist, all with the explicit goal of altering sleep duration (Beebe et al., 2008; Fallone, Seifer, Acebo, & Carskadon, 2002; Meltzer et al.,

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2015; Sadeh, Gruber, & Raviv, 2003). Most alter sleep duration by delaying or advancing bedtime and anchoring wake time. These studies show good participant compliance, as well as feasibility of altering bedtimes in school-aged youth and adolescents. Although a recent study in adult men demonstrated the feasibility of delaying both bed and wake times by 1 h (thereby holding the time in bed with opportunity to sleep constant; Zander, Faßl, & Randler, 2018), no pediatric studies to date have manipulated sleep timing in this way. It is an open question as to whether children (vs. adult men) are capable of adhering to such a protocol. Consequently, preliminary research is needed to establish whether it is feasible to systematically alter the timing of children's sleep. Results of this research could help researchers develop and refine methodology of future sleep timing manipulations. Results could also provide preliminary findings regarding a possible timeline of how quickly children can adapt to variable sleep schedules in the free-living environment. This information is needed to inform design of future studies and to augment clinical knowledge of the role of sleep timing and variable sleep schedules in children's health and functioning. Thus, the aim of this report is twofold; first, to discuss the feasibility of a single-subject, at-home experimental sleep timing manipulation study with 6–8 years olds. Second, to begin to lay the groundwork for documenting a timeline of how long it takes young school-aged children to adjust to shifting sleep schedules.

Using a single-subject, ABA design, we implemented an experimental paradigm where medically and psychologically healthy children entered a stabilized sleep pattern (Condition A1) for 3–12 days, then entered a 2-h phase delayed sleep pattern (Condition B) for 3–12 days, and then returned to their stabilized sleep pattern (Condition A2, identical to Condition A1) for 3–7 days, all while controlling for time spent in bed. Across all conditions, we tracked the clock time that children got into and out of bed, as well as the time they achieved sleep onset and offset (i.e., when they actually fell asleep and woke up). Using a priori criteria, we determined whether participants were adherent to the assigned time into/out of bed and sleep onset/offset. We hypothesized that there would be good participant retention, as well as good child adherence to the assigned times into and out of bed. We expected that children would be most adherent to assigned sleep onset times, and least adherent to sleep offset times, especially in the 2-h phase-delayed condition.

Methods

Participants

Six healthy, pre-pubescent children (ages 6–8, four male) not at-risk for any sleep, behavioral, or emotional disorders enrolled as part of a larger single-subject study investigating the impact of delayed sleep timing on dietary intake and physical activity. To avoid potentially inadvertently exacerbating any underlying mood or neurobehavioral disorders, only medically and psychologically healthy children were recruited. Families needed sufficient schedule flexibility to follow assigned sleep schedules, and data collection occurred during summer (for traditionally schooled children) or fall (for homeschooled children). Children were recruited through university and community-based advertisements. Children were majority white, with one African American child participating. Two children were traditionally schooled and four were homeschooled. Five of the six children had married parents and half of the parents serving as informants (primarily mothers) were homemakers, with the other half working. Family income ranged from less than $19,000 to over $100,000.

Eligibility

Eligibility was initially assessed via phone screener and then at an in-person screening visit. Parents completed questionnaires on child/parent demographics, child/parent medical history, history of diagnosed mood or neurobehavioral disorders, and child sleep habits at that visit. Children were excluded if parents reported history of diagnosed or suspected attention-deficit/hyperactivity disorder, oppositional defiant disorder, or anxiety disorder. Children and parents were also informed on study procedures and instructed on how to complete daily online sleep diaries.

Study Design

If eligible, following Institutional Review Board procedures, parents provided informed consent on behalf of their children. Participants entered the single-subject, ABA-style study. They began with a 7-day self-selected sleep pattern (Baseline), in order to establish a baseline sleep schedule and adjust to the sleep monitoring and equipment. They then entered a 3- to 12-day stabilized sleep pattern (Condition A1) in which their assigned time into/out of bed was set at their personalized average from Baseline. Children then entered a 3- to 12-day phase-delayed sleep pattern (Condition B) wherein their assigned time into/out of bed was 2 h later than Condition A1. Finally, children began a 3- to 7-day return-to-stabilized sleep pattern (Condition A2) in which their assigned time into/out of bed was 2 h earlier than Condition B and the same as Condition A1. Condition length was personalized to the individual child based on their adherence to the assigned sleep condition (see "Adherence Criteria" below) and stability of their caloric intake (primary aim of the larger study) within that condition. Study duration ranged between 16 and 38 days. Throughout

all conditions, study personnel conducted weekly home visits and monitored study performance daily through the online sleep diaries. Children were also instructed to wear wrist-mounted actigraphs and arm-mounted accelerometers; data from these devices are not presented in this manuscript. Children were provided with light-blocking eye masks and instructed to contact study personnel with any compliance difficulties. Families (rather than participating children, given that they were minors) were compensated for their time and effort with $50 at the end of each condition, for a total of $200 across the entire study. Families were informed upon consent that compensation was not dependent upon their child's adherence with respect to the intervention. See Fig. 1 for an example of a child's sleep schedule throughout all study conditions.

Measures

Sleep was measured subjectively via an online daily sleep diary. Each morning, parents received an email with a REDCap link where they could open the sleep diary. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies (Harris, Taylor, Thielke, Payne, Gonzalez, & Conde 2009). They were instructed to work collaboratively with their child to report on the clock time the child: got into bed, fell asleep, woke up in the morning, and got out of bed for the day. Although children wore wrist-mounted actigraphy throughout the study, there was significant device malfunction resulting in non-random missing data. Thus, actigraphy data are not presented in this manuscript.

Adherence Criteria

For the purposes of this study, children were deemed adherent to a study condition if the average reported time into/out of bed or sleep onset/offset was within ± 30 min of the assigned sleep schedule, respectively.

Outcomes of Interest

Outcome variables of interest related to study feasibility included (1) retention (number of participants who completed each study condition), (2) adherence across each condition to assigned time into bed, and (3) adherence across each condition to assigned time out of bed. Outcome

BASELINE

	7pm	8pm	9pm	10pm	11pm	12pm	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am
Monday			Bedtime = 9:00pm; Wake time = 7:00am; Sleep period = 600 minutes													
Tuesday				Bedtime = 9:30pm; Wake time = 7:30am; Sleep period = 600 minutes												
Wednesday			Bedtime = 9:00pm; Wake time = 6:40am; Sleep period = 580 minutes													
Thursday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Friday				Bedtime = 10:00pm; Wake time = 10:00am; Sleep period = 720 minutes												
Saturday				Bedtime = 10:00pm; Wake time = 9:40am; Sleep period = 700 minutes												
Sunday				Bedtime = 9:20pm; Wake time = 7:00am; Sleep period = 620 minutes												

Average bedtime =9:28pm; Average Wake time = 7:59; Average Sleep Period = 636 minutes

CONDITION A1

	7pm	8pm	9pm	10pm	11pm	12pm	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am
Monday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Tuesday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Wednesday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Thursday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Friday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												

Average bedtime = 9:30pm; Average Wake time = 8:00; Average Sleep Period = 630 minutes

CONDITION B

	7pm	8pm	9pm	10pm	11pm	12pm	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am
Saturday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Sunday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Monday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Tuesday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Wednesday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Thursday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Friday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Saturday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										
Sunday						Bedtime = 11:30pm; Wake time = 10:00am; Sleep period = 630 minutes										

Average bedtime = 11:30pm; Average Wake time = 10:00am; Average Sleep Period = 630 minutes

CONDITION A2

	7pm	8pm	9pm	10pm	11pm	12pm	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am
Monday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Tuesday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Wednesday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Thursday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Friday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												
Saturday				Bedtime = 9:30pm; Wake time = 8:00am; Sleep period = 630 minutes												

Average bedtime = 9:30pm; Average Wake time = 8:00; Average Sleep Period = 630 minutes

Fig. 1 Example of an assigned sleep schedule

variables of interest related to adjustment to the shifting sleep schedules included adherence across each condition to assigned (4) time of sleep onset and (5) time of sleep offset, as well as how many days into each condition assigned (6) sleep onset and (7) sleep offset were achieved.

Results

Study Feasibility Outcomes

Retention was excellent, with all 6/6 children completing all conditions of the study. Time into and out of bed adherence (getting into/out of bed within ± 30 min of assigned time) was excellent throughout the study; all 6/6 participants' average time into and out of bed adhered to their assigned sleep schedules across all conditions in the study.

Adjustment to Shifting Sleep Schedule Outcomes

Average Sleep Onset Adherence

Sleep onset adherence (actually falling asleep within ± 30 min of the assigned time) proved more difficult for most children. Across all conditions, half ($n = 3$) of the children's average sleep onset did not meet adherence criteria in at least one study condition. Upon closer inspection, this appears to be driven by difficulties in Conditions A1 and A2, when bedtimes were set to the children's typical baseline schedules (see Table 1 for participant baseline sleep patterns). Only 3/6 and 4/6 children's average time of sleep onset met their individual sleep onset adherence criteria during Condition A1 (stabilized sleep pattern) and Condition A2 (return-to-stabilized sleep pattern), respectively. Interestingly, achieving sleep onset when bedtime was set 2 h later appeared easier, with 5/6 children's average sleep onset meeting adherence criteria during Condition B (2-h phase delay pattern). Children whose average sleep onset did not meet adherence criteria during Condition A1 and A2 primarily fell asleep later than their assigned times into bed.

Average Sleep Offset Adherence

Conversely, patterns of average sleep offset adherence revealed a preference for earlier timing found in Condition A1 (stabilized sleep pattern) and Condition A2 (return-to-stabilized sleep pattern). Across all conditions, 4/6 children's average sleep offset fell ± 30 min outside their assigned wake time in at least one study condition. Half of the children ($n = 3$) failed to meet sleep offset adherence criteria when they were expected to wake 2 h later than usual during Condition B, with all non-adherent children waking earlier than the assigned wake time. However, nearly all (5/6) were adherent to sleep offset criteria during both Conditions A1 and A2. See Table 2 for further information.

Interestingly, two participants demonstrated average sleep onset and offset that adhered to assigned bed and wake times across all three conditions, suggesting effective adjustment of their actual sleep timing to each of these conditions.

Night-to-Night Sleep Onset Adherence

Length of time to achieve the first day of sleep onset or offset adherence also illuminated the difficulties participants experienced adhering to the assigned schedules. Participants took variable amounts of time to achieve their first day of sleep onset adherence, ranging from 2 to 11 nights. Interestingly, achieving sleep onset adherence early in the condition did not necessarily predict stable adherence throughout the rest of that condition. For example, participant 4 displayed inconsistent sleep onset adherence through night 7 of Condition B, despite adhering well for the first two nights. Night-to-night sleep onset adherence is graphically detailed in Fig. 2.

Night-to-Night Sleep Offset Adherence

Compared to sleep onset, length of time to achieve the first morning of sleep offset adherence displayed less fluctuations, as displayed in Fig. 3. Most children adhered to sleep offset criteria within three nights in Conditions A1 and A2; that is, they were able to adjust their wake times in conditions that were similar to their typical wake times. However, adherence to Condition B sleep offset criteria proved variable for participants, meaning, there was more variability in length of time to first wake up on time when they were expected to sleep 2 h later than usual. For example, Participant 6 adhered for only five nights of the 12-night Condition B. See Fig. 3 for graphical visual of night-to-night sleep offset adherence.

Conclusions

This single-subject ABA study explored a novel sleep timing manipulation protocol, where six young children were assigned to a stabilized sleep schedule (Condition A1), then to a delayed sleep schedule in which bed and wake times were delayed by 2 h (Condition B), and then to a return-to-stabilized sleep schedule (Condition A2). The study aimed to establish feasibility of this novel protocol in young children, as well as provide preliminary data regarding how long it takes young children to adjust to shifting sleep schedules. Overall, results suggest that larger scale sleep timing manipulations could be feasible, but would require some considerations and protocol modifications, depending on study

Table 1 Participant baseline sleep pattern

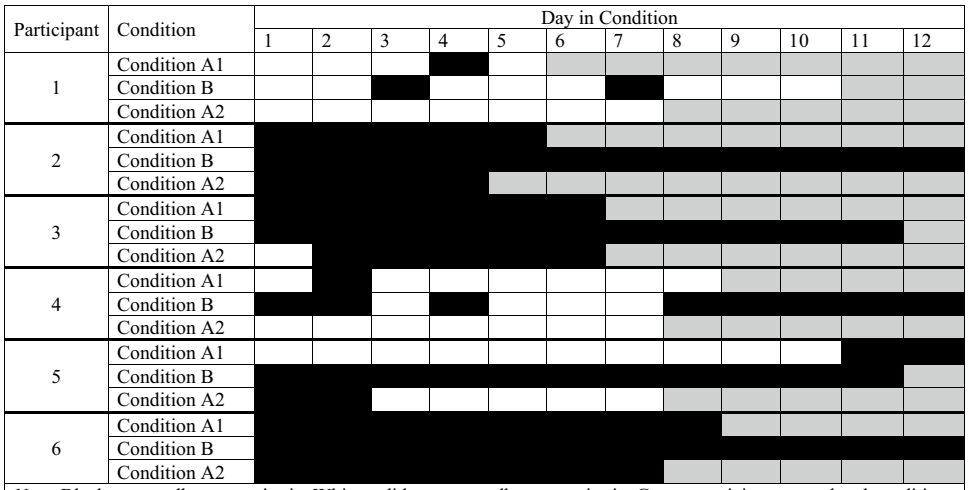
	Time into bed range	Mean time into bed	Sleep onset range	Mean sleep onset	Sleep onset latency range	Mean sleep onset latency	Sleep offset range	Mean sleep offset	Time out of bed range	Mean time out of bed
Participant 1										
	11:30 p.m.–2:00 a.m	12:27 a.m	12:00 a.m.–2:05 a.m	12:46 a.m	5–30	19	9:10 a.m.–11:30 a.m	10:30 a.m	9:35 a.m.–11:30 a.m	10:29 a.m
SD (mins)	–	50	–	42	–	9	–	53	–	25
Participant 2										
	9:20 p.m.–11:20 p.m	10:04 p.m	9:25 p.m.–11:25 p.m	10:10 p.m	5–10	6	6:01 a.m.–8:15 a.m	6:46 a.m	6:01 a.m.–8:15 a.m	6:46 a.m
SD (mins)	–	41	–	40	–	2	–	55	–	55
Participant 3										
	8:25 p.m.–9:45 p.m	8:45 p.m	8:45 p.m.–10:00 p.m	9:03	15–30	18	6:50 a.m.–7:30 a.m	7:05 a.m	6:55 a.m.–7:30 a.m	7:07 a.m
SD (mins)	–	28	–	27	–	6	–	12	–	12
Participant 4										
	8:30 p.m.–9:30 p.m	8:46 p.m	10:05 p.m.–11:00 p.m	10:31 p.m	75–150	105	7:55 a.m.–9:00 a.m	8:24 a.m	8:00 a.m.–9:15 a.m	8:37 a.m
SD (mins)	–	21	–	18	–	24	–	25	–	30
Participant 5										
	9:00 p.m.–11:00 p.m	9:40 p.m	10:00 p.m.–12:00 a.m	10:34 p.m	20–90	54	5:45 a.m.–9:30 a.m	8:04 a.m	6:15 a.m.–9:30 a.m	8:12 a.m
SD (mins)	–	44	–	47	–	23	–	70	–	62
Participant 6										
	8:00 p.m.–10:00 p.m	9:19 p.m	8:40 p.m.–10:00 p.m	9:27 p.m	0–30	9	7:58 a.m.–9:13 a.m	8:29 a.m	8:00 a.m.–9:15 a.m	8:34 a.m
SD (mins)	–	32	–	27	–	10	–	28	–	27

Table 2 Participant adherence to assigned sleep schedule

	Condition length (days)	Bedtime variables			Wake time variables		
		Assigned bedtime	Mean time into bed	Mean sleep onset	Assigned wake time	Mean sleep offset	Mean time out of bed
Participant 1							
Condition A1	5	12:30 a.m	12:30 a.m	1:47 a.m.[a]	10:30 a.m	9:54 a.m.[a]	10:09 a.m
SD (mins)			0	36		96	90
Condition B	10	2:30 a.m	2:30 a.m	3:42 a.m.[a]	12:30 p.m	12:29 p.m	12:31 p.m
SD (mins)			0	35		5	2
Condition A2	7	12:30 a.m	12:30 a.m	2:14 a.m.[a]	10:30 a.m	10:26 a.m	10:38 a.m
SD (mins)			0	36		7	12
Participant 2							
Condition A1	5	10:00 p.m	9:54 p.m	10:00 p.m	6:45 a.m	6:37 a.m	6:37 a.m
SD (mins)							
Condition B	12	12:00 a.m	11:55 p.m	11:56 p.m	8:45 a.m	8:29 a.m	8:30 a.m
SD (mins)			17	16		36	37
Condition A2	4	10:00 p.m	10:00 p.m	10:01 p.m	6:45 a.m	6:45 a.m	6:45 a.m
SD (mins)			0	0		0	0
Participant 3							
Condition A1	6	8:45 p.m	8:45 p.m	9:01 p.m	7:00 a.m	6:59 a.m	7:05 a.m
SD (mins)			0	3		2	3
Condition B	11	10:45 p.m	10:45 p.m	10:57 p.m	9:00 a.m	8:38 a.m	9:00 a.m
SD (mins)			0	5		20	2
Condition A2	6	8:45 p.m	8:55 p.m	9:14 p.m	7:00 a.m	6:57 a.m	7:02 a.m
SD (mins)			24	25		24	4
Participant 4							
Condition A1	8	8:45 p.m	8:51 p.m	9:45 p.m.[a]	8:25 a.m	8:10 a.m	8:35 a.m
SD (mins)			9	17		11	20
Condition B	12	10:45 p.m	10:41 p.m	11:11 p.m	10:25 a.m	9:21 a.m.[a]	10:26 a.m
SD (mins)			9	12		9	6
Condition A2	7	8:45 p.m	8:47 p.m	9:42 p.m.[a]	8:25 a.m	7:50 a.m.[a]	8:25 a.m
SD (mins)			8	9		49	0
Participant 5							
Condition A1	12	9:40 p.m	9:35 p.m	10:43 p.m.[a]	8:00 a.m	7:52 a.m	8:00 a.m
SD (mins)			12	31		22	27
Condition B	11	11:40 p.m	11:41 p.m	12:00 a.m	10:00 a.m	9:26 a.m.[a]	9:39 a.m
SD (mins)			5	6		34	19
Condition A2	7	9:40 p.m	9:40 p.m	10:27 p.m	8:00 a.m	7:57 a.m	8:02 a.m
SD (mins)			2	18		6	6
Participant 6							
Condition A1	8	9:20 p.m	9:20 p.m	9:27 p.m	8:30 a.m	8:26 a.m	8:38 a.m
SD (mins)			0	4		7	11
Condition B	12	11:20 p.m	11:20 p.m	11:25 p.m	10:30 a.m	9:42 a.m.[a]	10:31 a.m
SD (mins)			3	3		32	3
Condition A2	7	9:20 p.m	9:20 p.m	9:34 p.m	8:30 a.m	8:22 a.m	8:37 a.m
SD (mins)			0	8		8	13

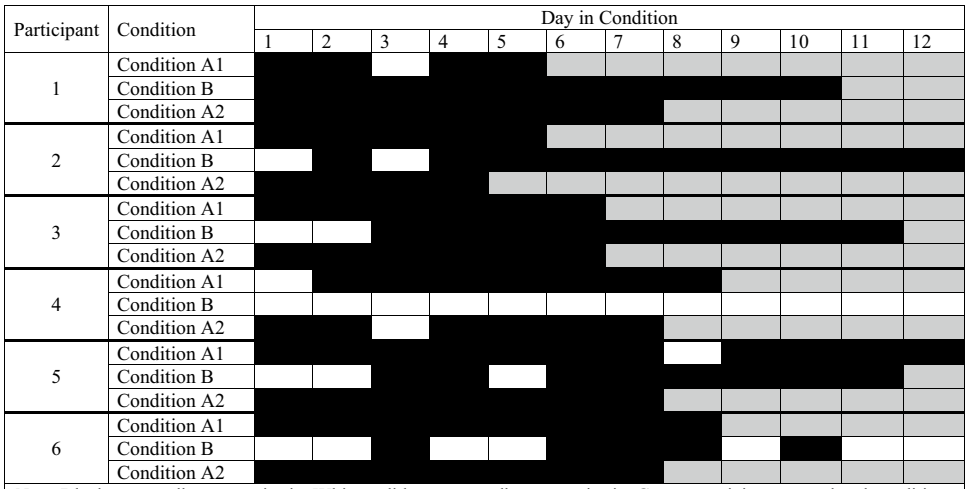
Condition length = number of days subject was in the condition

[a]Subject's average sleep variable for that condition did not adhere to assigned bed/wake time



Note. Black = met adherence criteria. White = did not meet adherence criteria. Grey = participant completed condition prior to these days. Sleep Onset Adherence = falling asleep within +/- 30mins of assigned bedtime. Condition A1 = 3-12 day stabilized sleep pattern (assigned time into/out of bed set at Baseline averages); Condition B = 3-12 day phase-delayed sleep pattern (time into/out of bed 2 hours later than Condition A); Condition A2 = 3-7 day return-to-stabilized-sleep pattern (time into/out of bed at Baseline averages, identical to Condition A1)

Fig. 2 Night-to-night sleep onset adherence



Note. Black = met adherence criteria. White = did not meet adherence criteria. Grey = participant completed condition prior to these days. Sleep Offset Adherence = waking up within +/- 30 mins of assigned wake time. Condition A1 = 3-12 day stabilized sleep pattern (assigned time into/out of bed set at Baseline averages); Condition B = 3-12 day phase-delayed sleep pattern (time into/out of bed 2 hours later than Condition A); Condition A2 = 3-7 day return-to-stabilized-sleep pattern (time into/out of bed at Baseline averages, identical to Condition A1)

Fig. 3 Night-to-night sleep offset adherence

goals. Retention was perfect across all conditions, with all participants completing all aspects of the study. Participants got into and out of bed with nearly perfect adherence in both phase-delayed (Condition B) and stabilized/return-to-stabilized sleep (Conditions A1/A2) conditions. That is, all six participants precisely followed study protocol (which simply instructed children to get into bed and stay in bed during the assigned times). However, actually falling asleep and waking up within 30 min of the assigned time into/out of bed was challenging for approximately half of the participating children.

When looking at actual times to sleep onset and offset, several interesting patterns emerged. First, three children had difficulty consistently falling asleep on time during Condition A1, which simply set a consistent bedtime based on their average bedtime from the previous week in baseline. Of those three, two (Participants 4 and 5) also had difficulty with sleep onset (taking 1–2 h to fall asleep after bedtime) during baseline, and one (Participant 1) had a significantly delayed sleep schedule at baseline. This could indicate an underlying mismatch between the children's natural circadian preference and their parent-prescribed bedtime at baseline, thus impacting their ability to shift later in the study. It could also be the case that habituating to a *stabilized* sleep schedule (even if it is similar in timing to baseline sleep patterns) may take a while. When assigned to go to bed and

wake up 2 h later during Condition B, children generally demonstrated less difficulty falling asleep than waking up. In contrast, when asked to revert back to their typical sleep timing in Condition A2 (which was 2 h earlier than in Condition B), most children struggled with falling asleep early enough. This finding may reveal the potent influence of circadian rhythms upon children's sleep behavior. Namely, that children in our study preferred maintaining their typical earlier wake time or later bedtime when the timing of their sleep was manipulated, even at the expense of extended sleep duration.

Future sleep timing manipulation studies may want to address several considerations identified from our "lessons learned." If future researchers are merely interested in manipulating the timing of when children are in bed, the current protocol would likely be sufficient. However, for studies that wish to fully shift children's sleep patterns (that is, their actual time of sleep onset and offset), they will likely need to consider several factors. First and foremost, sleep timing manipulation protocols are limited by time of year in which it is ethical and feasible to conduct them. We conducted this study during the summer months for children attending traditional school, as most children's school schedules could not accommodate shifting their sleep schedules even 1 h later. Thus, future studies with representative populations will also most likely need to collect data over the summer. Future studies should consider the baseline characteristics of the children's sleep, particularly as it relates to night-to-night sleep schedule variability and time to achieve sleep onset. Preliminary results from our study indicate that children who exhibited insomnia-like symptoms (taking > 30 min to fall asleep) during the preliminary baseline week struggled most with achieving the desired sleep onset times during the sleep manipulation. Thus, stabilizing baseline sleep may need to be a necessary first step prior to manipulating sleep timing. Longer condition periods may be required to ensure that subjects have sufficient time to adjust both to the external (i.e., environmental) and internal (i.e., circadian) drivers of their sleep schedules. Considering that some children were unable to fall asleep and wake up at the assigned times (even when times were personalized to their average individual sleep pattern), one might consider assessing whether environmental demands played a role in adherence, and what those demands might be (e.g., family members' non-concordant sleep schedules, desire for technology use). Moving forward, documenting the environmental context surrounding sleep would be an essential next step to determining the etiology of sleep timing issues.

Relatedly, it is notable that the children in our sample were healthy, did not exhibit baseline behavioral or emotional difficulties, and came primarily from in-tact families with high levels of family support and parental monitoring. Thus, replication in a larger and more diverse sample would be prudent. Replication on a larger scale could be difficult considering the "real world" challenges associated with adjusting sleep timing for most families. Children with primarily working caregivers, attending school, or with behavioral issues would likely face challenges adhering to this exact protocol, although this should be systematically assessed. Finally, researchers may consider the pros and cons of less intensive methods for data collection. Although we collected sleep diary data on a daily basis (as is necessary for a single-subject design), future studies may be able to employ group-based designs and forgo a few more aspects of this protocol (e.g., implementing a stabilized sleep condition), particularly with children who have stable, developmentally appropriate baseline sleep. Benefits to such an intensive data collection approach as ours included ability to individualize the sleep schedule and to monitor adjustment to the sleep condition on a daily basis, which may be particularly important in protocols that include youth with baseline sleep variability or long time to sleep onset.

There are several valuable clinical implications of this study. Our experimental paradigm mirrors normative self-selected changes in week and weekend bedtimes for school-aged children (Randler et al., 2012). However, there was a clear preference for earlier-than-assigned wake schedules in our young children, and shifting sleep patterns later typically resulted in curtailed sleep duration. Although this was a very small and homogeneous sample, these preliminary findings suggest that young children struggle to effectively adjust their sleep schedules from week-to-weekend, perhaps due to preferences for earlier and/or consistent wake times. Thus, in this population, maintaining consistent bed times may require greater clinical support (e.g., development of bed time routines) than maintaining consistent wake times. Considering that half of our participants struggled to consistently fall asleep at scheduled bed times that were specifically tailored to their typical sleep timing, establishing consistent sleep schedules may take more time and effort than previously assumed. Unsurprisingly, this may especially be the case for youth with variable sleep schedules or baseline difficulties falling asleep. While clinicians may anticipate that advocating for consistent and/or early bed times will produce consistent sleep within several days or a week, this may not be the case for certain children. Thus, realistic psychoeducation about how long it may take to establish consistency may be a necessary first step for parents attempting to improve their child's sleep habits.

There are some limitations to our findings. Most notably, results reported here were from a very small and relatively unrepresentative sample. These choices were intentional, as we wanted to prioritize participant safety and overall study feasibility over generalizability (given the novel study design). However, this clearly limits generalizability to the wider child population. Additionally, sleep data discussed

in this feasibility report were parent-reported via daily sleep diary, and therefore liable to the restrictions associated with subjective, parent proxy reporting. Although daily sleep diaries are low-cost, low-burden, and a recommended method of sleep data collection (Gaina, Sekine, Chen, Hamanishi, & Kagamimori, 2004), reporting could become less accurate over a long data collection period due to parent fatigue, and it is difficult to assess the accuracy of these data. As parent-reported sleep diaries are common within clinical settings, these findings may be most applicable for clinicians. This study did not take into account daytime napping. Given the impact of daytime sleep on homeostatic sleep pressure, it would certainly be important for future studies to consider napping, especially as it relates to children's ability to quickly achieve sleep onset.

In summary, our findings establish that experimentally manipulating time into/out of bed (although not necessarily the time of sleep onset/offset) among young school-aged children is feasible in an at-home, short-term protocol. We hope that our observations and "lessons learned" encourage future use of experimental protocols that evaluate the relationship between sleep timing and other biopsychosocial constructs. Future implementations of such experiments will likely require further modification (e.g., initial sleep stabilization, longer condition lengths, problem-solving logistics around schedule implementation) to answer the remaining question of how long it takes school-aged youth to effectively phase shift and meet assigned sleep onset/offset times. Overall, implementation of experimental sleep timing studies will likely assist researchers and clinicians interested in understanding and improving their patients' sleep schedules.

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Compliance with Ethical Standards

Conflict of interest Rachel S. Fisher, Kendra N. Krietsch, and David. M. Janicke declare that they have no conflict of interest.

Statement of Human Rights All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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