# Earlier Bedtimes Mediate the Effect of a Brief Behavioral Sleep Intervention on Children's Weight Status

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Whether the effect of a brief behavioral sleep intervention on child weight status resulted from observed differences in sleep duration and/or bedtimes was assessed. Findings demonstrate that the intervention's beneficial effect on weight status was due to earlier bedtimes, suggesting the potential importance of earlier bedtimes for obesity prevention. *(J Pediatr 2025;276:114265).*

The current pediatric obesity epidemic necessitates identification of novel approaches for prevention and treatment. Meta-analyses consistently document cross-sectional and prospective associations between longer sleep duration and lower weight status in children.[1-4] An experimental study conducted with school-aged children demonstrated that, when children slept more by going to bed earlier, they reported decreased caloric intake and weighed less.[5] Further, a recent behavioral sleep intervention demonstrated that children randomized to intervention increased their sleep duration relative to control, and those children who made clinically meaningful changes in their sleep across conditions (ie, increased their sleep by at least 30 minutes/night) manifested protective effects against increases in body mass index (BMI) over the 2-month study period.[6] Thus, extant evidence supports the potential of enhancing children's sleep as a novel approach to prevent excess weight gain.

Emerging work also provides compelling evidence for the potential importance of sleep timing for weight regulation. Experimental studies with adults demonstrate that shifts in sleep timing have clear implications for weight regulation.[7,8] Observational studies with children also demonstrate that earlier bedtimes, for example, are associated with lower weight status.[9] Further, protective effects for weight status observed in the above-noted pediatric clinical trials resulted from increasing sleep duration by moving children's bedtimes earlier. Discerning whether observed changes in sleep duration and/or timing influenced children's weight regulation is imperative because it could help to refine how best to enhance sleep for obesity prevention and treatment.

We, therefore, explored in secondary analyses the potential indirect pathways through which a brief behavioral sleep intervention may have affected change in children's weight status. We hypothesized that the effect of intervention on weight status would be greatest for children who achieved longer sleep duration and earlier bedtimes.

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| BMI | Body mass index |
| BMIz | Body mass index z-score |
| TIB | Time in bed |

## Methods

Details of this study were reported previously.[6] In brief, families were recruited into this 2-arm, randomized controlled trial between January 2012 and May 2016 from Providence, Rhode Island, and Philadelphia, Pennsylvania, using multiple strategies (eg, direct mailings, community postings). Children were enrolled primarily during the school year, but were also enrolled during summer months if they participated in a structured activity (eg, day camp, summer school) that mirrored their school year schedule. Families attended individual or group orientations where they were informed of the study's purpose and procedures. Trained research staff obtained written informed consent from parents and assent from children. Final eligibility was determined prior to randomization during a one-week baseline assessment. Children were asked to sleep as usual; if reported time in bed (TIB) was ≤9.5 hours per night (confirmed by actigraphy), the child was randomized using a variable-sized stratified permuted blocks randomization procedure developed by the study's statistician (by weight status and baseline TIB) and concealed in sealed envelopes. Staff blind to treatment allocation completed 1-week assessments with families at baseline, 2 weeks, and 2 months after randomization. Procedures were approved by the institutional review boards at The Miriam Hospital and Temple University. Data and safety monitoring occurred twice yearly by independent safety monitors. No adverse or serious adverse events were reported

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The study was registered at ClinicalTrials.gov (NCT01508793, www.clinicaltrials.gov).

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### Participants

Eligible children were 8 to 11 years of age and were reported to sleep approximately ≤9.5 hours per night (confirmed by actigraphy) and had a BMI-for-age and biological sex >10th percentile, but not >100% overweight. They needed to be able to understand and complete the protocol, be enrolled in a school with a start time consistent with area elementary schools, and have a primary caregiver who reported age of ≥18 years old. Children with a reported sleep disorder, medical or psychiatric condition, or medication use that could impact sleep or weight status were excluded. For the present secondary data analyses, additional exclusions included missing sleep data at 2 weeks and/or missing weight data at 2 months.

### Interventions

Details regarding the intervention, including its development, have been reported previously.[6] In brief, participants (parent and child together) received a 4-session behavioral intervention that focused solely on enhancing children's TIB by 60-90 minutes per night. Changes in TIB were primarily achieved by advancing children's bedtimes. The first 2 sessions were in person and focused on effective behavioral strategies to enhance TIB (eg, goal setting, self-monitoring, positive reinforcement). The second 2 sessions were by phone and reinforced behavioral strategies. Between phone sessions, children participated in a sleep challenge in which they were mailed an actigraph and sleep diary and challenged to continue to enhance their sleep.

Participants in the sleep as usual condition were asked to continue with their current sleep. They attended the same number of sessions as those randomized to the behavioral sleep intervention, but focused on the appropriate use of study devices and preparation for assessments.

Children wore the Actiwatch 2 (AW2; Phillips Respironics, Bend, OR) —a reliable and valid estimate of sleep compared with polysomnography[10]—on their nondominant wrist, 24 hours per day during each 1-week assessment. Data were collected in 1-minute epochs using a medium sensitivity threshold and were scored using Actiware software version 5.59.0015. Standard procedures[11] were used to establish sleep onset and wake. Primary variables of interest are the sleep period (ie, time between estimated sleep onset and wake) and bedtime (ie, time of estimated sleep onset).

Staff measured children for height and weight in duplicate while dressed in street clothes without shoes using a wall-mounted stadiometer and calibrated digital scale, respectively. BMI was calculated as weight (kg)/height ($m^2$). Normative age and sex reference data from the Centers for Disease Control and Prevention were used to calculate the BMI *z*-score (BMIz).[12]

We performed mediation analyses using the R package *medflex*.[13] We examined the mediators (ie, mean sleep period and mean bedtime at 2 weeks) in separate models. The outcome is BMIz at 8 weeks (2 months). We first included only baseline BMIz as a covariate and then included both baseline BMIz and the baseline measure of the respective mediator as covariates. That is, baseline sleep period was included as an additional covariate in the mediation model for sleep period at 2 weeks and baseline mean bedtime was included as an additional covariate in the mediation model for mean bedtime at 2 weeks. We used robust standard errors and an alpha level of 0.05 for statistical significance.

## Results

Of the 78 eligible participating families who were randomized, 71 (91%) were included in these secondary analyses (**Figure 1**). Children were aged 9.72 ± 1.00 years and primarily identified as female (69%). Forty-five percent (n = 32) identified as Black or African American. The mean BMIz at baseline was 0.91 ± 0.94. Those included in these secondary analyses did not differ from the overall sample on child age (9.690 ± 0.997 years of age), race (47% Black/African American), gender (67% female), BMIz (0.93 ± 0.94), or site (51% current sample from Providence, RI, vs 49% in the overall sample).

Consistent with primary analyses,[6] children randomized to intervention enhanced their sleep period relative to control at both the 2-week and 2-month assessments. Specifically, relative to control, children randomized to intervention were sleeping 47 ± 10 minutes per night more at 2 weeks, $t(69) = 4.684$, $P < .001$, and 44 ± 11.5 minutes per night more at 2 months, $t(64) = 3.798$, $P < .001$ (**Figure 2**, A). Children randomized to intervention, relative to control, also advanced their bedtimes by 51 ± 13 minutes per night more at 2 weeks, $t(69) = -4.061$, $P < .001$, and 35 ± 16 minutes per night more at 2 months, $t(64) = -2.192$, $P = .032$ (**Figure 2**, B).

When assessing the potential effect of intervention on weight status via bedtimes, an indirect effect of intervention (ie, the effect through the mediator) via 2-week bedtimes (adjusting for baseline BMIz) was observed ($z = -2.07$; $P = .039$), and this effect remained when adjusting for both baseline bedtime and BMIz ($z = -2.14$; $P = .033$). Specifically, it was estimated that children randomized to intervention went to bed 47 minutes earlier on average, relative to controls, at 2 weeks, which was associated with a lower BMIz of 0.03 at 2 months (**Figure 3**). The direct effect (ie, the effect not through the mediator) was not statistically significant ($z = 1.77$; $P = .078$). When assessing the potential effect of intervention on BMIz via children's 2-week sleep period (adjusting for baseline BMIz), neither a direct effect of intervention ($z = 1.54$; $P = .125$) nor an indirect effect via 2-week sleep period was observed ($z = -1.94$; $P = .053$). When adjusting for both baseline sleep period and baseline BMIz, statistical significance dropped further (direct effect, $z = 1.126$, $P = .260$; indirect effect, $z = -0.79$, $P = .429$). These findings regarding both bedtimes and duration were

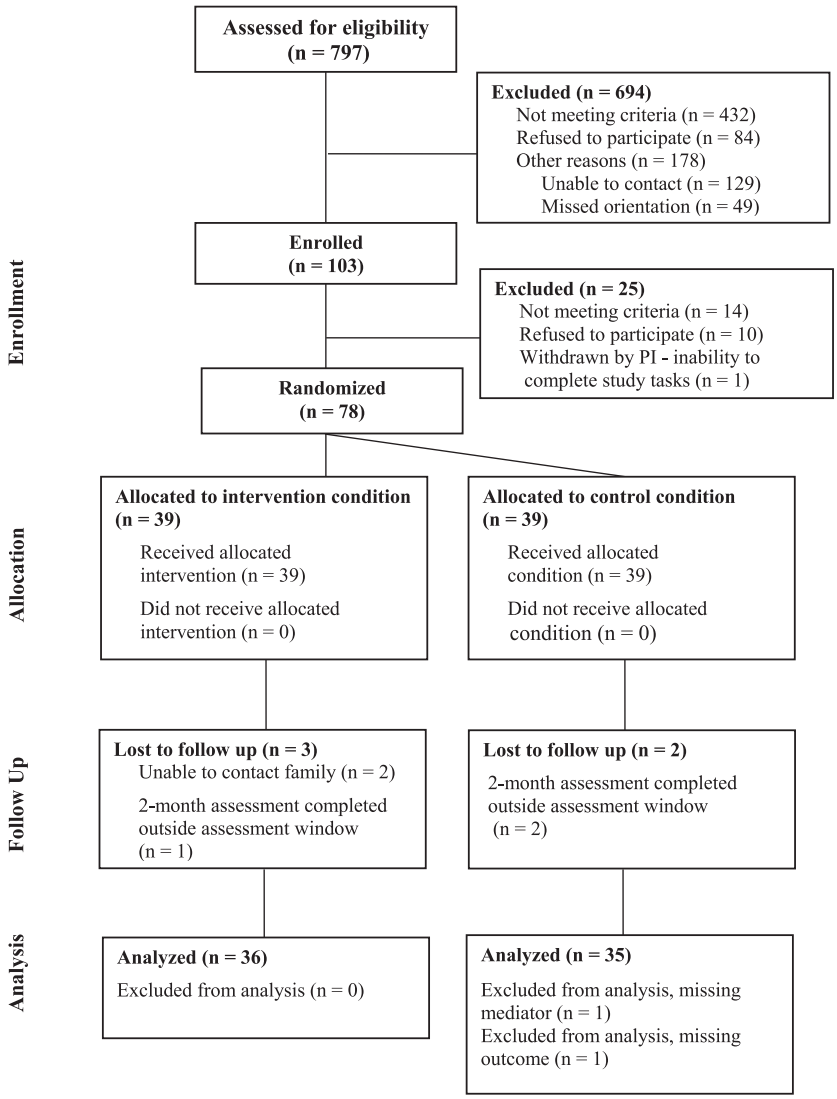


**Figure 1.** CONSORT flow diagram of progress through stages of a randomized trial. Five participating families were lost to follow-up and not included in analyses; 2 additional families were excluded owing to missing data for the mediator.

consistent but did not reach statistical significance when child BMI (adjusting for age and biological sex) was entered as the outcome of interest.

## Discussion

The present study demonstrates that a brief behavioral sleep intervention can enhance both the timing and quantity of school-aged children's sleep. Importantly, the effects of intervention on child weight status were observed through advancing children's bedtimes. Specifically, relative to control, children randomized to the intervention went to bed 47 minutes earlier by the 2-week assessment, which resulted in a lower BMIz by 0.03 at 2 months. Observed group differences in children's sleep period at 2 weeks did not mediate the effect of intervention on weight status. These secondary analyses not only reinforce primary study findings of the potential importance of enhancing children's sleep for optimizing weight regulation,[6] but also extend findings by demonstrating that earlier bedtimes seem to be a key factor through which the intervention impacted weight status significantly.

The observed effect of intervention on children's BMIz via earlier bedtimes is interesting, particularly within the context of emerging work with adults, which supports the importance of the timing of sleep for enhanced weight regulation.[7,8] For example, one experimental study with adults that mimicked sleep-wake schedules experienced by shift workers demonstrated that a delayed sleep schedule led to metabolic disturbance that favors weight gain.[7] The present findings are also supported partially by an experimental study with school-aged children that extended and restricted sleep by advancing and delaying bedtimes and found that sleep extension via advancing bedtimes resulted in lower measured weight.[5] Observational studies with children lend further

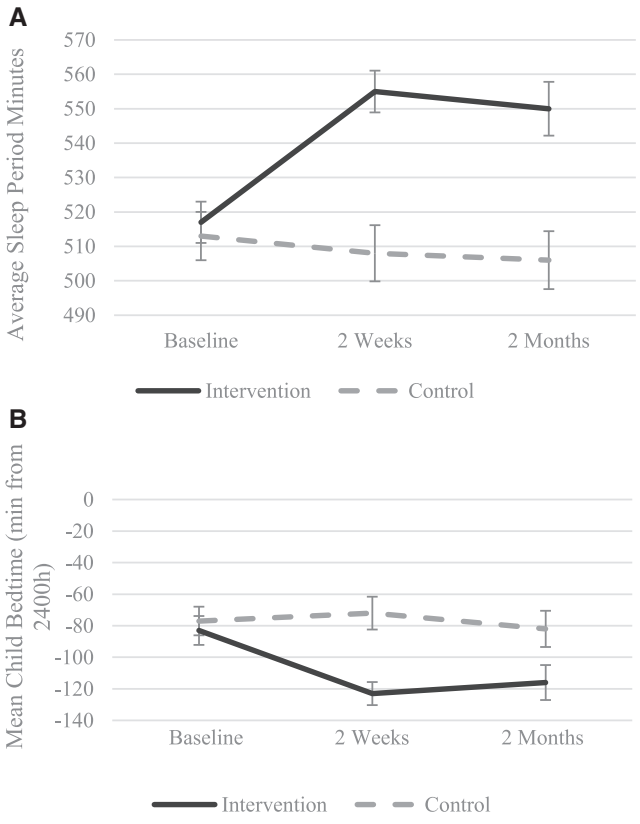


**Figure 2.** Change in sleep period and bedtimes in children randomized to intervention vs control (n = 71). Effect of the behavioral sleep intervention, relative to control on (**A**) mean actigraph estimated sleep period and (**B**) mean actigraph estimated bedtime, depicted as minutes from midnight (2400 h). Error bars represent standard errors of the mean.

support to the present findings in that there is growing evidence for the association between later bedtimes and higher weight status (independent of sleep duration).[9,14] All of these findings are consistent with a circadian biology perspective, which underscores the importance of the alignment of behaviors such as bedtimes with underlying circadian rhythms for optimal metabolic outcomes.[15,16]

The relatively small sample and short follow-up are 2 important limitations. In addition, going to bed earlier was associated with increasing sleep duration. Thus, it is

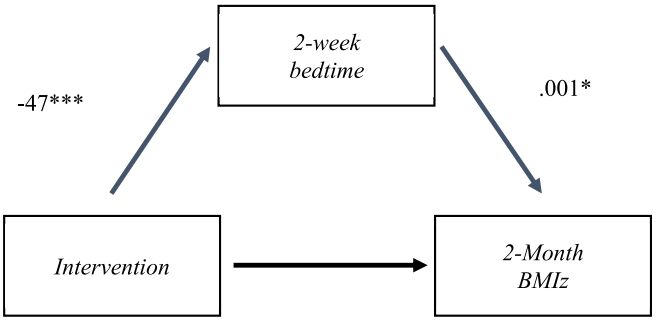


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**Figure 3.** Mediation of intervention effects by child bedtime at 2 weeks on 2-month BMIz (n = 71). There was no direct effect of intervention on BMIz at 2 months. There was an indirect effect of intervention via 2-week bedtime with the intervention leading to a 47-minute earlier bedtime relative to control at 2 weeks. Each minute children went to bed earlier results in a reduction in BMIz of 0.001. Thus, the overall indirect effect of going to bed 47 minutes earlier at 2 weeks resulted in a reduction in BMIz of 0.03. *$P < .05$; ***$P < .001$.

challenging to understand the unique contribution of bedtime vs duration in our models. Further, the intervention's focus on advancing bedtimes to increase children's sleep duration was primarily driven by an inability to delay wake times for most children due to the need to attend school. However, some children such as those with evening chronotype (ie, preference for later sleep timing) and older children/adolescents with advanced pubertal development may have challenges going to bed earlier and thus may not experience the same benefits as those observed herein. In addition, the observed indirect effect of the behavioral intervention on child BMIz was small, and although a consistent pattern was observed, findings were not significant when using BMI as the outcome of interest. Thus, it seems more likely that our findings speak to the potential of intervening on sleep for obesity prevention or as an adjunct to obesity treatment rather than as a primary intervention for pediatric weight control. Future studies with larger samples that are conducted over a longer follow-up and that consider important factors such as chronotype and pubertal development will be important to help determine the relative importance of enhancing children's sleep timing as an important approach for pediatric obesity prevention. ■

## CRediT authorship contribution statement

**Chantelle N. Hart:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Donna L. Coffman:** Writing – review & editing, Formal analysis. **Mary A. Carskadon:** Writing – review & editing, Conceptualization. **Hollie A. Raynor:** Writing – review & editing, Conceptualization. **Elissa Jelalian:** Writing – review & editing, Conceptualization. **Judith A. Owens:** Writing – review & editing, Conceptualization. **Nicola L. Hawley:** Writing – review & editing, Data curation, Conceptualization. **Rena R. Wing:** Writing – review & editing, Conceptualization.

## Declaration of Competing Interest

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C.N.H. is currently providing consultation on a grant funded by the Novo Nordisk Foundation. C.N.H. and E.J. previously provided consultation to Weight Watchers International. R.R.W. previously served on the Scientific Advisory Board at NOOM. Neither the Novo Nordisk Foundation, Weight Watchers, nor NOOM provided financial support for this study, nor did they have any influence on the methods in this study. There are no additional conflicts of interest relevant to this article to disclose.

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