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Naturalistic, multimethod exploratory study of sleep duration and quality as predictors of dysregulated eating in youth with overweight and obesity

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Abstract

Although poor sleep has been found to adversely impact eating and weight regulation in youth, past research is limited by retrospective reporting and/or non-naturalistic designs. We investigated the feasibility of combining three momentary, ecologically valid approaches to assessing sleep and eating behavior, and associations between these constructs, among youth (aged 8-14y) with overweight/obesity (n=40). Participants completed 14 overlapping days of actigraphy assessment and smartphone-based ecological momentary assessment (EMA) of eating behavior, of which 3 days also included computerized, self-guided 24-hour dietary recall. Feasibility of completing measures concurrently was evaluated by generating frequencies of compliance. Associations between sleep indices and next-day eating behavior were examined via generalized estimating equations. Of 29 participants who provided EMA and 24-hour recall data that aligned with previous night actigraphy data, both EMA and sleep data were available on an average of 8.6 out of 14 possible days, and both 24-hour recall and sleep data on an average of 2.7 out of 3 possible days. Each additional hour of sleep was associated with consuming fewer calories from solid fats, alcohol, and added sugars (b=0.70; p=.04). Combining naturalistic, momentary assessments of sleep and eating behavior appears to be acceptable in youth. Larger experimental studies are needed to further understand associations between sleep parameters and eating behavior.

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1. Introduction

Although causes of overweight/obesity are multifactorial, dysregulated eating behaviors leading to excess energy intake are a major factor in their onset and maintenance (French, Epstein, Jeffery, Blundell, & Wardle, 2012). One such behavior that is prevalent among youth with overweight/obesity is loss of control (LOC) eating, involving a sense that one cannot control what or how much one is eating irrespective of the amount of food consumed (Goldschmidt, 2017). In addition to cross-sectional associations with overweight/obesity, LOC eating is prospectively associated with weight gain/adiposity (Sonneville et al., 2013; Tanofsky-Kraff et al., 2006; Tanofsky-Kraff et al., 2009) and suboptimal psychosocial functioning (Goldschmidt et al., 2008; Schluter, Schmidt, Kittel, Tetzlaff, & Hilbert, 2016; Tanofsky-Kraff et al., 2011; Tanofsky-Kraff et al., 2004), and may undermine weight control treatment (Goldschmidt, Khoury, et al., 2018; Sysko et al., 2012; Wildes et al., 2010). Therefore, understanding factors that contribute to occurrence of LOC eating episodes may inform treatments targeting excess weight gain in children.

Poor sleep quality and/or quantity (e.g., difficulties initiating sleep, sleep fragmentation/ nighttime awakenings, short sleep duration, and other constructs) have been associated with an increased risk for pediatric overweight and obesity in multiple cross-sectional and prospective studies (Fatima, Doi, & Mamun, 2016; Miller, Kruisbrink, Wallace, Ji, & Cappuccio, 2018), indicating that improving sleep hygiene may be a viable target for interventions addressing these conditions (Hart, Hawley, & Wing, 2016). Sleep is postulated to impact body weight via a number of neuroendocrine, metabolic, cognitive, and behavioral pathways (St-Onge, 2017). Research conducted primarily in non-obese samples suggests that at both the between- and within-subjects levels, sleep restriction enhances hunger, potentially via appetite-regulating hormones such as the orexigenic hormone ghrelin and the anorexigenic hormone leptin (Boeke, Storfer-Isser, Redline, & Taveras, 2014; Leproult & Van Cauter, 2010; Spiegel, Tasali, Penev, & Van Cauter, 2004; St-Onge, O’Keeffe, Roberts, RoyChoudhury, & Laferrere, 2012), and increases neural reward sensitivity to food cues (Benedict et al., 2012; St-Onge, McReynolds, et al., 2012; St-Onge, Wolfe, Sy, Shechter, & Hirsch, 2014), all of which could lead to excess energy intake and subsequent increases in body weight. Alternatively, poor quality sleep is associated with decreased executive functioning at the between-subjects level (Sadeh, Gruber, & Raviv, 2002), which could inhibit regulation of eating behavior and lead to subsequent feelings of LOC. Indeed, increased time to sleep onset, poor sleep continuity, and shortened sleep duration have been associated with overeating and LOC eating behaviors in adults at the between-subjects level (Trace et al., 2012; Tzischinsky, Latzer, Epstein, & Tov, 2000; Vardar, Caliyurt, Arikan, & Tuglu, 2004; Yeh & Brown, 2014), although research characterizing associations between sleep and disordered eating behavior has been relatively limited in pediatric samples.

Two recent naturalistic studies of youth across the weight spectrum reported that experimental sleep restriction was associated with higher energy intake (Hart et al., 2013) and greater intake of energy-dense desserts and sweets (Beebe et al., 2013), but neither study specifically examined the experience of LOC. By contrast, Tzischinsky and Latzer (2006) found that children with overweight/obesity and concurrent binge eating (i.e., objectively large LOC episodes) had lower sleep efficiency and increased wakefulness (both measured via actigraphy) than control children with overweight/obesity. Yet, a major limitation to this body of research is that eating behavior was retrospectively reported, which may be particularly problematic in youth given developmental factors that impede recall and understanding of complex constructs (Fan et al., 2006; Matthews, Hall, & Dahl, 2014). Therefore, combining objective and subjective methods of real-time, naturalistic data collection may advance the field's understanding of the relation between sleep and eating behavior in youth.

The aims of this exploratory pilot study were to: 1) assess the feasibility of combining three methods of naturalistic assessment of sleep and eating behavior, namely actigraphy, an objective method for measuring sleep patterns in the natural environment (Ancoli-Israel et al., 2003); ecological momentary assessment (EMA), an experience sampling technique in which events and associated behaviors, emotions, and cognitions are self-reported in near real-time in the natural environment (Stone & Shiffman, 1994); and 24-hour dietary recall involving detailed self-reports of the quantity of all foods and beverages consumed within the prior 24 hours; and 2) investigate whether sleep quantity and/or quality is related to alterations in eating behavior on the following day. Given that actigraphy is a non-intrusive technology, whereas EMA and dietary recalls are more labor-intensive, we expected that compliance would be higher for the actigraph protocol relative to the EMA and dietary recall protocols. We further hypothesized that shorter sleep duration (as reflected in total sleep time; TST) and poorer sleep quality [as reflected in increased nighttime awakenings, higher wake after sleep onset (WASO) scores, and lower sleep efficiency] would be associated with greater energy intake, poorer dietary quality, and elevated risk of LOC eating on the following day.

2. Materials and Methods

2.1 Participants and procedures

Participants were children and adolescents with overweight or obesity who were involved in a larger pilot study investigating a broad array of contextual factors associated with eating behavior in the natural environment (Goldschmidt, Smith, et al., 2018). Primary aims of this larger study were to identify physiological, emotional, interpersonal, and environmental antecedents and consequences of LOC eating, and to evaluate the prevalence of LOC eating in the natural environment among a heterogeneous sample of young people. The present study represents the first investigation of associations between sleep and eating behavior from this sample.

Participants were recruited from two academic institutions in Chicago, IL (The University of Chicago Medicine and Illinois Institute of Technology) via community flyers, direct pediatrician referrals, and phone logs from previous studies. To be included, youth had to have a body mass index (BMI; kg/m^2) ≥ 85^{th} age- and sex-adjusted percentile and be between the ages of 8-14 years. Exclusion criteria were: medical conditions or medications known to influence sleep, weight, or appetite (e.g., sleep apnea); eating disorders other than binge eating disorder (as assessed by diagnostic items from the Child Eating Disorder Examination; Bryant-Waugh, Cooper, Taylor, & Lask, 1996); inability to read and understand English fluently; and concurrent treatment for overweight/obesity. Caregivers of interested individuals completed a phone screen to assess basic study entry criteria, and eligible participants and their caregiver(s) attended a baseline study visit. In total, 92 youth were screened via phone, 44 of whom presented to the research sites for a baseline evaluation, and 40 of whom provided adequate EMA data (e.g., at least 7 days of EMA recording) to be considered in the current analyses. At the baseline assessment, participants provided written informed assent/consent, had their height and weight measured, and completed interviews and questionnaires assessing sleep, eating patterns, and psychosocial functioning. Participants and their caregivers were then trained to complete the EMA, actigraphy, and dietary recall protocols. Training included both parents and children, lasted approximately 30-60 minutes, and was led by the research assistant, who 1) visually proceeded through each EMA screen with instructions on rating oneself in each domain; 2) demonstrated proper watch placement and filled out a sample sleep diary with the family; and 3) completed an abbreviated sample dietary recall online with the family, highlighting the level of detail necessary for accurate reporting.

Participants were asked to complete EMA recordings after each eating occasion (event-contingent); before bedtime (interval-contingent); and at 3-5 semi-random times throughout the day (signal-contingent; Wheeler & Reis, 1991). EMA recordings were not collected during the school day, such that signaled prompts occurred between 7:00-8:00am, 3:00-4:00pm, and 6:00-7:00pm on weekdays and every 2-3 hours between 8:00am-9:00pm on the weekends. During all recordings, participants were instructed to report on characteristics of any recent eating episode that had not been previously recorded. This combination of signal-, event-, and interval-contingent recordings has been successfully implemented in previous EMA studies of youth with overweight/obesity (Hilbert, Rief, Tuschen-Caffier, de Zwaan, & Czaja, 2009; Ranzenhofer et al., 2014). A 1-day practice period during which adherence was ≥70% of EMA ratings qualified children to initiate the 14-day study period; these data were not used in statistical analyses to reduce concerns about the effect of immediate reactivity to self-monitoring. Participants and their caregivers were contacted by phone by a member of the study team after the first day of EMA recording, and every 2-3 days thereafter, to receive feedback regarding compliance rates and address questions or concerns regarding assessment procedures. These phone calls were unscripted and typically involved informing participants about completion rates and incentives earned, problem-solving technical issues (e.g., poor Internet connection), and trouble-shooting any reasons for suboptimal compliance (e.g., keeping smartphone volume at an adequate setting, leaving the actigraph watch in plain sight to enable re-placing it on the wrist as soon as possible after any removals).

Participants were instructed wear wrist actigraphy monitors (Actiwatch 2, Respironics/Phillips, Bend, OR) continuously (except during contact sports or swimming) on the non-dominant wrist, unobstructed by clothing, throughout the 14-day protocol. For each night of actigraphy data collection, participants were instructed to mark the time they began falling asleep and the time they awakened by pressing an event marker button on the actigraphy monitor, which is a standard procedure. This was supplemented by daily sleep diaries (see "Measures" section for more details). Dietary intake was assessed via three, non-consecutive 24-hour dietary recalls collected using the self-guided Automated Self-Administered 24-hour Dietary Assessment Tool for Children (ASA24-Kids), version 2016, developed by the National Cancer Institute, Bethesda, MD. The ASA24-Kids is a Web-based data collection tool with complementary nutrient analysis of all foods and beverages consumed during the recall timeframe. Modifications for children include use of an animated avatar to guide children through response options while maintaining their interest; simplification of wording for food and beverage items; and inclusion of common misspellings to minimize food-finding difficulties. ASA24-Kids recordings were completed on two randomly selected weekdays and one randomly selected weekend day during the 14-day protocol. Participants and their caregivers were contacted via phone by research staff to indicate that a recall day had been selected, and they were then instructed to log on to the ASA24 website and report everything they ate or drank from 0:00h-23:59h on the previous day. Caregivers and children were trained in completing the ASA24-Kids together during the baseline evaluation, as children often require caregiver input to report on aspects of dietary intake (e.g., brand names, food preparation techniques, portion size amounts). Research staff also guided children and caregivers together through ASA24-Kids data collection procedures by phone throughout the 14-day protocol, which has been suggested as a means to improve recall accuracy and compliance (Diep et al., 2015).

Participants received $50 for the intake assessment; $50 for completion of the 14-day protocol; and up to $50 for daily assessments prorated according to degree of response to random signals ($1 for each response to a total of 50 semi-random signals over the course of the 14-day protocol). Study procedures were approved by The University of Chicago and Illinois Institute of Technology Institutional Review Boards.

2.1 Measures

2.2.1 Baseline measures.—Height and weight were measured in light indoor clothing by a trained research assistant via stadiometer and calibrated digital scale, respectively. Child BMI z-score was calculated using Centers for Disease Control and Prevention growth charts and accompanying procedures (Kuczmarski et al., 2000). Demographic data were reported by children and caregivers, and included children's age, gender, race/ethnicity, current medications, and medical problems. Children's behavior problems were assessed via the Achenbach Child Behavior Checklist (CBCL; Achenbach, 1991), a parent-report measure of child psychosocial functioning and competency that has good reliability and validity (Achenbach, 1991; Achenbach & Elderbrock, 1991). Sleep items were excluded from the total score calculations to avoid confounding effects on psychosocial functioning.

2.2.2 EMA.—At eating episode recordings, participants reported on the type of eating episode they experienced (meal, snack, or binge). Ratings for LOC ("While you were eating, did you feel a sense of loss of control?"; "While you were eating, did you feel that you could not stop eating once you had started?"; "While you were eating, did you feel like you could not resist eating?"; "While you were eating, did you feel like a car without brakes, you just kept eating and eating?") were made on a 1- to 5-point Likert-type scale (1-"no, not at all," and 5-"yes, extremely"). These items were modeled after conceptualizations of LOC in previous EMA studies (Goldschmidt et al., 2014; Hilbert et al., 2009; Ranzenhofer et al., 2014). The four items assessing LOC were summed to form a total score (range=4-20) based on their high internal consistency (α=.91). LOC days were characterized as those on which there was a score of above 4 during at least one eating episode, indicating that some degree of LOC was experienced during at least one eating occasion.

2.2.3 Actigraphy.—Actigraphy is a well-established measure of sleep in the natural environment. It has been validated against the "gold standard" polysomnography, with agreement rates for minute-by-minute sleep—wake identification exceeding 90% (Ancoli-Israel et al., 2003; Sadeh et al., 2002). Actigraphy data were collected continuously and stored in 30-second epochs. In-bed time began with the first minute of a 10-minute period in which the activity counts were all zero and wake-up time was the first minute of a 10-minute period in which the activity counts were all greater than zero (Sadeh, Sharkey, & Carskadon, 1994). Data were analyzed based on the "medium" threshold (meaning that the number of activity counts required to be considered "awake" was 40, as compared to 20 for the "low" threshold and 80 for the "high" threshold) for sleep-wake detection in Philips Actiware v 6.0.7 software, which is the default threshold. Data collected are described in Table 1, and included time in bed (TIB), sleep duration (total sleep time, or TST), wake time, bed time, sleep efficiency (sleep duration divided by the number of minutes in the rest interval), awakenings, and WASO (number of minutes of wake time detected after the participant initially fell asleep). These measures were constrained to nighttime sleep. Sleep intervals were defined as the period between bed time and wake time. The amount of time between bed time and sleep onset is defined as sleep latency. Sleep diaries developed by the American Academy of Sleep Medicine were used to inform coding of sleep and wake times during preliminary actigraphy analyses, such that diary data informed the identification of boundaries for when sleep could have started and ended based on the time the participant got into and out of bed each night. Participants (with caregiver assistance/corroboration when necessary) were instructed to indicate the start and end time of all sleep episodes, including nighttime sleep/awakenings and naps. Actigraphy and sleep diary data were used in conjunction to determine TST, number of nighttime awakenings, WASO, and sleep efficiency (i.e., bedtimes and wake times noted on the sleep diaries were used to verify the boundaries noted by actigraphy, within which to identify sleep and wake periods in the actigraphy data). WASO is a measure of sleep fragmentation (Shrivastava, Jung, Saadat, Sirohi, & Crewson, 2014), and sleep efficiency is the percentage of time spent in bed actually spent asleep. No restrictions were placed on sleep as the study was designed to assess naturalistic associations between sleep and eating behavior.

2.2.4 Dietary recall.—Dietary data from the ASA24-Kids provided estimates for total energy intake at both the eating occasion and day levels, as well as diet quality, measured by the Healthy Eating Index 2010 (HEI-2010; Guenther et al., 2013), for each recall day. The ASA24-Kids uses a modified version of the United States Department of Agriculture's Automated Multiple Pass Method to reduce bias by reviewing the previous day's diet with participants up to six times (Park et al., 2018). Participants are instructed to provide information on quantity of all food and beverages consumed as well as the time, eating occasion and location at which they were consumed. The ASA24 has been validated against interviewer-administered 24-hour recalls and biomarkers and may provide more accurate portion size estimations (Kirkpatrick et al., 2016; Kirkpatrick et al., 2014; Park et al., 2018; Thompson et al., 2015). Whereas collecting three, non-consecutive 24-hour dietary recalls is the most accurate and reliable method for assessing dietary intake in children (Burrows, Martin, & Collins, 2010), under-reporting is common, particularly in older children and those with overweight or obesity (Lioret et al., 2011). Accordingly, recalls for which participants reported <500 calorie intake (n=6) were not used in data analyses due to implausibility of reported intake.

2.3 Statistical analysis

All statistical analyses were conducted using SAS 9.4 (2014; SAS Institute, Inc., Cary, NC). Descriptive statistics were generated for demographics and anthropometrics at baseline. The primary aim, to assess the feasibility of children and adolescents completing concurrent measures of eating-related constructs, sleep, and diet in real-time for 14 days, was evaluated by determining overlapping adherence for all three measures (i.e., number of days participants completed EMA, ASA24-Kids, and wore the Actiwatch). We also compared characteristics of children who provided matching EMA and 24-hour recall data that aligned with actigraphy data on their prior night's sleep ("completers") to those that did not ("non-completers"); however, these comparisons are descriptive only due to small sample sizes.

To assess the secondary aim to examine the relationships of sleep with eating behaviors and dietary intake, actigraphy data measuring sleep-related constructs were date-matched to the EMA- and ASA24-Kids-measured eating behavior data separately. As this was an exploratory study, and research on sleep and eating behavior in youth is emerging, we explored a range of sleep-related variables, including TST, number of nighttime awakenings, WASO, and sleep efficiency. Given that participants contributed multiple days of data for each measure, observations were correlated. Thus, a generalized estimating equation accounting for both a binomial distribution (with LOC dichotomized as a yes/no variable) and repeated measures was used to determine the odds of experiencing LOC eating based on the prior night's sleep. A similar model assuming a normal distribution was used to estimate the relationships of the prior night's sleep with energy intake and diet quality as assessed via ASA24-Kids. All analyses reflect between-subjects effects. Given the continuous nature and normal distribution of total energy intake and diet quality, this second model assumed a normal distribution. Results are reported both unadjusted, and adjusting for weekend vs. weekday (given evidence that pediatric sleep and eating behavior vary on weekends vs. weekdays; Hansen, Janssen, Schiff, Zee, & Dubocovich, 2005; Hart, Raynor, Osterholt, Jelalian, & Wing, 2011), age, sex, BMI and CBCL total scores excluding sleep-related items (given prior research linking internalizing and externalizing symptoms to both sleep and LOC eating in children; Baddam, Canapari, van Noordt, & Crowley, 2018; Byrne, LeMay-Russell, & Tanofsky-Kraff, 2019).

Because this was an exploratory study designed to generate effect sizes and assess for the presence of any associations of interest between sleep and eating behavior that should be further evaluated in future studies, power analyses are not presented and it was concluded that adjusting for multiple comparisons would limit discoveries from these exploratory data. Therefore, alpha was set at .05 for all analyses.

3. Results

3.1 Descriptive characteristics

To assess our primary aim related to feasibility, we found that of 40 participants who completed this study, 29 provided matching EMA and 24-hour recall data that aligned with actigraphy data on their prior night's sleep. On average, these 29 participants provided 13.1 days of EMA data and 11.2 days of sleep data (out of a possible 14 days). These data overlapped on 8.6 days, on average, and the EMA, sleep and ASA24-Kids data overlapped on an average of 2.7 days (out of a possible 3 days). As shown in Table 2, participants with complete data who were included in subsequent statistical analyses were 11.6±1.9 years of age, on average, and 56.7% were female. Nearly 80% of participants were from a racial/ethnic minority group, and more than 60% had mothers who pursued education beyond a college degree. The average BMI z-score was 2.1 units, which is consistent with this sample of youth with overweight or obesity. Those without complete data (i.e., participants who did not have EMA, ASA24-Kids and actigraphy data) were older and were more likely to be male, to have a racial/ethnic minority background, and to have a mother with less education (statistical comparisons between completers and noncompleters could not be performed due to small sample sizes). Actigraphy data suggest that participants slept 7h 17m (range=1h 4m-14h 36m) each night and, on average, experienced 31.8 awakenings each night. Participants reported consuming 1,684.1±772 calories per day, on average, (range=541.5 to 4,581.0 calories/day), and their mean diet quality, as measured by the total HEI-2010 score, was 43.5±11.9 out of a possible score of 100 (range=5.04 to 82.6).

3.2 Associations between sleep and next-day eating behavior

In the analysis of LOC eating (as measured by EMA) and sleep, participants contributed a total of 257 observations (days), 44 (19.4%) of which included an eating occasion at which LOC was reported. On days on which LOC eating occurred, participants consumed significantly more calories as compared to non-LOC days (2,436.7±742 calories vs. 1,675.7±686 calories, respectively; p=.008). Table 3 includes descriptive data for sleep characteristics on LOC vs. non-LOC days; when we statistically examined whether prior night's sleep (TST, number of night time awakenings, WASO, and sleep efficiency, all modeled separately) in relation to odds of having an LOC eating episode the following day, none of these relationships were significant after adjusting for age, sex, BMI z-score and CBCL total score (excluding sleep-related items; Table 4).

Table 5 shows the associations of measures of sleep (TST, number of nighttime awakenings, WASO, and sleep efficiency) with total energy intake and diet quality as assessed by HEI-2010. TST was positively associated with reported energy intake, although findings were no longer significant after adjusting for weekend vs. weekday, age, sex, BMI z-score, and CBCL total score. In further exploring these findings, after adjusting for weekend vs. weekday, age, sex, z-BMI, and CBCL total score, participants had 0.76 the odds of skipping breakfast with each additional hour of sleep, which was marginally significant (p=.09). Finally, while the relationships of sleep measures and overall diet quality (i.e., total HEI-2010 score) were not significant, we did find that each additional hour of sleep was associated with consuming fewer calories from solid fats, alcohol, and added sugars (b=0.70; p=.04) after adjusting for weekend vs. weekday, age, sex, BMI z-score, and total CBCL score. Given the recommendation to limit calories from solid fats, alcohol, and added sugars to <20% of total energy intake, a higher score for this component reflects a lower intake.

4. Discussion

The primary aim of this exploratory pilot study was to evaluate the feasibility of assessing sleep duration/quality and eating behavior in children and young adolescents using multiple naturalistic, momentary methodologies. We found that nearly 75% of participants provided adequate sleep and eating behavior data to be included in analyses. Participants contributed an average of 8.06 EMA recordings per day that were linked to actigraph sleep data from the previous night (from a maximum of 14 days), and 2.7 ASA24-Kids recordings linked to actigraph sleep data from the previous night (from a maximum of 3 days) over the 14-day study, indicating that the protocol, although potentially burdensome, was acceptable and resulted in moderate to high compliance in a sample of children and young adolescents. It should be noted, however, that participants were compensated for participation, which may have introduced selection bias and potentially skewed compliance data. Additionally, older participants, males, youth from racial/ethnic minority backgrounds, and those with mothers who had received less education were less likely to have complete data across all three assessment methodologies (although it is unclear if these differences were statistically significant). This is consistent with the previous EMA compliance literature (Wen, Schneider, Stone, & Spruijt-Metz, 2017) and suggests that special efforts may be needed to optimally engage these youth (e.g., providing incentives that are more appealing to these demographic characteristics).

A secondary aim was to assess whether sleep parameters were related to next day eating behavior. Despite the small sample size, several findings of statistical or marginal significance emerged (although as the study was observational in nature, the findings should be interpreted with caution, particularly regarding directions of causation). First, contrary to expectation, greater TST was associated with slightly greater next day energy intake. It is noteworthy that this association was attenuated and was no longer significant when covariates were included. Moreover, given the finding that each additional hour of sleep was associated with lower odds of skipping breakfast, it is possible that this association may be accounted for, at least in part, by the fact that well rested children and young adolescents are more likely to consume breakfast. Although investigation of physical activity was outside the scope of this study, it is also possible that youth who were better rested engaged in more activity throughout the day, which in turn promoted increased hunger and energy intake. This possibility should be explored in future research. More consistent with previous findings (Beebe et al., 2013), each additional hour of sleep was associated with consuming fewer calories from solid fats, alcohol, and added sugars (b=0.70; p=.04) after adjusting for covariates. Given the non-experimental design, it is equally plausible that longer sleep time is associated with improved dietary choices the next day, or that improved dietary choices lead to longer subsequent sleep time (or that some unmeasured variable affects both dietary choice and sleep time). Future research should seek to explicate the direction of these associations so as to guide intervention efforts.

Contrary to expectation, sleep was not related to EMA-reported LOC severity on the following day. This is likely due to the low base rates of self-reported LOC in this sample, which was recruited solely on the basis of having overweight/obesity, irrespective of baseline eating pathology. However, of note, there was a marked difference in variance size for nighttime awakenings on days on which LOC eating occurred relative to days on which it did not (see Table 2), which may reflect a disruption in sleep homeostasis on nights preceding LOC versus non-LOC days. Future research—including data collected in a laboratory capable of assessing sleep homeostatic physiology—should explore associations between LOC eating and sleep (particularly focusing on variance in sleep metrics) in samples enriched for maladaptive eating.

This study was strengthened by the use of multiple forms of technology-based methodologies (both objective and subjective) to characterize sleep and eating behavior in the natural environment and at the momentary level. Other strengths include the generalizable sample of youth with overweight/obesity who were recruited from the community, and the assessment of different facets of sleep and eating behavior (e.g., quality and quantity). Given that this was an observational pilot study that focused on feasibility, the primary limitation was the small sample size. However, the relatively good compliance suggests that these assessment techniques could be undertaken in larger samples to characterize sleep and eating behavior in children and young adolescents, and the current study provides valuable information about effect sizes that could inform power calculations for larger studies. All eating-related constructs were assessed via self-report and analyzed at the between-subjects level, which could have biased the results. Future research may benefit from integration of sensor-based or laboratory assessment of eating behavior, and exploration of within-person findings to inform intervention development. Additionally, there was no non-overweight control group, and thus it cannot be assumed that results are specific to youth with overweight/obesity. Although actigraphy is a validated method for assessing sleep in the natural environment, the Actiware algorithm, which was set to a “medium” wake threshold in the current study, may be overly sensitive to motion and, as a result, tends to overestimate the number of awakenings relative to polysomnography (Paquet, Kawinska, & Carrier, 2007). This could explain the high average number of awakenings per night in the current sample, although it should be noted that the setting was the same for every participant, and thus nighttime awakenings nevertheless reflect within-study patterns. Future research should explore whether established thresholds are appropriate for youth with overweight/obesity. In addition, participants were required to indicate the start and end of the overall nighttime sleep period via pressing a button on the actigraph watch, which could have affected compliance and/or sleep onset. Finally, participants did not undergo baseline overnight polysomnography, so undiagnosed sleep apnea may be a confounding variable that was not accounted for.

5. Conclusions

Given that sleep deficiency poses a vulnerability to multiple risky health-related behaviors (Pasch, Laska, Lytle, & Moe, 2010), yet is modifiable via intervention (Blake, Sheeber, Youssef, Raniti, & Allen, 2017), improving sleep hygiene may be a promising avenue for enhancing regulation of eating and weight in young people (Hart et al., 2016). Future research should replicate and extend our findings in larger samples to better characterize prospective associations between sleep and eating behavior, and identify potential mechanisms explaining these associations.

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Abbreviations:

LOC	loss of control
EMA	ecological momentary assessment
TST	total sleep time
WASO	wake after sleep onset
BMI	body mass index
ASA24-Kids	Automated Self-Administered 24-hour Dietary Assessment Tool for Children
CBCL	Achenbach Child Behavior Checklist
TIB	time in bed
HEI-2010	Healthy Eating Index 2010

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Table 1.

Detailed description of sleep parameters

Parameter	Definition	Source of data
Bed time	Clock time representing time in bed	Sleep diary, actigraphy
Wake time	Clock time representing time of awakening	Sleep diary, actigraphy
Time in bed (min)	Time from resting in bed to getting up	Actigraphy
Sleep onset latency (min)	Time from resting in bed to sleep onset	Actigraphy
Sleep onset	First minute of a 10-minute period after bed time in which activity counts were zero	Actigraphy
Wake after sleep onset min)	Time spent awake after sleep onset	Actigraphy
Sleep efficiency, %	Proportion of time in bed spent asleep	Actigraphy
Total sleep time (min)	Time from sleep onset to awakening	Actigraphy
Nighttime awakenings	Number of awakening after sleep onset	Actigraphy
Sleep interval (min)	Minutes between bed time and wake time	Actigraphy

Table 2.

Participant characteristics

	Full sample (*N*=40)	**Participants with incomplete data (*n*=11)**	**Participants with complete data (*n*=29)**
Age, y	11.8±1.9	12.4±2.3	11.6±1.9
% female	55.0%	45.5%	56.7%
Race/Ethnicity			
Non-Hispanic, White	15.4%	0%	20.7%
Non-Hispanic, Black	64.1%	80%	58.6%
Non-Hispanic, Other	2.5%	0%	3.5%
Hispanic (all races)	18.0%	20%	17.2%
Maternal education			
High school degree or less	18.9%	10%	17.9%
Some college	10.8%	40%	10.7%
College degree	18.9%	30%	10.7%
More than college	51.4%	20%	60.7%
BMI z-score	2.1±0.5	2.0±0.6	2.1±0.5

Table 3.

Sleep patterns across study days

	All days		Loss of control eating days (*n*=44)	Non-loss of control eating days (*n*=213)
	Range	***M±SD***	***M±SD***	***M±SD***
Total sleep time	1.1-14.6	7.2±1.9	7.2±1.9	7.1±2.0
Nighttime awakenings	0.0-71.0	31.8±13.5	31.7±27.5	31.9±13.5
Wake after sleep onset	0.0–219.0	44.7±32.3	45.4±29.6	44.5±32.2
Sleep efficiency, %	21.5-99.9	84.0±11.3	82.7±12.6	84.2±11.0

Note: Data included in this table are for illustrative purposes only; results of statistical analyses assessing associations between sleep and loss of control eating are report in Table 4.

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Table 4.

Odds of experiencing loss of control eating, as measured by ecological momentary assessment, based on measures of sleep

	Odds ratio	95% Confidence Interval
Total hours of sleep		
Unadjusted model	0.84	(0.67 to 1.05)
Fully adjusted model	0.86	(0.63 to 1.16)
Number of nighttime awakenings		
Unadjusted model	0.98	(0.94 to 1.02)
Fully adjusted model	0.99	(0.95 to 1.03)
Wake after sleep onset		
Unadjusted model	0.99	(0.98 to 1.02)
Fully adjusted model	1.00	(0.98 to 1.01)
Sleep efficiency		
Unadjusted model	0.98	(0.96 to 1.02)
Fully adjusted model	0.97	(0.94 to 1.00)

Note: Fully adjusted models include week vs. weekend day, age, sex, BMI z-score and CBCL total score (minus sleep-related items) as covariates.

Table 5.

Relationships of measure of sleep with dietary intake, as measured by ASA24-Kids dietary recalls

	Effect estimate	*p*-value
Total energy intake		
Total hours of sleep		
Unadjusted model	78.1 calories	.05
Fully adjusted model	29.2 calories	.43
Number of nighttime awakenings		
Unadjusted model	9.1 calories	.21
Fully adjusted model	−5.3 calories	.55
Wake after sleep onset		
Unadjusted model	0.4 calories	.93
Fully adjusted model	−4.5 calories	.15
Sleep efficiency		
Unadjusted model	−1.5 calories	.84
Fully adjusted model	1.3 calories	.82
Diet quality (total Healthy Eating Index score)		
Total hours of sleep		
Unadjusted model	0.31	.61
Fully adjusted model	0.39	.49
Number of nighttime awakenings		
Unadjusted model	0.11	.50
Fully adjusted model	0.28	.06
Wake after sleep onset		
Unadjusted model	0.05	.55
Fully adjusted model	0.10	.09
Sleep efficiency		
Unadjusted model	−0.15	.27
Fully adjusted model	−0.17	.27

Note: Adjusted models include week vs. weekend day, age, sex, BMI z-score and CBCL total score (minus sleep-related items) as covariates. The Healthy Eating Index, 2010 measures compliance with the Dietary Guidelines for Americans, 2010 and the total score is out of 100 points.