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Behavioral and Social Routines and Biological Rhythms in Prevention and Treatment of Pediatric Obesity

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Abstract

A growing body of research supports the potential importance of behavioral and social routines for children's health promotion and obesity risk reduction. Evidence in support of this comes from multiple lines of research, which suggest that specific behavioral routines, namely eating and sleep routines, may be protective against excessive weight gain and development of pediatric obesity. From a circadian perspective, alignment of behavioral and social routines with underlying circadian rhythms may be particularly important for enhancing children's weight regulation. Engaging in appropriately timed behavioral and social routines may serve to entrain circadian rhythms that affect metabolism and weight regulation. Thus, in addition to promoting healthier eating, activity, and sleep behaviors for prevention and treatment of pediatric obesity, it may also be important to consider promotion of consistency in and optimal timing of these behaviors in an effort to enhance extant prevention and treatment approaches.

Keywords

pediatric obesity; prevention; treatment; routines; rhythms

Pediatric obesity has been labeled an epidemic, with approximately 18% of children 6-11 years old with obesity (Hales, Fryar, Carroll, Freedman, & Ogden, 2018). Although there has been debate as to whether or not rates of pediatric obesity in the United States are plateauing, recent estimates suggest that obesity continues to affect a large percentage of school-aged children, with racial/ethnic minority children and those from lower socioeconomic backgrounds at increased risk (Ogden et al., 2018). Medical and psychosocial consequences associated with pediatric obesity have been well documented (Pulgaron, 2013), underscoring the need for preventive and treatment efforts.

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As a whole, evidence supports potential efficacy of preventive interventions (Brown et al., 2019; Waters et al., 2011), and efficacy of family-based lifestyle interventions (Ho et al., 2012) for pediatric obesity. A number of expert guidelines for prevention and treatment of pediatric obesity have been developed (O'Connor et al., 2017; Spear et al., 2007; Styne et al., 2017). As reflected in the U.S. Preventive Services Task Force (USPSTF) recommendations (O'Connor et al., 2017), treatment should be multicomponent, of high intensity (i.e. > 26 contact hours), and include attention to dietary intake and physical activity, supported by behavioral strategies. Most approaches are family based, targeting individual (child) and family behaviors, and focusing on achieving a negative energy balance to promote weight loss (i.e., decreasing caloric intake and sedentary behaviors while increasing energy expenditure via physical activity). Such approaches capitalize on effective behavioral strategies to promote behavior change, including working with families on setting realistic and achievable goals, self-monitoring eating and activity behaviors, use of positive reinforcement to support behavior change, and problem-solving with families towards goal attainment (Epstein, Roemmich, & Raynor, 2001).

In contrast, preventive interventions have primarily involved school-based approaches typically focused on targeted eating (e.g., decreasing energy-dense foods and beverages; increasing fruits and vegetables) and activity (e.g., decreasing screen time; increasing steps) behaviors in an effort to prevent excessive weight gain (Wang et al., 2015). A variety of strategies have been employed to support behavior change, including environmental and policy changes as well as capitalizing, in part, on effective behavioral strategies noted above. Although prevention efforts are delivered on a larger scale, making them more universally available, studies yield mixed findings with regard to efficacy (Hung et al., 2015; Wang et al., 2015).

Despite promise of prevention and treatment approaches, not all children demonstrate a meaningful response (Wilfley, Hayes, Balantekin, Van Buren, & Epstein, 2018). Thus there is a need to identify novel approaches for prevention and treatment. In the present paper, it is contended that in addition to being mindful of what and how much children eat as well as how active they are, it is also important to consider the consistency and timing of these behaviors in relation to underlying circadian rhythms (i.e., a rhythmic biological cycle over approximately 24 hours; (Scheer & Shea, 2009) for sleep versus wake. A growing body of research suggests that synchrony between behaviors, social interactions, and underlying circadian rhythms may be important for optimizing health and well-being (Ehlers, Frank, & Kupfer, 1988; Haynes, Gengler, & Kelly, 2016), including risk for excessive weight gain and/or development of obesity and associated comorbidities (Baron & Reid, 2014; McHill & Wright, 2017). This point was highlighted in a workshop convened by the National Institute for Diabetes and Digestive and Kidney Diseases which showcased emerging research on the role of sleep and circadian disruption in affecting metabolism, energy balance and diabetes risk (Arble et al., 2015). Much of this work has focused on adult populations. The present paper focuses on school-aged children, while also highlighting key findings from animal models and adolescent and adult human studies to support this argument.

Importance of Circadian Rhythms for Overall Health

The importance of the timing of behaviors for health and development may have its roots in underlying biological processes designed to enhance survival. Almost all organisms display near-24 hour circadian rhythms across a number of processes including the sleep-wake cycle (Baron & Reid, 2014; Scheer & Shea, 2009), which are controlled by an internal timing system that is aligned with and influenced by the light-dark cycle (Scheer & Shea, 2009). In mammals, circadian rhythms are supported by both a central clock, which is located in the suprachiasmatic nucleus (SCN) as well as peripheral clocks located throughout the body (Bray & Young, 2006; Scheer & Shea, 2009). External environmental cues, also called zeitgebers, are important for synchronizing circadian rhythms with the 24-hour clock (Scheer & Shea, 2009). Light is believed to be the most powerful zeitgeber (Scheer & Shea, 2009), which acts on the central clock located within the SCN. However, other factors, such as the timing of eating, are believed to help entrain circadian rhythms as well (Scheer & Shea, 2009).

Maintenance of circadian rhythms is believed to confer evolutionary advantage as it helps the organism organize activities around such factors as food availability (Scheer & Shea, 2009) while also maximizing the organism's ability to anticipate environmental changes and efficiently adapt biological processes (Bray & Young, 2006; Laposky, 2009). A number of physiological and biological processes demonstrate diurnal rhythms (Baron & Reid, 2014). Of particular relevance for weight regulation, are demonstrated variations in glucose regulation across the 24-hour period (Van Cauter, Polonsky, & Scheen, 1997) as well as more recent findings demonstrating diurnal rhythms in the gut microbiome (Kaczmarek, Thompson, & Holscher, 2017), and even in reported hunger and appetite in adult humans (Scheer, Morris, & Shea, 2013).

Individual behaviors and social rhythms, which are the behavioral patterns that individuals exhibit on a day-to-day basis (Haynes et al., 2016), work in concert with underlying circadian rhythms to either help entrain a 24-hour circadian rhythm or promote circadian misalignment (i.e., asynchrony between behaviors and circadian rhythms). Animal models provide a solid evidence base for the importance of the alignment of food intake with periods of wakefulness for optimizing weight regulation (Jiang & Turek, 2017). Experimental studies with adults support these findings with particular implications for circadian misalignment on glucose regulation (McHill & Wright, 2017; Reutrakul & Van Cauter, 2014) and resultant changes in weight (McHill & Wright, 2017). Misalignment has been associated with obesity and metabolic disturbance (McHill & Wright, 2017; Reutrakul & Van Cauter, 2014). Shift work is a prime example of how the mistiming of routine behaviors promote circadian misalignment and ultimately poor health outcomes, including increased risk of developing obesity and type 2 diabetes (McHill & Wright, 2017; Reutrakul & Van Cauter, 2014). Of note, smaller deviations in behaviors from underlying circadian rhythms may also lead to poorer health and psychological outcomes. For example, social jetlag, which is a measure of the difference between social rhythms and circadian rhythms and defined as the difference in sleep timing on work versus free days, has been associated with poor health behaviors and health outcomes, including obesity (Roenneberg, Allebrandt, Mellow, & Vetter, 2012).

In line with above, extant pediatric research supports the underlying premise that behavioral and social routines are important for decreasing risk of pediatric obesity. For example, family routines are associated with decreased obesity risk (Anderson & Whitaker, 2010). Further, family-based behavioral treatment approaches for weight regulation capitalize upon a number of strategies meant to enhance routine behaviors, including the importance of parental involvement not only as a mechanism of social support but also to provide structure within the home environment in favor of healthier eating, activity, and (more recently) sleep behaviors. This work has largely been conducted without considering alignment of routine behaviors with underlying circadian rhythms, yet emerging research sheds light on an underlying biological basis for the importance of routine behaviors for children's weight regulation, particularly the timing of eating and sleep behaviors. Thus, the present paper aims to review research on the potential importance of the *timing* of sleep, eating and activity behaviors for weight regulation. Given findings to date, the focus is on children's eating and sleep behaviors-first as important routine behaviors for pediatric weight regulation, and then in consideration of their alignment with circadian rhythms-as a potentially novel approach for pediatric weight regulation.

Routine Behaviors and Child Health Outcomes

Routines are referenced extensively in the literature on family processes and have been defined as "... observable repetitive behaviors which directly involve the child and at least one adult acting in an interactive or supervisory role, and which occur with predictable regularity in the daily and/or weekly life of the child" (Sytsma, Kelley, & Wymer, 2001). Participation in family routines is thought to have a positive influence on children's emotional and behavioral regulation (Fiese et al., 2002; Zajicek-Farber, Mayer, & Daughtery, 2012) and have been associated with positive child outcomes across a number of domains (e.g., Bater & Jordan, 2017; Greening, Stoppelbein, Konishi, Jordan, & Moll, 2007; Spagnola & Fiese, 2007). Routines may affect weight regulation indirectly through the pathway of emotion regulation and directly through establishment of regular family mealtimes and bedtime habits (Anderson & Whitaker, 2010; Jones, Fiese, & Team, 2014). For example, a randomized controlled trial conducted with families of preschool-aged children found that a 6-month, home-based intervention designed to enhance such routines decreased children's BMI relative to control (Haines et al., 2013).

Further evidence supporting the importance of routines comes from observational studies that have demonstrated seasonal variations in children's health behaviors and weight gain trajectories. The Structured Day Hypothesis suggests that the structured nature of school days can be seen as protective against obesogenic behaviors, as it facilitates routinized patterns, provides energy-controlled meals, regular opportunities for physical activity, and a routine sleep schedule on weekdays, while summer typically involves less structure and may provide greater exposure to the home food environment, fewer opportunities for physical activity, greater access to sedentary behavior, and dysregulated sleep (Brazendale et al., 2017).

Empirical evidence largely supports this hypothesis. Findings demonstrate that children's weight status tends to stabilize or decrease during the academic year and increase during the

summer, particularly among children from low-income backgrounds and those with overweight/obesity (Franckle, Adler, & Davison, 2014; Moreno, Johnston, & Woehler, 2013; von Hippel, Powell, Downey, & Rowland, 2007). This pattern has also been observed in obesity prevention trials, with improvements in weight status achieved during the school year lost during the summer months (Baranowski et al., 2014; Economos et al., 2013). Thus, as a whole, routine behaviors have been associated with a healthier weight status.

Routine in Eating Behaviors

Eating Patterns.—More specifically, routine eating behaviors such as eating patterns, are considered to influence health, including childhood obesity (United States Department of Agriculture, 2015). In the area of childhood obesity, eating patterns have traditionally been conceptualized as the amount and types of food consumed. However, they can also be described in regards to the consistency with which eating occurs, such as in a regular or chaotic pattern, (Berg & Forslund, 2015). A regular, as compared to chaotic, eating pattern is considered more desirable, as it is generally associated with better appetite regulation and reduced problematic eating. For example, adults with a consistent eating pattern (i.e., consume breakfast and lunch without any snack in between, with a consistent inter-meal interval between breakfast and lunch) show entrainment of appetitive hormones at habitual eating times, which could assist with appetite regulation and/or enhance metabolic processes (Frecka & Mattes, 2008).

In children, eating regularity has most often been examined in regards to the eating frequency of meals and snacks. Similar to the adult literature, there is no standard definition of what constitutes a meal, snack, or eating occasion, thus across studies the definition varies. Even given the lack of clear definitions for eating occasions, a meta-analysis found that a greater number of eating occasions, an eating pattern that may indicate more regular intake of meals and snacks, was associated with a lower weight status in children aged 2 to 19 years, with this effect more pronounced for boys than for girls (Kaisari, Yannakoulia, & Panagiotakos, 2013). Further, time trend analysis in children 2 to 18 years found that eating frequency has increased from 1977-1978 to 2003-2006 (Popkin & Duffey, 2010), with studies indicating that the increase in eating frequency appears to be from greater consumption of snacks (Jahns, Siega-Riz, & Popkin, 2001), combined with a potential decrease in meals, particularly breakfast (Nicklas et al., 2004; Siega-Riz, Popkin, & Carson, 1998). Time trend analyses from 1984 to 2014 of the daily overnight fast in children 3 to 18 years also found an increase over time (i.e., longer overnight fast), which was theorized to be due to a decrease in breakfast consumption (Roßbach et al., 2017). These studies suggest a few key points. First, eating frequency is increasing in youth, which may indicate a more regular pattern of intake. However, due to the reduction in consumption of breakfast and increase in snacks, the pattern of intake may be pushed to occur later in the day. Thus, while one might expect decreasing rates of obesity over the time span during which frequency-and potentially regularity in intake-increased (i.e., a phenomenon contrary to what has been observed), additional changes in eating patterns such as shifts in intake to later in the day may also be important factors in determining obesity risk (a point discussed further below).

Breakfast consumption.—Habitual breakfast consumption in children is believed to be an important eating pattern in addressing childhood obesity (Dietary Guidelines Advisory Committee (DGAC), 2010) as it may assist with appetite regulation (Blondin, Anzman-Frasca, Djang, & Economos, 2016). The 2010 Dietary Guidelines for Americans (DGAs) Advisory Committee examined the relationship between breakfast consumption and risk of overweight and obesity in youth and reported moderate strength of evidence among children who skip breakfast (DGAC, 2010). A systematic review to update the 2010 US National Evidence Library used for the 2010 DGAs continued to support conclusions for moderate strength of evidence that skipping breakfast increases risk of adiposity during childhood and adolescence, and that habitual breakfast consumption appears to prevent excess adiposity development during this time period as well (Blondin et al., 2016). Of note this grade of evidence indicates research in this area is inconsistent, may include studies of weaker design, and studies may be susceptible to some bias (DGAC, 2010). Interestingly, some studies have found that youth who regularly consume breakfast often consume as much or more energy, rather than less energy, than their breakfast skipping counterparts (Deshmukh-Taskar et al., 2010; Rampersaud, Pereira, Girard, Adams, & Metz, 2005). Thus, while habitual breakfast consumption has been believed to be important for childhood obesity, the body of evidence is mixed, and the mechanism does not appear to be due to enhanced appetite regulation producing a lower energy intake.

Time Restricted Feeding.—Time restricted feeding is an eating pattern that is a form of intermittent fasting. This type of eating pattern has consistent times of eating and fasting, without guidelines of when and what to consume (Gabel et al., 2018). Time restricted feeding follows a diurnal pattern, with a set window of time during the day in which eating occurs (i.e., 10 am to 6 pm) followed by a daily fast that is usually 14 to 20 hours long (Gabel et al., 2018), establishing a routine of when eating occurs. Little research with time restricted feeding has been conducted in humans, and in particular children, but the research that has been conducted suggests that this eating pattern may be helpful for weight loss and reducing metabolic risk (Gabel et al., 2018; Gill & Panda, 2015). What is not clear at this time is if having a consistent routine versus the time of day when the eating and fasting periods occur, is important for enhancing outcomes. For example, a cross-over study in 15 men at risk for type 2 diabetes that tested two, 7-day time restricted feeding conditions, with one feeding period occurring between 8 am and 5 pm, and one feeding period occurring between 12 pm and 9 pm, found that glycemic response was significantly improved in the two time restricted feeding conditions, but the timing of the feeding condition had no effect on glycemic response (Hutchison et al., 2019). Taken together, findings regarding eating behaviors provide a signal for the importance of eating routines in weight regulation.

Routine in Sleep Behaviors: Duration and Consistency

Over the past decade there has been increasing recognition of sleep as an importance behavior for pediatric weight regulation. Research to date has focused on both longer duration in sleep as a routine behavior associated with decreased obesity risk (Anderson & Whitaker, 2010) as well as variability in bedtimes and wake times on weekdays and weekends (Miller, Lumeng, & LeBourgeois, 2015).

Sleep Duration.—Meta-analyses of observational studies with children provide compelling evidence of the protective effect of greater sleep duration for decreased obesity risk (Fatima, Doi, & Mamun, 2015; Ruan, Xun, Cai, He, & Tang, 2015). For example, one meta-analysis of prospective studies demonstrated that each additional hour of sleep a child achieved was associated with a 21% reduced risk of overweight/obesity (Ruan et al., 2015).

Meta-analysis of adult experimental studies (Al Khatib, Harding, Darzi, & Pot, 2016) provides evidence that sleep restriction, relative to rest, is associated with changes in eating behaviors that favor weight gain over time. Experimental studies with adolescents have been mixed (Beebe et al., 2013; Klingenberg et al., 2012). However, an experimental study with children 8 to 11 years old in which time in bed was both increased and decreased for 1.5 h/night (relative to sleep achieved at baseline) demonstrated that, relative to the increased sleep condition, when children's sleep was restricted for one week, children were reported to eat approximately 134 kcal/day more and weighed 0.22 kg more at the end of the experimental week (Hart et al., 2013). Secondary analyses demonstrated that, relative to the increased condition, during the restricted sleep condition (i.e., when children were up later), differences in reported food intake were reported to occur after 2000h (Hart et al., 2015). In fact, on average, families reported a shift towards later average meal intake during the restricted sleep condition. Experimental trials with adults have been consistent in demonstrating a shift in intake to later in the day with associated weight gain when sleep is restricted (Markwald et al., 2013; Spaeth, Dinges, & Goel, 2013). Thus, it is notable that sleep restriction is associated with an eating pattern of greater food intake later in the day that seems to favor weight gain.

Sleep Consistency.—Emerging research has also demonstrated that decreased variability in sleep time between weekdays and weekends is associated with decreased adiposity and/or obesity risk (Miller et al., 2015). Specifically, Spruyt and colleagues (2011) observed that, relative to those with normal weight or overweight, children 4 to 10 years old with obesity had greater variability in sleep duration on weekends than on weekdays. Further, in addition to greater duration, greater stability in sleep was associated with better metabolic health in children (Spruyt, Molfese, & Gozal, 2011). A second study with preschool-aged children from low-income backgrounds found that variability in bedtimes moderated the association between sleep duration and subsequent rate of BMIz change such that longer nocturnal sleep duration was associated with decreased rates of BMIz change only among those children who did not shift their bedtime from weekdays to weekends by 45 minutes or more (Miller et al., 2014). Consistent with this, social jetlag has been associated with obesity and metabolic disturbance. Specifically, Stoner and colleagues (2018) observed in children 8 to 10 years of age, that greater social jetlag was associated with higher percent body fat, fat mass (kg), fat mass index (kg/m²), BMI, and waist-to-hip ratio. For example, a one hour difference in sleep timing on school versus weekend days was associated with a 3% increase in body fat and 0.89 kg/m² increase in BMI. However, findings have not always been consistent with at least one study finding contrary associations between social jetlag and weight status in adolescents (de Zwart, Beulens, Elders, & Rutters, 2018).

Emerging Research Supporting the Importance of Aligning Eating and Sleep Routines with Circadian Rhythms

Emerging research highlights the potential importance of not only routine eating and sleep behaviors, but the timing of such routine health behaviors to optimize pediatric obesity prevention and treatment approaches.

New research suggests that the timing and distribution of energy intake throughout the day may be important in influencing health and weight status (Mathias, Almoosawi, & Karagounis, 2017b). Interestingly, although as noted above, regular breakfast consumption was not associated with decreased caloric intake (Deshmukh-Taskar et al., 2010; Rampersaud et al., 2005), breakfast consumption may influence the overall timing and distribution of energy intake, which in turn, may be important for weight regulation. For example, a cross-over study with adults who were asked to eat breakfast daily for 7 days or skip breakfast daily for 7 days found greater daily energy intake when breakfast was consumed, but timing of when energy was consumed differed when breakfast was consumed versus when it was skipped (Reeves et al., 2014). Specifically, this investigation found that energy intake was shifted later in the day when breakfast was skipped, and that the shift was found to occur particularly in the later evening (Reeves et al., 2014). This suggests that how energy is distributed in the day, or when eating is occurring, may be different for habitual breakfast eaters, which may have implications for weight regulation.

Results from observational studies with adults have found that eating a greater proportion of daily energy intake or meals in the evening is associated with overweight or obesity (Berteus Forslund, Lindroos, Sjostrom, & Lissner, 2002; Bo et al., 2014; J. B. Wang et al., 2013). In contrast, eating a greater amount of energy earlier in the day was related to body mass reduction over six years in healthy individuals (Kahleova, Lloren, Mashchak, Hill, & Fraster, 2017), greater 6-year weight loss following bariatric surgery (Ruiz-Lozano et al., 2016), and increased weight loss during 20 weeks of obesity treatment (Garaulet et al., 2013b). Two 3-month weight loss interventions implemented a dietary prescription in which a greater amount of energy was prescribed to be consumed earlier in the day (Jakubowicz, Barnea, Wainstein, & Froy, 2013; Lombardo et al., 2014). Both studies found greater weight loss when more energy was consumed earlier, as compared to later, in the day (Jakubowicz et al., 2013; Lombardo et al., 2014). As a whole, studies provide compelling evidence for the importance of the timing of energy distribution throughout the day for weight regulation.

Little research has been conducted with youth on this topic, particularly looking at energy intake early versus late in the day, and findings across two observational studies have been mixed (Coulthard & Pot, 2016; Eng, Wagstaff, & Kranz, 2009). However, data from the 2013-2014 National Health and Nutrition Examination Survey found that in youth aged 4 to 18 years energy intake was largest in the evening and smallest in the morning (Mathias, Almoosawi, & Karagounis, 2017a), which may be an energy distribution timing pattern that is problematic for weight management. Taken together, research in this area suggests that eating early in the day (breakfast) may have importance, but that the timing of disbursement of energy intake may be more influential on weight status. This crucial difference may help explain the inconsistencies in the literature on breakfast consumption. From a circadian

rhythms perspective, mistimed eating may result in alterations in metabolic processes that negatively impact weight status (McHill & Wright, 2017). In turn, eating that is aligned with underlying circadian rhythms may enhance weight regulation.

Beyond timing of eating behaviors, emerging research has also demonstrated that the timing of children's sleep, particularly later bedtimes, is associated with increased adiposity and/or obesity risk (Miller et al., 2015). Specifically, Golley and colleagues (2013) observed that relative to children 9 to 16 years old with earlier bedtimes, those with later bedtimes had higher BMIz score, lower diet quality, lower reported intake of fruits and vegetables, and greater reported intake of energy-dense, nutrient-poor foods. However, no difference was observed in reported caloric intake (Golley et al., 2013). An additional study found that, among children 9 to 16 years, those with later bedtimes (regardless of whether or not rise times were early or late) had a greater likelihood of having overweight or obesity, reporting more than two hours/day of screen time (e.g., TV viewing), and engaging in less than the recommended 60 minutes/day of moderate to vigorous physical activity (Olds, Maher, & Matricciani, 2011). Mi and colleagues (2019) further observed that later bedtimes were associated with high systolic blood pressure in youth 8 to 17 years old. However, the timing of bedtime was not associated with additional metabolic outcomes nor with total energy nor macronutrient intake (Mi et al., 2019). Consistent with these findings, Jarrin and colleagues (2013) found that later bedtimes on school days and weekend days were associated with greater waist and hip circumferences, and higher BMI and percent body fat (although some associations were attenuated when controlling for covariates). Finally, a recent study demonstrated that later bedtimes were associated with meal timing, including a later first meal and greater after-dinner intake as well as greater reported fat intake (Spaeth et al., 2019). Thus, overall, the timing of sleep and eating behaviors appear to be interrelated in children and may have implications for weight regulation.

There are a number of reasons why the timing of sleep and eating distribution may be important for weight regulation. For example, misalignment in timing of sleep and eating behaviors with circadian rhythms may result in alterations in a number of hormones affecting metabolic health. Misalignment has been associated with impaired glucose tolerance, negative impact on appetite and satiety-signaling hormones, and negative impact on melatonin, which has been proposed as a mediator between endogenous circadian rhythms and metabolism (McHill & Wright, 2017; Reutrakul & Van Cauter, 2014). Further, two experimental studies with adults point to diet induced thermogenesis (DIT; i.e., energy expenditure related to the ingestion of food, and also known as the thermic effect of food (Lam & Ravussin, 2016) as an additional potential mechanism. In both studies, DIT was observed to be lower in the evening than in the morning (Morris et al., 2015; Romon, Edme, Boulenguez, Lescroart, & Frimat, 1993), and appeared to be primarily influenced by the endogenous circadian system than by sleep versus wake behaviors (Morris et al., 2015). Consistent findings were observed in an investigation of simulated nightshift work (McHill et al., 2014). Thus, even if caloric intake is unchanged, if there is greater caloric intake in the evening relative to the morning, changes in weight could follow. It is important to note, however, that DIT represents a small proportion of overall energy expenditure (Lam & Ravussin, 2016). Nonetheless, it may represent an additional mechanism through which mistimed eating may impact weight regulation.

Conclusions and Future Directions

A number of lines of research suggest that promoting consistent behavioral and social routines that are aligned with underlying circadian rhythms could enhance pediatric obesity prevention and treatment. This is not to say that the core components of effective family-based interventions, which include focus on effective behavioral strategies to promote healthier eating, activity and sleep behaviors, are not central to the prevention and treatment of pediatric obesity. Rather, studies described above speak to the need to also consider the timing of and consistency in these behaviors to enhance children's weight regulation. Limitations of this work are not withstanding, and include predominant focus on adult samples, over-reliance on observational designs in pediatric studies and relatively few randomized controlled trials conducted to date. Further, understanding the real world applicability of behavioral interventions designed to enhance timing of these health behaviors is imperative. This may be particularly important for children whose parents work longer hours and/or perform shift work, and within the context of other components of children's lives that may not at this time be matched for this alignment (i.e., the school eating environment). Nonetheless, convergence of findings across behavioral, social and biological domains highlight the importance of better understanding the timing of eating, sleep and activity behaviors as a novel approach for prevention and treatment of pediatric obesity.

There are a number of potential future directions for research in this area with a need to build a stronger pediatric evidence base being most central. For example, implicit in many lifestyle interventions for pediatric obesity is establishment of consistent eating patterns throughout the day (e.g., typically designed to prevent excessive hunger and resultant excess energy intake) to ensure adherence to a calorie-restricted diet. Whether such consistency predicts treatment outcomes is unclear, but could provide rationale for pursuing such an approach in future randomized controlled trials. Further, as noted above, it is not only the timing but perhaps the distribution of calories throughout the day that may be important – with a greater proportion of caloric intake earlier in the day being associated with more favorable weight-related outcomes (e.g., Garaulet et al., 2013a; Kahleova et al., 2017). As such, it will be essential to determine the potential role of caloric distribution on enhancing children's weight regulation.

Research is also needed to assess whether enhancing sleep duration and timing (either alone or together with changes in the distribution of eating behaviors) can confer benefits beyond standard approaches for weight regulation. Individual differences in chronotype – or underlying circadian biology – may need to be considered to ensure that changes in the timing of sleep and eating best align with underlying circadian biology (Beebe, Zhou, Rausch, Noe, & Simon, 2015). This may be particularly important to understand during adolescence—a developmental period marked by shifts to later sleep-wake timing (Crowley et al., 2007). For example, Beebe and colleagues (2015) found that chronotype moderated the impact of sleep extension (i.e., advancing bedtimes) on caloric intake in adolescents. Specifically, those with later chronotype demonstrated little effect of a change in sleep on caloric intake while those with an earlier chronotype reduced caloric intake in the evening when sleep was extended.

Of the research conducted to date, most has focused on timing of eating and sleep behaviors for enhancing weight regulation. The role of the timing of activity behaviors should be further explored. There is evidence that the timing of physical activity may play a role in entrainment of circadian rhythms with an experimental study in adults demonstrating that exercise in the morning was more beneficial than in the evening hours (Rubio-Sastre et al., 2014). Additional evidence suggests that earlier chronotype is associated with greater physical activity in both young children (Kohyama, 2007) and adolescents (Schaal, Peter, & Randler, 2010). However, additional work is needed to better understand the potential role of timing of children's physical activity for weight regulation and improved cardiometabolic health.

Building upon above, from a prevention perspective, it will be important to better understand whether targeted approaches that focus not only on energy balance, but lifestyle changes that align behavioral and social routines with circadian rhythms will enhance outcomes. Targeting out of school time is of increased interest given the above-noted associations between summer vacations, poorer eating and activity behaviors and changes in weight status. In fact, Tovar and colleagues (2010) found that children who had increased structure by virtue of participating in camp activities had a higher activity index and were less likely to commonly eat their meals in front of the television than those who did not participate in these activities. This suggests that strategies to enhance structure and/or that better align eating and sleep behaviors with circadian rhythms may protect against seasonal weight gain. In fact, it has been argued that there may be underlying chronobiological reasons supporting establishment of consistent sleep, eating and activity behaviors in summer months as a means of buffering against observed weight gain (see Moreno et al., 2019 for review). However, interventions designed to provide access to summer camps (e.g., a means of enhancing structure and/or alignment of sleep and eating behaviors with circadian rhythms) found mixed benefits for weight regulation (Evans, Fernandes, Howie, Wing, & Jelalian, 2018; Hopkins et al., 2019). Beyond out of school time, there has been increased recognition that the timing of school itself may have important implications for pediatric health. Specifically, studies focused on delaying school start times, particularly during adolescence, as a mechanism for aligning sleep and eating behaviors with shifts in circadian rhythms. Evidence suggests that later school start times may confer benefits for weight regulation in adolescents (Garipey, Janssen, Sentenac, & Elgar, 2018). However, more work is needed to determine the potential impact of an optimally timed school day for obesity risk reduction.

Additional work is needed to tease apart the relative importance of the timing and regularity of eating and sleep behaviors to enhance children's weight regulation. To date experimental studies have focused primarily on adults. Although some observational studies with children provide a signal for the potential impact of properly timed sleep and eating routines, additional observational studies as well as pediatric experimental studies are warranted. For example, pediatric studies that compare the effect of consistent eating and sleeping patterns that are aligned or misaligned with circadian rhythms on weight outcomes would strengthen the evidence base regarding the relative importance of the timing of these behaviors for pediatric weight control. If alignment proves advantageous for weight outcomes, future research should also investigate if aligning several energy balance behaviors (i.e., sleep, eating) in an intervention enhances outcomes as compared to just aligning one (i.e., sleep).

Understanding the underlying physiological mechanisms that support how such changes enhance children's weight regulation is a critical component of this work.

In summary, current high rates of pediatric obesity and limitations of extant prevention and treatment efforts point to a need to think creatively about new approaches to enhance children's health and decrease excess weight gain. Promoting healthy eating and activity behaviors will remain a central component for weight regulation. However, a growing body of research supports the importance of also considering when and how consistently children engage in health behaviors for prevention and treatment of obesity, and suggests that better understanding how alignment of eating and sleep behaviors with underlying circadian rhythms may be worthy of further investigation.

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Public Significance Statement:

Emerging work suggests that appropriately timed eating and sleep routines may assist with weight regulation in children. Additional work with pediatric populations is needed to determine whether such an approach can enhance current prevention and treatment efforts.

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