Sleep, Internalizing Symptoms, Executive Functioning, and Diabetes Outcomes in Adolescents with Type 1 Diabetes Mellitus

Ashley Charlene Moss
Marquette University

SLEEP, INTERNALIZING SYMPTOMS, EXECUTIVE FUNCTIONING, AND DIABETES OUTCOMES IN ADOLESCENTS WITH TYPE 1 DIABETES MELLITUS

By

Ashley C. Moss, M.S.

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ABSTRACT
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Insufficient sleep is a nearly universal problem during adolescence and is likely associated with various biopsychosocial and contextual factors present with this developmental period. Youth with type 1 diabetes mellitus (T1DM) may experience greater sleep difficulties, poorer sleep quality, and greater daytime sleepiness/fatigue compared to healthy youth. Also, sleep difficulties are associated with poorer diabetes outcomes (e.g., treatment adherence). Understanding how sleep may impact illness management during adolescence is critical given increasing rates of non-adherence during this developmental period. Although research suggests poor sleep is associated with decreased neurocognitive functioning and increased internalizing behavior among healthy youth, limited research has examined these relationships in adolescents with T1DM. Further, adolescents with T1DM are at increased risk for difficulties with executive functioning and internalizing behaviors compared to healthy peers, and these difficulties have been implicated in T1DM-related outcomes. As such, the present study examined relationships among adolescent-reported sleep quality, quantity, and diabetes-related outcomes and the indirect effects of sleep quality on T1DM-related outcomes through internalizing symptoms and executive functioning.

Eighty-one adolescents diagnosed with T1DM (ages 12-17) and their caregivers completed the study. Caregivers and adolescents completed questionnaires assessing adolescents' executive functioning and adherence to diabetes management tasks. Adolescents completed additional questionnaires assessing sleep quality, daytime sleepiness, and internalizing symptoms. Adolescents' medical records were reviewed to collect most recent hemoglobin A_{1c} (HbA_{1c}) values, which represent metabolic control.

Results partially supported hypotheses in that poorer sleep quality, greater daytime sleepiness, and longer sleep duration on the weekend were associated with poorer treatment adherence, but not metabolic control. As predicted, sleep quality was associated with adherence through anxiety, depression, and executive functioning. Daytime sleepiness was associated with adherence through anxiety and had a direct effect on adherence independent of anxiety, depression, and executive functioning.

Overall, results underscore the importance of assessing sleep quality and quantity in adolescents' with T1DM. Targeting sleep as a point of intervention may help to improve adherence behaviors through internalizing symptoms and executive functioning.

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INTRODUCTION

Insufficient sleep is a nearly ubiquitous problem during adolescence. A recent population-based survey found that nearly 69% of adolescents in the United States sleep less than 8 hours on school nights (Eaton et al., 2010). Various biopsychosocial and contextual factors appear to converge during adolescence and may account for the pervasive nature of insufficient sleep commonly observed during this stage of development (Becker, Langberg, & Byars, 2015; Carskadon, 2011; LeBourgeois, Giannotti, Cortesi, Wolfson, & Harsch, 2005). Although a substantial amount of research has demonstrated that most adolescents do not sleep the recommended amount (i.e., eight hours), a paucity of research has considered sleep within the context of type 1 diabetes mellitus (T1DM). Although this area of research is in its infancy, numerous studies have shown that youth[1] with T1DM experience greater sleep difficulties, poorer sleep quality, and greater daytime sleepiness/fatigue compared to healthy youth (Blanz, Rensch-Reimann, Fritz-Sigmund, & Schmidt, 1993; Caruso et al., 2014; Matyka, Crawford, Wiggs, Dunger, & Stores, 2000; Perfect et al., 2012; Pillar et al., 2003; Varni, Limbers, Bryant, & Wilson, 2009; Villa et al., 2000; Yeshayahu & Mahmud, 2010). Underlying bioregulatory processes such as hypoglycemia, poor glycemic control, and rapid glycemic change appear to be associated with poor sleep in youth with T1DM (Caruso et al., 2014; Matyka et al., 2000; Perfect et al., 2012; Perfect, 2014; Pillar et al., 2003; Porter Gyrne, Stick, & Jones, 1996; Yeshayahu & Mahmud, 2010). Additionally, illness-related sequelae, such as stress associated with managing a chronic illness, may differentially impact sleep in youth with T1DM (Perfect, Elkins, Lyle-Lahroud, & Posey, 2010). Difficulties with sleep may further impact self-regulatory skills, such as regulating cognitions, emotions, and behaviors associated with diabetes management that support adherence and glycemic control (Turner, Queen, Butner, Wiebe, & Berg, 2016). Therefore, adolescents with T1DM may be at particular risk for difficulties with sleep due to a combination of biospsychosocial and illness-related factors. Although research examining the relationship between sleep and illness management in individuals with T1DM is in its infancy, the American Diabetes Association (2017) has recommended providers assess sleep patterns and sleep duration as a part of regular comprehensive medical evaluations. Recently, researchers have started to focus their efforts on developing clinically relevant sleep interventions for youth with T1DM (Perfect et al., 2016).

Understanding how sleep may impact adherence to diabetes management tasks during adolescence is clinically relevant, as rates of non-adherence have been found to increase substantially during this developmental stage (Kichler, Moss, & Kaugars, 2012; Weissberg-Benchel et al., 1995). Initial research suggests sleep difficulties are associated with poorer diabetes outcomes, such as adherence (Hazen et al., 2015; McDonough, Clements, DeLurgio, & Patton, 2017). Research regarding the relationship between sleep difficulties and glycemic control in youth with T1DM is equivocal (Adler, Gavan, Tauman, Phillip, & Shalitin, 2016; Blanz et al., 1993; Caruso et al., 2014; Happe et al., 2005; Jaser & Ellis, 2016; Perfect et al., 2012; Perfect, 2014; Villa et al., 2000, Yeshayahu & Mahmud, 2010). Research suggests that neurocognitive functioning and internalizing behavior, such as anxiety and depression, may be compromised by poor sleep among healthy youth (Beebe, 2011; Moore et al., 2009; Moore & Meltzer 2008; Sarchiapone et al., 2014). Limited research examining these associations among youth with T1DM suggests poorer sleep quality and daytime sleepiness are associated with increased symptoms of depression (Adler et al., 2016; Hazen et al., 2015; Perfect et al., 2012) and poorer executive functioning among youth with T1DM (Caruso et al., 2014).

The relationship between sleep, neurocognitive functioning, and internalizing behavior may be particularly relevant to youth with T1DM as they may be at increased risk for experiencing neurocognitive deficits (Caruso et al. 2014; Desrocher & Rovet 2004; Gaudieri, Chen, Greer, & Holmes, 2008; Northam, Rankins, & Cameron, 2006) and greater internalizing symptoms (Kovacs, Goldston, Obrosky, & Bonar, 1997; Northam, Matthews, Anderson, Cameron, & Werther, 2004) compared to their otherwise healthy peers. Internalizing symptoms and neurocognitive deficits have been implicated in illness management and T1DM outcomes (Bagner, Williams, Geffken, Silverstein, & Storch, 2007; Bernstein, Stockwell, Gallagher, Perez et al., 2017; Rosenthal, & Soren, 2013; Johnson, Eider, Young, Brierley, & Heller, 2013; Lawrence et al., 2005; Whittemore et al., 2002). As such, there is a need to understand how internalizing behaviors and neurocognitive functioning may influence the relationship between sleep and illness management and outcomes in youth with T1DM.

Sleep

Definition of Sleep

Sleep is a universal (Pace-Schott & Hobson, 2002) and dynamic (Pallayova, Donic, Gresova, Peregrim, & Tomori, 2010) process characterized by a heightened threshold for sensory input, attenuation of motor output, changes in central and peripheral physiology, and a diminished level of conscious awareness (Pace-Schott, 2010). Although sleep comprises approximately 1/3 of our lives (Sejnowski & Destexhe, 2000), the purpose of sleep in humans is not well understood (Frank, 2006).

Sleep appears to be vital for both physical and mental health, as well as performance and safety (Czeisler, 2015). While there is no unifying theory, sleep is generally hypothesized to allow for the body and mind to rest while various processes take place (National Sleep Foundation [NSF], 2006) such as the reorganization and consolidation of memory, the rehearsal of new learning or genetically programmed behaviors, and the generation of immobility at times when activity would otherwise be dangerous and/or waste energy resources (Bryant, Trinder, & Curtis, 2004).

Measurement of Sleep

Objective measures of sleep.

Polysomnography. While there are numerous objective and subjective measures available to examine sleep, polysomnography (PSG) is considered the gold standard for objective assessment of sleep (Buckhalt, Wolfson, & El-Sheikh, 2009; Collop, 2006). Polysomnography typically involves the monitoring and transduction of various physiological signals including EEG and may involve electromyography (nerve and muscle functioning), electrocardiogram (heart), electrooculography (leads placed above eyes), respiration using nasal thermistor or nasal cannula pressure transducer, pulse, respiratory effort, and oxygen saturation (Collop, 2006). Although PSG is considered the gold standard for measuring sleep, it is expensive and requires specialty-trained personnel to score and interpret complex output (Buckhalt et al., 2009). Conducting PSG with children may pose particular methodological challenges as PSG is frequently conducted in an unfamiliar laboratory setting, which may directly affect children's sleep. Furthermore, parents may be hesitant to leave children in an unfamiliar setting with unfamiliar adults (Beebe et al., 2008; Fallone, Seifer, Acebo, & Carskadon, 2002). Changes in respiratory rates and patterns across development act to further compound aforementioned methodological challenges in conducting pediatric PSG. As developmental changes are associated with variable presentations and

etiologies of sleep-related disorders in children as compared to adults, it is not appropriate to evaluate pediatric PSG against adult PSG norms; however, the interpretation of pediatric PSG may be particularly difficult as there is limited normative data available for interpretation purposes (Griebel & Moyer, 2006).

Actigraphy. An alternative objective measure of sleep that may be appropriate to use with pediatric populations is actigraphy. An actigraph is a small, relatively unobtrusive watch-like device worn on the non-dominant wrist that allows for recording and storage of data generated by daytime and nighttime movements over the course of days, weeks, or longer (Acebo, 2006). Actigraphy has a distinct advantage over PSG as it allows for non-invasive measurement of sleep-wake patterns in a child's natural environment and has been effectively used in research with children and adolescents ages 0-18 years (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012).

Despite its advantages, actigraphy is not without its limitations. In a review of validation studies, Meltzer and colleagues (2012) found that research uniformly shows that actigraphy has high sensitivity but low specificity across all age ranges (i.e., infants through adolescents). That is, while actigraphy appears to reliably identify sleep similar to that of other objective measures of sleep, it appears to have limited ability to accurately detect wake after sleep onset in pediatric populations (Meltzer et al., 2012), particularly during times of transition between wake and sleep (Acebo, 2006). For example, Johnson and colleagues (2007) found that actigraphy underestimated sleep compared to PSG in 181 adolescents due to overestimation of the amount of time spent awake after sleep onset. That is, actigraphy may be oversensitive to and code nocturnal movement as awake rather than asleep. As a result, actigraphy tends to underestimate total sleep time (Johnson et al., 2007) in pediatric populations. Although actigraphy has become an increasingly popular objective measure of sleep in pediatric populations, there are no current practice standards regarding recording parameters and scoring of actigraph signals in children and adolescents. Meltzer and colleagues (2012) note that no specific normative data is available for interpreting actigraphy in pediatric populations. Furthermore, limited research has considered the impact of rapid changes in sleep across development on scoring thresholds for actigraphy.

Subjective measures of sleep.

Sleep diary. Sleep may also be measured using various subjective methods, including sleep diaries. Although sleep diaries may be used in conjunction with actigraphy, they are often used as stand-

alone measures and are considered the gold standard for the subjective measurement of sleep (Carney et al., 2012). Sleep diaries typically involve self- or other-monitoring of various metrics of sleep, including, but not limited to, sleep onset latency (i.e., the time it takes to fall asleep), wake after sleep onset (i.e., arousals from sleep), total sleep time, total time spent in bed, sleep efficiency (i.e., percentage of time asleep out of total amount of time in bed), and perceived sleep quality (Tremaine, Dorrian, & Blunden, 2010). Sleep diaries are typically completed in the evening before going to bed and in the morning upon waking and allow for the quantitative measurement of various aspects of sleep across multiple days. Sleep diaries may be more reliable that other subjective report measures of sleep because they rely on immediate recall of information, rather than retrospective memory (Wolfson et al., 2003).

Sleep diaries also have numerous limitations. First, individuals tend to overestimate sleep latency (i.e., time it takes to fall asleep; Acebo, 2006; Chambers, 1994), underestimate total amount of time spent asleep, and are not always aware of nocturnal waking events (Chambers, 1994; Short, Gradisar, Lack, Wright, & Carskadon, 2012). Use of parental report of child/adolescent sleep using sleep diary may have limited reliability as parental knowledge about their children's sleep is often restricted and biased (Sadeh, 1996). Despite their widespread use, there is relatively little research comparing sleep diaries to other objective measures of sleep, like PSG, in non-sleep-disordered populations of children and adolescents (Tremaine et al., 2010).

Self- and other-report questionnaires. Numerous self- and other-report (primarily parent/caregiver) measures have been developed to capture the multidimensional nature of sleep. Youth- and caregiver-report sleep questionnaires are a critical component of assessing sleep as these measures may provide unique insight into youth's sleep quality. Questionnaires are primarily retrospective in nature and tend to focus on assessing typical sleep patterns, sleep disturbances, or sleep-related behavior (e.g., sleep habits/hygiene, sleep quality) over a specific period of time (Lewandowski, Toliver-Sokol, & Palermo, 2011). Subjective report measures are easy to use (Wolfson et al., 2003), are cost effective, and require less time to complete as compared to objective measures of sleep; however, sleep questionnaires have their limitations.

First, subjective questionnaires tend to be retrospective in nature and are therefore highly dependent upon the respondent's memory of past events. As such, the accuracy and reliability of self- or

other-reports of sleep may be limited compared to sleep diaries or other objective measures of sleep (Wolfson et al., 2003). Wolfson and colleagues (2003) suggest that adolescents may report most recent, salient, and/or most socially desirable responses, rather than the most accurate information. Additionally, questionnaires often rely on parental reports and may be problematic as parents may be unable to accurately report on their child's sleep, especially night awakenings, and the time it takes their child to fall asleep at night (Sadeh, 1996; Werner, Molinari, Guyer, & Jenni, 2008). Additionally, parental reports of sleep quality and daytime sleepiness are based on observations and may not accurately reflect their child's subjective experience. It is unclear when children and adolescents become more accurate reporters of their own sleep than their parents.

In summary, objective measures of sleep are the preferred method for quantifying sleep and examining sleep architecture in children and adolescents, although caution may be warranted given the lack of developmentally-appropriate norms for pediatric populations. Among subjective report measures, sleep diaries are considered the gold standard for quantifying sleep in children and adolescents. Self- and other-report questionnaires provide a unique opportunity to examine subjective perceptions of sleep quality and other behaviors that alternative measures may not provide.

Insufficient Sleep During Adolescence

Age is the most significant factor known to impact both sleep architecture and quality of sleep (Rosenthal, 2006). While it is recommended that school aged children (ages 6-13) obtain 9 to 11 hours of sleep and adolescents (ages 14-17) obtain 8-10 hours of sleep per night (Hirshkowitz et al., 2015), research suggests that the majority of adolescents sleep less than the recommended amount. In a nationally representative survey of 14,041 high school students, Eaton and colleagues (2010) found that nearly 69% of adolescents reported sleeping less than 8 hours on school nights. Additionally, research consistently shows increasing rates of insufficient sleep across adolescence (i.e., total sleep time decreases with age; Eaton et al., 2010; NSF, 2006; NSF, 2014) despite the fact that adolescents' need for sleep does not decrease compared to preadolescence (Carskadon, Wolfson, Acebo, Tzischinsky, & Seifer, 1998; Carskadon et al., 1980). Biopsychosocial and contextual factors may account for the pervasive nature of insufficient and irregular sleep observed during adolescence (see Figure 1; Becker et al., 2015; Carskadon, 2011; LeBourgeois et al., 2005).

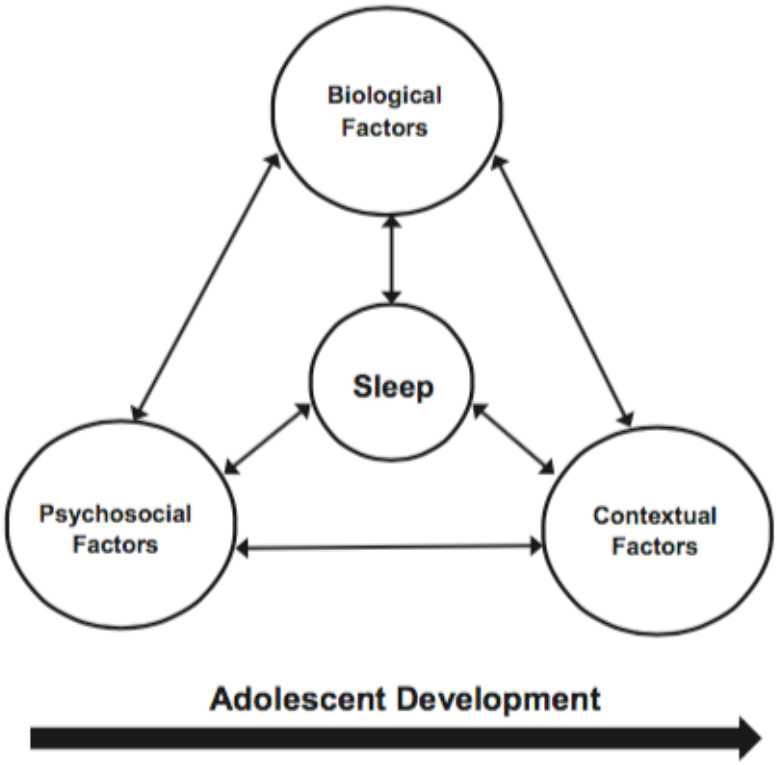

Figure 1. Biopsychosocial and contextual model of sleep in adolescence (Becker, Langberg, & Byars, 2015).

Biological factors. Biologically, the transition from childhood to adolescence (i.e., puberty) is associated with various neurodevelopmental changes that may impact sleep onset and architecture. Research suggests that neurodevelopmental changes are associated with circadian phase delay (Process C; Carskadon, 2011) and slowed accumulation of homeostatic sleep pressure (Process S; Becker et al., 2015). These neurodevelopmental changes translate to the preference for later sleep onset, and therefore later bedtime, during adolescence (Giannotti, Cortesi, Sebastiani, & Ottaviono, 2002) and a bioregulatory driven delay in sleep onset during adolescence (Carskadon, 2011).

Psychosocial factors.

Bedtime. In addition to biological changes that occur during this stage of development, adolescents are confronted with various psychosocial pressures, expectations, and responsibilities that may impact their sleep. As adolescence is a developmental period often characterized by increasing levels of independence and autonomy, one psychosocial factor that may be implicated in the pattern of inadequate sleep during adolescence is increased bedtime autonomy (Carksadon, 2011). Parent-determined bedtime has been found to have a positive effect on adolescent sleep, including earlier bedtime, more sleep, and less daytime fatigue as compared to adolescents who set their own bedtimes. Despite the benefits associated with parental-set bedtime, parent-determined adolescent bedtime steadily decreases with age across adolescence (Short et al., 2011). As a result, adolescents whose parents do not set their bedtimes tend to go to bed later and sleep less than their peers whose parents continue to set their bedtimes (Short et al., 2011).

Electronic media use. Another psychosocial factor that may negatively impact adolescent sleep is the use of electronic devices at night (e.g., cell phones, computers/laptops, tablets, televisions, electronics, video games, music devices). The NSF *Sleep in America Poll*: *Sleep in the Modern Family* (2014) reported that approximately 72% of children have at least one and 51% have at least two or more electronic devices in their rooms. Of note, the number of electronics present in a child's room appears to increase as a function of age; while 72% of all children ages 6 – 17 have at least one electronic device in their rooms, that percentage increases to nearly 90% among adolescents ages 15-17.

Although it is increasingly common to find electronic devices in the rooms of adolescents, particularly older adolescents, research suggests that their use may have a direct negative effect on sleep. In a comprehensive review of the impact of electronic media use on sleep of children and adolescents, Cain

and Gradisar (2010) found that children and adolescents who use electronic devices before bedtime experience shorter, later, and/or more disrupted sleep as well as poorer daytime functioning (e.g., daytime sleepiness and disruptive behavior) compared to children and adolescents who do not use electronic devices. Use of electronic devices before bed may make it more difficult for adolescents to sleep as electronic device use may increase arousal (Cain & Gradiser, 2010; Carskadon, 2011). Furthermore, exposure to bright light, particularly from televisions or computer screens, may suppress the release of melatonin and consequently delay circadian rhythms and sleep onset (Higuchi, Motohashi, Liu, & Maeda, 2005).

School start time. School start time in the US is a well-recognized and important contextual factor when considering sleep in adolescence (Kirby, Maggi, & D'Angiulli, 2011), as early school start times may place strict limitations on adolescents' ability to meet their sleep needs (Carskadon, 2011). A policy statement released by the American Academy of Pediatrics (2014) recommended that school start times be delayed until 8:30 am or later for both middle and high school. Research among adolescents in the United States has unequivocally shown that early school start times are associated with adolescents obtaining less sleep and experiencing increased levels of fatigue and daytime sleepiness (Danner & Phillips, 2008; Dexter, Bijwadia, Schilling, & Applebaugh, 2003; Owens, Belon, & Moss, 2010). In a study examining the effect of school start time on adolescent sleep, Dexter and colleagues (2003) showed that adolescents in 10^{th} and 11^{th} grade who had an earlier school start time (7:50 am) reported receiving significantly less sleep and experienced significantly more daytime sleepiness than adolescents whose school start time was 45 minutes later. In one college preparatory school it was found that delaying school start time by 30 minutes had a significant positive impact on the percent of adolescents who were able to obtain eight hours of sleep per night (Owens et al., 2010). Similarly, Danner and Phillips (2008) examined the impact on adolescents' sleep of a large school district in Kentucky delaying their school-start times by one hour. As expected, duration of sleep increased during the school year following the change in school start time and the percentage of adolescents reporting sleeping eight or more hours per night increased from 35.7% to 50%.

Other psychosocial factors. Other psychosocial factors that may indirectly impact sleep during adolescence include increased academic pressure/workload and involvement in extra-curricular activities/work. Specifically, the amount of time spent studying outside of school has been found to be

associated with incidence and persistence of restricted sleep (i.e., sleeping six hours or less) among adolescents (Roberts, Roberts, & Xing, 2011). Further, time spent completing homework may increase adolescents' stress (Kouzma & Kennedy, 2002) and anxiety, which may further impact sleep onset (Becker et al., 2015) through increased activation of the HPA axis and subsequent physiological arousal due to the release of cortisol. Working a part-time job and engaging in extracurricular activities may also negatively impact sleep quality/duration during adolescence (Roberts et al., 2011; Safron, Schulenberg, & Bachman, 2001; Vinha, Cavalcante, & Andrade, 2002) because these activities may limit the amount of time available for adolescents to sleep (Vinha et al., 2002).

Research has shown that insufficient sleep is a nearly ubiquitous problem among adolescents in the U.S. The convergence of various biological, psychosocial, and sociocultural factors during adolescence are thought to result in adolescents' tendency to initiate sleep later, awaken earlier, and sleep for shorter periods of time (Becker et al., 2015; Carskadon, 2011). Pubertal changes, including a delay in circadian rhythm and slowed accumulation of sleep pressure, result in delayed sleep onset (Carskadon, 2011). These bioregulatory changes are compounded by increased bedtime autonomy, academic pressure, technology use at bedtime/in the bedroom, and early school start times (Carskadon, 2011). While bioregulatory mechanisms appear to cause sleep onset delay, psychosocial factors maintain and promote shorter sleep times during adolescence. Taken together, these biopsychosocial factors contribute to a set of well-recognized problems including late nights, erratic sleep/wake schedules, and insufficient sleep on school nights (Holm et al., 2009).

Although sleep is negatively affected by the convergence of various biopsychosocial factors during adolescence, sleep in children and adolescents with chronic illness may be further compromised by disease processes, as well as illness-related sequela.

Sleep in Pediatric Chronic Illness

While sleep difficulties are nearly ubiquitous during adolescence, research suggests that sleep-wake disturbances are especially prevalent among children and adolescents with acute and chronic illnesses (Hysing, Sivertsen, Stormark, Elgen, & Lundervold, 2009; Long, Krishnamurthy, & Palermo, 2008; Meltzer, Ullrich, & Szefler, 2014; Pasarelli et al., 2006; Yuksel et al., 2007). For example, research suggests that youth with T1DM experience greater sleep difficulties than healthy youth (Blanz et al., 1993;

Matyka et al., 2000; Monaghan, Herbert, Cogen, & Streisand, 2012; Perfect et al., 2012). Underlying disease processes and illness-related sequelae, such as medication use, hospitalization, stress associated with illness management, and mental health functioning, likely account for at least some sleep difficulties commonly observed in youth with chronic illness (Lewandowski, Ward, & Palermo, 2011; Lewin & Dahl, 1999). Sleep difficulties may be particularly concerning for youth with chronic illness as poor sleep may exacerbate underlying health difficulties, which may disrupt sleep even further (Amin, Bean, Burklow, & Jeffries, 2005; Hanson & Chen, 2008; Lewandowski et al., 2011; Parisi et al., 2010).

Type 1 Diabetes Mellitus

Type 1 diabetes mellitus is the second most prevalent chronic illness in children and adolescents after asthma, and T1DM is estimated to impact 1 in 300 children before the age of 18 (Maahs, West, Lawrence, & Mayer-Davies, 2010) and is most often diagnosed in children between the ages of 9 and 15 (Watkins, Drury, & Howell, 1996). T1DM is an autoimmune disease that is genetically mediated and involves impaired glucose metabolism due to insulin deficiency secondary to the destruction of beta cells of the pancreas, which are responsible for the production of insulin (Brannon, Feist, & Updegraff, 2014; Shrestha, 2010; Wysocki, Buckloh, & Greco, 2009). This deficiency results in an increase in glucose in the bloodstream, which damages other body systems such as blood vessels and nerves (Shrestha, 2010). T1DM is associated with various short- and long-term health consequences. In the short term, T1DM is associated with increased risk for hypoglycemia (i.e., dangerously low levels of blood glucose in the body), which is often accompanied by feelings of weakness, nervousness, sweatiness, blurred vision, headache, and changes in mood. T1DM is also associated with increased risk for hyperglycemia (i.e., extremely high levels of blood glucose), which may lead to diabetic ketoacidosis (i.e., a condition in which the body begins to breakdown fatty acids in the liver resulting in a secretion of ketones into the bloodstream, thus increasing the acidity of the blood; Beaser, 2007), loss of consciousness, coma, or even death (Wysocki et al., 2009). In the long term, poorly controlled T1DM can lead to various micro- and macrovascular complications (Maahs et al., 2010; Wysocki et al., 2009) such as stroke, heart attack/heart disease, circulatory disorders, amputation, kidney disease, nerve damage, and retinopathy (Wysocki et al., 2009).

Diabetes Management and Adherence

Diabetes management requires adherence to a complex medical regimen including administering several daily insulin injections, self-monitoring of blood glucose, monitoring carbohydrate intake, and engaging in daily exercise (Wysocki et al., 2009). Research suggests that youth with T1DM, especially older adolescents (Kovacs, Goldston, Obrosky, & Iyengar, 1992), experience difficulties with adherence (Kichler et al., 2012). Additionally, Weissberg-Benchel and colleagues (1995) found that adolescents with T1DM displayed high levels of diabetes mismanagement, particularly with regard to missing blood glucose checks and insulin injections.

Numerous methods and psychometrically sound measures are available for assessing adherence among individuals with T1DM, including self- and other-report measures (e.g., Self-Care Inventory Revised, SCI-R; Weinger, Butler, Welch, & La Greca, 2005), diary/interview measures (e.g., 24-hour recall interview; Johnson, Silverstein, Rosenbloom, Carter, & Cunningham, 1986), electronic monitoring (e.g., blood glucose checks/meter downloads; Quittner, Modi, Lemanek, Ievers-Landis, & Rapoff, 2008), and provider reports (e.g. estimates of blood glucose testing frequency; Kichler, Kaugars, Maglio, & Alemzadeh, 2012).

Methodological challenges. There are a number of unique challenges associated with the measurement of adherence in children and adolescents with chronic illness. First, measures of adherence often use variable time frames (e.g., previous 24 hours, previous two weeks, or one to three months) making it difficult to compare, at least directly, and synthesize data across measures. Another major challenge in measuring adherence is that advancement in medical treatments typically outpaces the ability to develop valid and reliable measures of adherence, which may render previous measures obsolete. As multiple reporters are often used in pediatric research (e.g., child and/or caregiver), it is often unclear whose responses are *most* accurate and reliable. Finally, rapidly changing medical treatments/prescriptions make it difficult to track specific adherence behaviors (Quittner et al., 2008).

Subjective reports. Adherence is frequently measured using subjective self- or other-reports with questionnaires or through the use of interviews. Subjective report measures have numerous strengths; they are inexpensive, often comprehensive in nature, and allow for collection of information from multiple informants (e.g., patient, caregiver, health care providers, teachers, etc.). Additionally, structured/semi-

structured interviews allow for follow-up questions, which may provide additional important information regarding patient or others' perceptions regarding medical regimen and barriers to adherence.

Subjective reports are, however, not without their limitations. Weaknesses of subjective report measures include the tendency to overestimate adherence to medical regimen; variable reliability of participant recall due to dependence on respondent's memory; tendency to assess more global beliefs about behavior rather than frequency of specific behavior; assessment of only one person's perspective; and difficulties associated with administering self-report measures to children eight years of age or below (Quittner et al., 2008).

Daily diary/interview methods. Daily diary methods, such as a 24-hour recall interview (Johnson et al., 1986), are typically conducted over the phone and have several advantages over self- or other-report measures. First, these types of measures are typically conducted in real time or after a short period of time has passed since the behavior has been performed (e.g., previous 24 hours). Additionally, because of the shortened time frame, daily diary measures are better able to assess specific behaviors that have recently occurred, rather than global perspective of behavior. As daily diary methods are time limited in nature, they also tend to facilitate the identification of various barriers to adherence. Finally, daily diary measures tend to be unobtrusive in nature as patients and their families are typically unaware that activities associated with their medical treatment are the focus of assessment (Modi & Quittner, 2006).

While daily diary methods have their advantages over other subjective report measures, there are numerous limitations. Daily diary measures require a greater time commitment from both reporters and individuals administering these types of measures compared to subjective reports, and they typically require specialized training. Additionally, scheduling phone calls can be difficult as some families do not have regular access to a phone, do not answer calls, or have limited availability to speak on the phone. Finally, diary measures often produce complicated data sets that require complex analytical approaches (Larson & Delespaul, 1992; Modi & Quittner, 2006).

Electronic monitoring. Technological advances have allowed for the development of automated measures of adherence (Quittner et al., 2008), such as glucometers, which are used to regularly monitor blood glucose levels in individuals with diabetes. Electronic monitors can store real-time information ranging from several months to three years, and data can be easily downloaded for analysis by users or

medical providers. Electronic monitoring has the distinct advantage of being able to provide real-time, continuous, and long-term measurement of an adherence behavior and can be used to determine non-adherence to blood glucose monitoring (Quittner et al., 2008). A major disadvantage of electronic monitoring systems is that they may malfunction (Quittner et al., 2008). Additionally, electronic monitors such as glucometers do not provide information regarding other adherence behaviors such as taking the correct dose of insulin at the right time, consuming the correct proportion of food, or accurately counting carbohydrates. Despite its limitations, electronic monitoring is considered more accurate than other measures of adherence because monitors are more "objective" in nature and often reveal poorer adherence when compared to self- or other-reports (Riekert & Rand, 2002).

Provider report. Provider reports of adherence may be made based on clinical impressions of frequency of daily blood glucose checks (Kichler et al., 2012). Although research has demonstrated provider reports are associated with average daily blood glucose checks in adolescents with T1DM (Kichler et al., 2012), provider reports are often unreliable (Johnson, 1992). Specifically, providers are often aware of patient's health status (e.g., metabolic control), which may skew their ratings of adherence. Furthermore, provider ratings of patient adherence are often global in nature as patients are often rated as adherent or non-adherence. Finally, global ratings of adherence, such as provider reports, are unable to capture the complexity of adherence to diabetes management tasks (Johnson, 1992).

Although self- or other-report measures, diary/interview measures, and electronic monitoring are considered valid and reliable approaches to measuring adherence in children and adolescents with T1DM, Quittner and colleagues (2008) recommend using at least two different forms of measurement when examining adherence in children and adolescents with chronic illness. As a review of adherence measures is beyond the scope of this paper, the interested reader is encouraged to read Quittner et al. (2008) for a thorough review of various adherence measures commonly used in pediatric psychology.

Metabolic Control

Hemoglobin A1C (HbA_{1c}) is a biological blood assay that is used as an objective measure of average glycemic control during the previous two to three months (American Diabetes Association [ADA], 2017b). In a landmark study, the Diabetes Control and Complications Trial Research Group (DCCT; 1993) found that maintaining near normal HbA_{1c} greatly reduces risks associated with diabetes. Adherence to

diabetes management tasks and the implementation of an intensive insulin treatment have been found to be associated with optimal glycemic control (i.e., HbA_{1c}; DCCT, 1993). Although the recommended level of HbA_{1c} for all children and adolescents with T1DM is <7.5% (ADA, 2017a), the DCCT found that near-normalization of blood glucose levels was significantly more difficult to obtain among adolescents than among adults (DCCT, 1993). Normalization of blood glucose levels may be more difficult during adolescence due to hormonal changes associated with puberty, which may alter insulin sensitivity, thus making glycemic control more difficult (Anderson, Brackett, Ho, & Laffel, 1999; Dabadghao, Vidmar, & Cameron, 2001; Moran, 2002). Additional factors, such as increasing levels of physical activity and changes in nutritional intake, may also impact glycemic control during adolescence (Wysocki, Buckloh, Lochrie, & Antal, 2005). Furthermore, increasing levels of non-adherence may also contribute to significant deterioration of glycemic control observed during this developmental period (Du Pasquier-Fediaevsky et al., 2005).

Although metabolic control may be considered a measure of adherence, direct methods involving the measurement of biological specimens (such as those involved in HbA_{1c} blood assays) measure outcomes rather than the process of adherence to medical recommendations (Kyngäs, Kroll, & Duffy, 2000). While research has demonstrated that adherence to T1DM management tasks is strongly correlated with metabolic control (Hood, Peterson, Rohan, & Drotar, 2010), this relationship is not always found. The lack of relationship between adherence and metabolic control may be a function of various biopsychosocial factors that influence HbA_{1c} (Anderson et al., 1999; Dabadghao et al., 2001; Moran, 2002; Wysocki et al., 2005) independent of adherence. Therefore, measurement of both adherence to T1DM management tasks and metabolic control are vital to understanding both the process and outcome associated with T1DM self-care.

Sleep in Youth with T1DM

Sleep Quality in Youth with T1DM

Despite evidence of the prevalence of poor sleep in healthy youth, as well as those with chronic illness, there is a paucity of research assessing sleep among youth with T1DM. The majority of emerging research suggests that youth with T1DM experience more frequent and severe sleep disturbances than

youth without chronic illness (Blanz et al., 2012; Caruso et al., 2014; Matyka et al., 2000; Monaghan et al., 2012; Perfect et al., 2012) and greater daytime sleepiness (Adler, Gavan, Tauman, Phillip, & Shalitin, 2016), although these findings are not universal (Adler et al., 2016; Estrada, Danielson, Drum, & Lipton, 2012). Nearly 76% of youth with T1DM report insufficient sleep (Estrada et al., 2012). Barone and Menna-Baretto (2011) suggest underlying bioregulatory processes (i.e., hypoglycemia, poor glycemic control, and rapid glycemic change) may account for these sleep difficulties (see Figure 2).

Defining sleep quality. Although sleep quality is accepted as a clinical construct, it represents a complex and multifaceted phenomenon that is not so readily defined. "Sleep quality" represents a constellation of various aspects of sleep, including quantitative (e.g., duration, sleep onset latency, arousals from sleep) as well as subjective aspects such as "depth" or "restfulness." The exact elements of sleep quality are increasingly unclear as they may differ between individuals in relative importance (Buysse, Reynolds, Monk, Berman, & Kupfer, 1988).

Measurement of sleep quality. Given the inherent subjective nature of sleep quality, objective measures of sleep, such as actigraphy and PSG can provide estimates of continuity of sleep (Meltzer et al., 2013) and may correlate with perceived quality of sleep, but they do not provide information regarding subjective quality (Buysse et al., 1988; Meltzer et al., 2013). Subjective measures of sleep quality provide valuable information regarding the perception of individual's sleep-related behaviors and patterns that objective measures are unable to measure (Lewandowski et al., 2011). As such, subjective report measures are considered essential aspects of comprehensive sleep evaluations (Lewandowski et al., 2011).

Objective measurement of sleep quality. Research examining sleep quality in youth with T1DM has utilized both objective and subjective measures. Studies utilizing PSG have demonstrated that youth with T1DM experience alterations in sleep architecture and more frequent nocturnal arousals than healthy controls (Matyka et al., 2000; Perfect et al., 2012, Pillar et al., 2003). In a study examining sleep, glucose, and daytime functioning, Perfect and colleagues (2012) found that youth with T1DM (ages 10 – 16, $n = 50$) spent significantly more time in stage 2 sleep[2] and less time in restorative stage 3 sleep[3] than healthy controls ($n = 40$). Although only a small percentage of sleep was affected (i.e., approximately 5% based on seven hours of sleep), such alterations in sleep architecture may have serious consequences for the amount of slow wave sleep youth with T1DM are able to achieve (Perfect et al., 2012). Perfect and colleagues

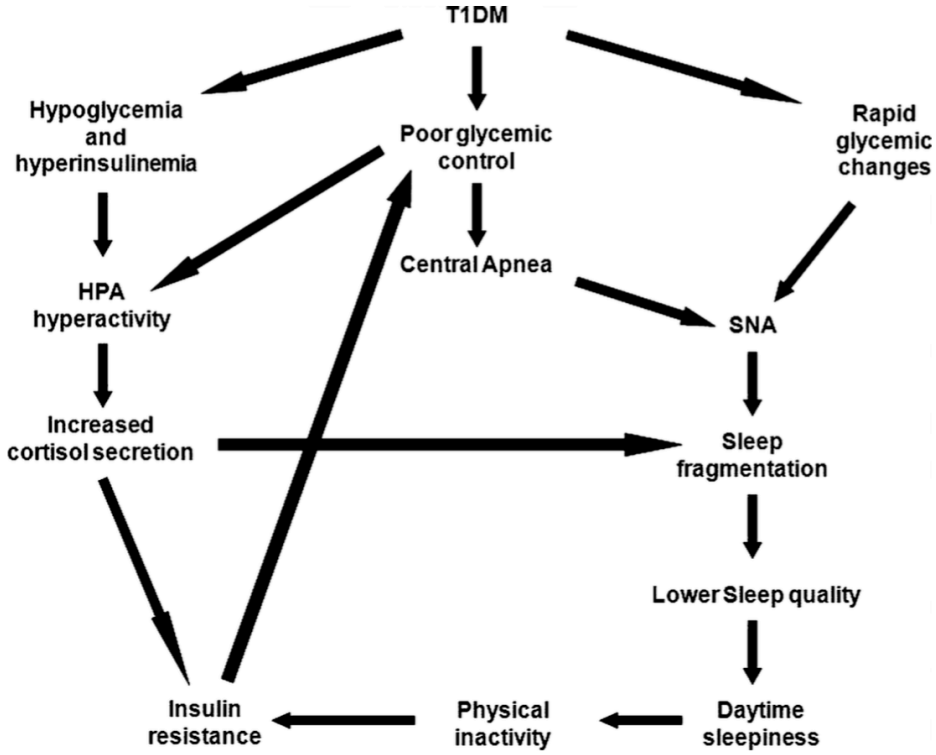

Figure 2. Hypothetical model of the impact of type 1 diabetes mellitus on sleep (Barone & Menna-Barreto, 2011)

estimate that youth with T1DM spend 21 minutes less in slow wave sleep (SWS; stage 3) than healthy controls, which would result in an average loss 2.45 hours of SWS per week. This is particularly concerning given that this pattern of sleep architecture is associated with daytime sleepiness, decreased mood, difficulties with behavior, decreased quality of life, and school performance (Perfect et al., 2012). Furthermore, recent research examining the relationship between sleep duration and diabetes management found that an increase in sleep of only 15- to 20-minutes translates to a one-event increase in both blood glucose checks and average daily insulin bolus in adolescents with T1DM (McDonough et al., 2017).

Additionally, the impact of nocturnal hypoglycemia on sleep quality in youth with T1DM has been examined. Hypoglycemia frequently occurs in youth with T1DM, particularly during sleep (Davis, Russell, Keating, Jones, & Byrne, 1997). This is concerning because nocturnal hypoglycemia events are typically asymptomatic (Ahmet, Dagenais, Barrowman, Collins, & Lawson, 2011) and are associated with increased risk for seizure or coma (Davis et al., 1997).

At this time, it is unclear how nocturnal hypoglycemia may impact sleep quality in youth with T1DM. Two studies have demonstrated that nocturnal hypoglycemia does not appear to affect sleep continuity in youth with T1DM. However, in a study assessing the interaction between nocturnal hypoglycemia and sleep in children with T1DM (mean age = 12.6, n = 15), Pillar and colleagues (2003) observed significant alterations to sleep architecture in youth with T1DM who experienced nocturnal hypoglycemia. Specifically, nocturnal hypoglycemia appears to deepen sleep through increased sleep efficiency, decreased sleep onset latency, and greater overall total amount of sleep. These findings are consistent with the hypothesis that nocturnal hypoglycemia would not result in arousal from sleep and are particularly alarming in light of the known risks associated with hypoglycemia (i.e., seizure and coma) as they suggest youth are less likely to wake in order effectively intervene and prevent further decrease in blood glucose levels. Differing results across these three studies may be a function of varying methodological approaches assessing hypoglycemia. Pillar and colleagues (2003) defined hypoglycemic events more stringently (i.e., <2.7 mmoL/L) than other studies (i.e., <3.5 mmoL/L; Matyka et al., 2000; Porter et al., 1996), suggesting that the severity of hypoglycemia may play a key role in whether and to what extent sleep architecture is affected by nocturnal hypoglycemia.

Finally, T1DM appears to be associated with increased risk for apneic events during sleep in children and early adolescents. Villa and colleagues (2000) found that children and early adolescents (ages 5 – 11, *n* = 25) with T1DM experience more frequently apneic events compared to healthy controls (*n* = 20). Additionally, children and early adolescents in poor control ($HbA_{1c} \geq 8.0\%$) experienced more frequent apneic events than those in good control ($HbA_{1c} \geq 7.9\%$).

Summary. Taken together, current research examining sleep quality using objective measures of sleep suggest that T1DM-related disease processes may interact with underlying bioregulatory mechanisms involved in sleep resulting in altered sleep quality in youth with T1DM. Although this line of research is crucial for understanding sleep quality in youth with T1DM, its contribution is limited, as it does not consider youths' subjective experiences of sleep quality.

Subjective measurement of sleep quality. Understanding the subjective experience of sleep quality is critical, yet a limited number of studies have utilized subjective report measures to examine sleep quality with youth with T1DM. Initial evidence suggests that youth with T1DM experience decreased sleep quality compared to healthy appears (Blanz et al., 1993; Caruso et al., 2014; Varni et al., 2009), although this finding is not universal (Adler et al., 2016; Estrada et al., 2012; Yeshayahu & Mahmud, 2010). Current research examining sleep quality using subjective report measures is methodologically diverse in terms of reporter, assessments used, and aspects of sleep quality assessed.

Sleep disturbance. Emerging evidence suggests that youth with T1DM experience significant sleep disruptions and disturbances. A recent study found approximately 60% of youth with T1DM experienced clinically significant sleep disturbances, based on parent report (Perfect, 2014). Additionally, it appears that youth with T1DM experience greater sleep disturbances than their otherwise healthy peers. In a study examining parent-reported sleep, neurocognitive, and behavioral functioning in children and adolescents, Caruso and colleagues (2014) found that children and adolescents with T1DM (ages 6 – 16, *n* = 46) experienced significantly greater sleep disturbances compared to healthy controls (*n* = 36). This is consistent with the finding that adolescents with T1DM (ages 17 – 19, *n* = 93) report experiencing greater sleep disturbances than healthy controls (*n* = 93; Blanz et al., 1993). Although Blanz and colleagues (1993) assessed sleep disturbances in adolescents (ages 15 – 17), it was done so at the symptom level, and they did not provide information regarding aspects of sleep disturbance assessed.

Despite converging evidence that youth with T1DM experience decreased sleep quality associated with sleep disturbances, only two studies have assessed adolescents' perspective of sleep disturbances using validated and reliable measures designed specifically to assess sleep disturbances and quality (i.e., Jaser et al., 2016; McDonough et al., 2017). In a study examining associations between sleep disturbances, diabetes management, and glycemic control, Jaser and colleagues (2016) found approximately 20% of adolescents and young adults with T1DM (ages 13-20, n = 159) reported poor to very poor sleep quality. Notably, while McDonough and colleagues (2017) utilized a validated and reliable measure of sleep quality, researchers did not provide specific descriptive information regarding adolescent-reported sleep quality.

Finally, Turner and colleagues (2016) assessed sleep quality in high school seniors with T1DM; however, sleep quality was assessed in high school seniors with T1DM using only a single item (i.e., "How well did you sleep last night?"). Generalizability of results from Turner et al. (2016) to adolescents younger than seniors in high school may be limited.

Use of parent-report measures to assess youths' sleep disturbances (e.g., Caruso et al., 2014; Perfect, 2014) is methodologically concerning given that previous research has shown that information provided by proxy reporters is not necessarily equivalent to youths' own perspective (Achenbach, McConaughy, & Howell, 1987). Parents may underestimate their child's sleep disturbances throughout the night because they are not typically present while the child is sleeping (Schreck & Richdale, 2011). Furthermore, parent reports of adolescents' sleep may represent the time adolescents are in their bedrooms at night (Short, Gradisar, Lack, Wright, & Chatburn, 2013) rather than time spent sleeping. Parents may overestimate the amount of sleep adolescents obtain, thus reporting on their child's sleep in a more idealized way (i.e., estimating adolescent went to bed earlier and obtained more sleep than adolescents reported). If parents do not provide an accurate estimate of adolescents' sleep, they may not be aware of, and therefore underreport, issues associated with restricted sleep (Short et al., 2013) or quality of sleep.

In light of these limitations, additional research is necessary to better understand adolescents' perspective of their own sleep disturbances and quality. It is vital that future research assess sleep disturbances throughout adolescence using a standardized, reliable, and valid measure of sleep disturbances

and quality. Addressing these methodological limitations will improve our understanding of the relationship between T1DM and sleep disturbances in adolescents with T1DM.

Total Sleep Time. A paucity of research has examined the relationship between T1DM and total sleep time in youth with T1DM. Emerging evidence suggests that youth with T1DM receive similar amounts of sleep as healthy controls (Estrada et al., 2012; Yeshayahu & Mahmud, 2010); however, it is unclear how methodological issues may impact these findings.

A major methodological weakness of the current research examining total sleep time in youth with T1DM is the use of non-equivalent control groups. Estrada and colleagues (2012) compared child and adolescent (ages 5 – 19) reports of typical sleep duration to their relatives, who ranged in age from 5.2 – 82.5 years. Given that age is the most significant factor associated with sleep, comparing adolescents' sleep to individuals of such a wide age range may be inappropriate. Despite this limitation, results are consistent with findings of Yeshayahu and Mahmud (2010) who compared sleep duration in adolescents (ages 12 – 18) to matched controls of similar age.

In both studies, children and adolescents provided estimates of their "typical" sleep times in order to estimate typical sleep duration. Although validity and reliability data for reporting estimated school night and weekend times against sleep diary and actigraphy has been documented (Woflson et al., 2003), there is evidence to suggest that adolescents' estimates of sleep duration may be skewed. Wolfson and colleagues (2003) examined adolescents' (ages 13.8 – 19.9, n = 302) self-reported survey estimates of sleep patterns in comparison to sleep diary and actigraphy. Adolescents reported receiving more sleep on the weekends, going to bed earlier on school nights, and waking later on the weekends on the self-report survey measure than on the sleep diary and actigraphy (Wolfson et al., 2003). These results suggest that adolescents actually overestimated the amount of sleep they obtained on weekends and underestimated the time they went to bed. Although total sleep duration did not significantly differ on school nights, the finding that adolescents tended to overestimate weekend sleep suggests that self-report survey measures of adolescents' sleep may not be sufficient for estimating adolescents' sleep duration.

Given these methodological limitations, future research should examine adolescent sleep duration using other reliable measures of sleep, such as sleep diaries or actigraphy. Sleep diaries are likely more accurate than retrospective measures of sleep over a longer period of time given that sleep diaries are

completed closer to actual timing of sleep. Additionally, it will be important that future research use age-matched control groups in order to better understand sleep across the lifespan.

Fatigue. To date, only one study has examined fatigue in children and adolescents with T1DM. Given clinical observation that fatigue is often associated with T1DM, Varni and colleagues (2009) examined various aspects of fatigue (i.e., general fatigue, sleep/rest fatigue, cognitive fatigue) in youth with T1DM compared to youth receiving active treatment for cancer and healthy controls. Based on both parent- and youth self-report, participants with T1DM reported similar levels of fatigue as participants with cancer and significantly more fatigue across all domains than healthy controls. Interestingly, parents reported that youth with T1DM experienced greater cognitive fatigue than youth with cancer. Results suggest that fatigue may be an important construct to assess to better understand how it may impact daily functioning in adolescents with T1DM.

Sleep and Disease Outcomes in Youth with T1DM

Adherence. To date, four studies have examined the relationship between sleep and adherence to diabetes management tasks in youth with T1DM. Hazen and colleagues (2015) examined the relationships among sleep difficulties, adherence, and glycemic control among children and adolescents (ages 10 – 18). Sleep difficulties were assessed using four items (i.e., 'overtired without good reason', 'sleeps more than most kids during the day and/or night', 'sleeps less than most kids', and 'trouble sleeping') from the Child Behavior Checklist parent-report measure (Achenbach, 2001). Adherence to diabetes management tasks was assessed using child and adolescent reports of adherence during the previous two weeks and average daily blood glucose checks. Results suggest that sleeping more than most youth is associated with poorer adherence to diabetes management tasks. It may be that sleeping too much may impact diabetes management by interfering with the timing of care activities (Hazen et al., 2015). For example, children who sleep too much may delay or even miss times when care activities are required, such as blood glucose checks, insulin injections, or eating. More recent research suggests sleep duration, and not sleep quality, is associated with frequency of blood glucose checks, such as longer sleep duration is associated with more frequent blood glucose checks (Jaser et al., 2016; McDonough et al., 2017; Turner et al., 2016).

Given the limited scope of research examining the relationship between sleep and adherence, specifically with regards to aspects of sleep and adherence, additional research is needed to better

understand associations among aspects of sleep and adherence to diabetes management tasks. Furthermore, it will be important that measures assess adolescents' perspective of their sleep quality, given the aforementioned limitations with parent reports of sleep in children.

Metabolic control. A limited number of studies have examined the relationship between sleep and metabolic control. Research suggests that children and adolescents who sleep more than most youth have poorer metabolic control (Hazen et al., 2015); however, typical sleep duration in adolescents is not associated with HbA_{1c} (Yeshayahu & Mahmud, 2010). Given the cross-sectional nature of the previous studies, it is unclear if sleep duration is a symptom or cause of poor glycemic control in youth with T1DM. One explanation may be that glycemic control and blood glucose levels affect sleep at a biophysiological level, which is consistent with the finding that youth with T1DM who are in poor control experience significant altered sleep continuity (i.e., less time in restorative stage 3 sleep and greater time in lighter stage 2 sleep; Perfect et al., 2012).

Although difficulties with sleep initiation are associated with poorer metabolic control (Happe, Treptau, Ziegler, & Harms, 2005), additional research suggests that disturbed sleep is not always associated with HbA_{1c} (Blanz et al., 1993; Caruso et al., 2014; Jaser et al., 2016). Recent research suggests better sleep quality is associated with lower HbA_{1c}, but only among male adolescents and young adults, and not females (Jaser et al., 2016). Taken together, current research suggests that specific aspects of sleep disturbances may be associated with metabolic control, rather than sleep disturbances in general. Given the aforementioned limitations associated with the studies by Blanz and colleagues (1993) and Caruso and colleagues (2014), it is vital that future research examine the relationship between adolescents' perspective of sleep disturbances and metabolic control using a standardized, reliable, and valid measure of sleep disturbances.

Notably, sleep and metabolic control may be complicated by the occurrence of the "dawn phenomenon," particularly in adolescents with T1DM. The dawn phenomenon is "an increase in either the insulin requirements or the plasma glucose concentration, in the absence of hypoglycemia or waning insulin levels, occurring between the hours of 0400 and 0800" (Carroll & Schade, 2005, pp. 55-56). Clinically, the dawn phenomenon is known to increase morning blood glucose levels resulting in a transient increase of 10 mg/dL or an increase in required insulin of at least 20% from overnight nadir (i.e., lowest

level). The dawn phenomenon is known to affect approximately 54% of all individual with T1DM. The most likely mechanism underlying the dawn phenomenon is the nocturnal release of growth hormone; however, the exact pathway through which the dawn phenomenon occurs is unknown. The peak in production of growth hormone during puberty may, in part, explain the need for increased insulin during adolescents (Carroll & Schade, 2005). Furthermore, given that fasting hyperglycemia is associated with both greater daytime blood glucose levels and subsequent poorer glycemic control (Carroll & Schade, 2005), the dawn phenomenon may have far-reaching implications for disease outcomes in T1DM (e.g., poorer metabolic control). Clinically, early morning hyperglycemia can impact the choice, timing, and dose of nighttime insulin as well as programming of continuous subcutaneous insulin infusion pumps (Carroll & Schade, 2005) in order to counteract the effects of the dawn phenomenon on blood glucose and overall metabolic control.

Summary. Current research examining the relationship between sleep quality and diabetes outcomes is limited. Emerging evidence suggest that sleep quality may be associated with adherence to diabetes management tasks and metabolic control; however, given significant methodological limitations, future research is necessary to understand adolescents' perspectives of their own sleep quality as it relates to diabetes outcomes. Furthermore, youth with T1DM experience similar levels of fatigue as youth undergoing active cancer treatment (Varni et al., 2009). Therefore, consideration should be given to the potential impact of fatigue and daytime sleepiness as they relate to metabolic control and adherence to diabetes management.

Potential mediators of the relationship between sleep and disease outcomes. While multiple studies have demonstrated that childhood sleep problems predict the development of symptoms of anxiety, depression, and neurocognitive functioning in healthy adolescents over time (Beebe, 2011; Moore et al., 2009; Moore & Meltzer, 2008; Sarchiapone et al., 2014), a limited number have considered these relationships in youth with T1DM. This is particularly necessary given the finding that individuals with T1DM are at increased risk for difficulties associated with mood (Kovacs et al., 1997; Northam et al., 2004) and neurocognitive deficits (Caruso et al., 2014; Desrocher & Rovet, 2004; Gaudieri et al., 2008; Northam et al., 2006), both of which are implicated in negatively affecting T1DM adherence and glycemic control (Bagner et al., 2007; Bernstein et al., 2013; Johnson et al., 2013; Lawrence et al., 2005; Whittemore

et al., 2002). As such, it is extremely important to consider the impact of sleep on internalizing symptoms and neurocognitive functioning, as well as the implication for diabetes management among youth with T1DM.

Current research regarding the relationship between sleep, internalizing symptoms, neurocognitive functioning, and diabetes-related outcomes was reviewed within the context of a mediation model presented in Figure 3. In the model, aspects of sleep (i.e., sleep quality, daytime sleepiness, and total sleep time) are hypothesized to impact T1DM-related outcomes (i.e., adherence and glycemic control) through internalizing symptoms and neurocognitive functioning. Additionally, Table 1 summarizes literature regarding the associations among sleep, internalizing behaviors, neurocognitive functioning, and diabetes outcomes in youth with T1DM.

Psychological functioning. There is robust support for the relationship between impaired sleep and greater internalizing symptoms (i.e., anxiety, depression, withdrawal, somatization) in healthy adolescents (Beebe, 2011; Fallone et al., 2002). Research has demonstrated that sleep difficulties are associated with an increase in symptoms of depression and anxiety in healthy adolescents (Morrison, McGee, & Stanton, 1992; Roberts, Roberts, & Chen, 2001; Wolfson & Carskadon, 1998). Longitudinal research examining the sleep and internalizing behavior suggests sleep problems in early childhood (i.e., 3-4 years of age) predict higher levels of anxiety and depression during middle childhood and adolescence (Gregory, Eley, O'Connor, & Plomin, 2004; Gregory & O'Connor, 2002). While anxiety and depression are dimensions of internalizing difficulties, there is value in examining separate clusters of symptoms unique to each diagnostic category.

Depression. Elevated rates of depressive symptoms have been identified in studies examining sleep problems among adolescents (Morrison et al., 1992; Roberts et al., 2001). Research examining the relationship between sleep and symptoms of depression is often cross-sectional in nature (e.g., Johnson, Roth, Schultz, & Breslau, 2006; Moore et al., 2009; Pasch, Laska, Lytle, & Moe, 2010; Roberts et al., 2001; Wolfson & Carskadon, 1998), which fails to capture the causal relationship between sleep and depression; however, longitudinal research has demonstrated a bidirectional relationship between sleep and depression, such that more symptoms of depression are associated with more disrupted sleep, which in turn are associated with increased symptoms of depression (Moore & Meltzer, 2008; Moore et al., 2009).

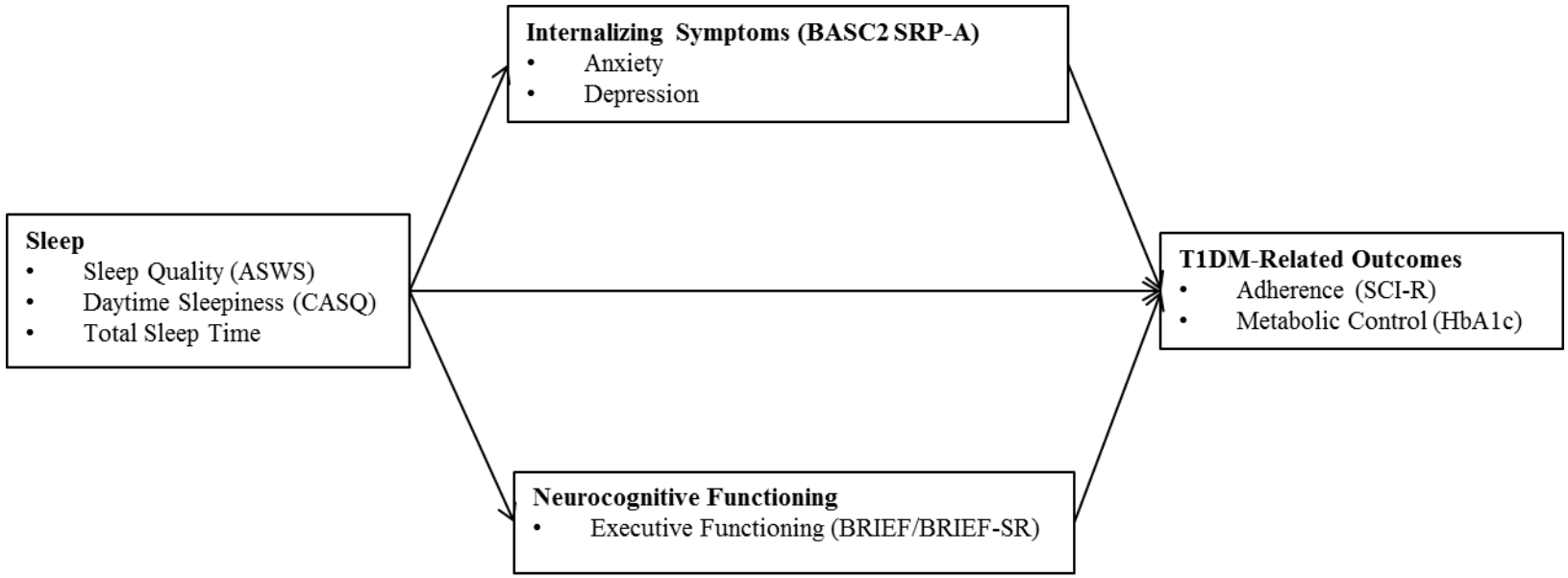

Figure 3. Proposed model examining the relationships among aspects of sleep and T1DM-related outcomes through internalizing symptoms and executive functioning

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
Adler et al., 2016	Israeli children (6-12.1 years old, *n* = 45), adolescents (12.2-17.9 years old, *n* = 45), young adults (18-30 years old, *n* = 64), each group had healthy control group with same sample size†	**Method:** Adolescent Sleep Wake Scale (going to bed, falling asleep, maintaining sleep, reinitiating sleep, wakefulness, total score), modified Epworth Sleepiness Scale, additional sleep parameters (daytime sleep duration, nocturnal sleep duration, snoring/breathing problems during sleep) **Results:** No significant difference between adolescents with T1DM and healthy controls on ASWS, adolescents with T1DM reported fewer difficulties with disorder breathing, daytime sleepiness was significantly lower among adolescents with T1DM than healthy controls	**Method:** Children's Depression Inventory **Results:** Poorer sleep quality was associated with higher levels of depression among both adolescents with T1DM and healthy controls	N/A	N/A	N/A	No association between HbA_{1c} and sleep disturbances or symptoms of depression
Blanz et al., 1993	Youth w/ T1DM (17-19 years old, *n* = 93), matched control group (*n* = 93)	**Method:** Semi structured interview, included questions on sleep disturbances **Results:** Youth with T1DM reported significantly more sleeping disturbances than healthy controls (single symptom level)	**Method:** Semi structured interview, included questions on internalizing (depression/anxiety) symptoms **Results:** Relationship between mood and sleep not reported	N/A	N/A	N/A	No association between HbA_{1c} and sleep disturbances
Caruso et al., 2014	Youth w/ T1DM (6-16 years old, *n* = 49), healthy control group (*n* = 36)	**Method:** Sleep Disturbance Scale for Children (disorders of breathing, initiating and maintaining sleep, arousal, sleep-wake transition, daytime somnolence, sleep hyperhidrosis), caregiver report	**Method:** Behavior Assessment System for Children-2 (internalizing and externalizing behaviors), caregiver report	**Method:** Behavior Rating Inventory of Executive Function (behavior regulation and meta-cognition), caregiver report	N/A	N/A	No association between HbA_{1c} and sleep

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM Continued*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
		Results: Compared to controls, youth with T1DM reported significantly greater sleep problems	**Results:** Compared to controls, youth with T1DM reported significantly greater atypicality, depression, somatization, and withdrawal; T1DM status predicted mood through sleep	**Results:** EF significantly reduced in youth with T1DM compared to controls; impaired sleep associated with increased executive dysfunction; T1DM status predicted EF through sleep			
Estrada et al., 2012	Youth w/ T1DM (5-19 years old, some adults 20+ years old *n* = 78), family relatives (*n* = 235)	**Method:** Reported previous day's sleep and wake times **Results:** No associations among T1DM status, sleep duration, and insufficient sleep	N/A	N/A	N/A	N/A	N/A
Happe et al., 2005	Youth w/ T1DM (3-18 years old, *n* = 46) siblings (4-23 years old, *n* = 50), parents (*n* = 75)	**Method:** Standardized restless leg syndrome questionnaire (3 questions); follow-up clinical evaluation with medical provider to confirm diagnosis **Results:** No significant difference in RLS symptoms and frequency of diagnosis between youth with T1DM and controls	N/A	N/A	N/A	N/A	Elevated HbA_{1c} associated with poorer sleep initiation
Hazen et al., 2015	Youth w/ T1DM (10 – 18 years old, *n* = 72) and their parents	**Method:** Child Behavior Checklist, 4 sleep disruption questions: 'overtired without reason', 'sleeps more than most kids during the day and/or night', sleeps less than most kids during the day and/or night', 'trouble sleeping' (parent-report)	**Method:** Child Behavior Checklist, Withdrawn/Depressed subscale (parent-report)	N/A	**Method:** Self-Care Inventory (adolescent-report) **Method**: Average number of blood glucose checks per day	N/A	Higher HbA_{1c} associated with sleeping more. Sleep variables together did not significantly predict HbA_{1c}
		Results: 15% reported trouble sleeping, 22% reported overtired, 29% reported slept more than most, 18% reported slept less than most	**Results:** Greater depressive symptoms associated with sleeping more, being overtired, and trouble sleeping		**Results:** Sleeping more associated with poorer adherence		

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM Continued*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
Jaser et al., 2016	Adolescents and young adults w/ T1DM (13 – 20 years old, *n* = 159)	**Method:** Pittsburgh Sleep Quality Index (sleep duration, sleep disturbances, sleep quality) **Results:** Approximately 20% reported poor or very poor sleep quality, average sleep duration was 7.4 hour	N/A	N/A	**Method:** Mean daily frequency of blood glucose testing over 30 days **Results:** Longer sleep duration associated with more frequent blood glucose checks for males only	N/A	Better sleep quality associated with lower HbA_{1c} among males, but not females
Matyka, et al., 2000	Youth w/ T1DM (5-13 years old, *n* = 29) 2 healthy controls: 1. Siblings/friends (PSG and PSG with metabolic profiling; *n* = 7) 2. Age and sex-matched (PSG only; *n* = 15)	**Method:** PSG, 3 non-consecutive nights **Location:** Participant Home **Results:** Compared to controls, youth with T1DM experienced significantly more wakefulness during sleep; nocturnal hypoglycemia not associated with alterations in sleep architecture	N/A	N/A	N/A	**Method:** Intravenous cannula on dorsum hand**;** **s**ampled every 15 minutes**;** hypoglycemia defined as <3.5 mmoL/L **Results:** Nocturnal hypoglycemia occurred more often during stage 4 sleep than REM	N/A
McDonough et al., 2017	Adolescents with T1DM (12-18 years old, *n* = 45)	**Method:** 14-night sleep diary, Sleep Disorders Scale for Children (disorders of breathing, initiating and maintaining sleep, arousal, sleep-wake transition, daytime somnolence, sleep hyperhidrosis)	N/A	N/A	**Method:** Frequency of SMBG, total daily boluses, and administration of mealtime associated boluses	N/A	Relationship between sleep and HbA_{1c} not reported

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM Continued*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
		Results: Averaged approximately 8.57 hours of sleep/night			**Results:** Mean and changes in sleep duration significantly associated with SMBG and daily insulin boluses, not mealtime bolus		
Perfect et al., 2012	Youth w/ T1DM (10-16 years old, *n* = 50); matched controls (*n* = 40)	**Method:** PSG, 3 non-consecutive nights; actigraphy, 5 nights **Location:** Participant home **Method:** School Sleep Habits Survey (sleep patterns, sleep disturbances, depressed mood, sleepiness, circadian preference)	**Method:** School Sleep Habits Survey, subscale on depressed mood	N/A	N/A	**Method:** Continuous blood glucose monitoring	Higher HbA_{1c} levels associated with increased stage 2 and decreased stage 3 sleep
		Results: Compared to controls, youth with T1DM experienced significantly more stage 2 and less stage 3 sleep	**Results:** Daytime sleepiness significantly associated depressed mood; actigraphy parameters not associated with mood			**Results:** Higher glycemic values associated less time spent in stage 3 sleep	
Perfect, 2014	Youth w/ T1DM (10-16 years old, *n* = 50)	**Method:** Sleep diary, 5 nights **Method:** Questionnaires: School Sleep Habits Survey, Sleep Self-Report (sleep environment, sleep behaviors, daytime sleepiness), Children's Sleep Habits Questionnaire-Parent Report **Results:** 30% of children experience significant sleep disturbances; adolescents generally slept more on weekends than weekdays	N/A	N/A	N/A	N/A	Higher HbA_{1c} associated with less total sleep time

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM Continued*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
Pillar et al., 2003	Youth w/ T1DM (mean age = 12.6, +/- 2.9, *n* = 15) and matched controls (age and BMI, *n* = 15)	**Method:** PSG, 1 night **Location:** Hospital	N/A	N/A	N/A	**Method:** Continuous blood glucose monitor; blood sampled every 10 seconds, recorded average blood glucose every 5 minutes; hypoglycemia defined as <2.7 mmoL/L	No association between HbA_{1c} and nocturnal hypoglycemia
		Results: Trend toward youth with T1DM with nocturnal hypoglycemia experiencing increased TST, decreased sleep latency, and increased sleep efficiency compared to controls. Youth with T1DM (non-hypoglycemic) experienced greater brief arousals, increased sleep latency and decreased sleep efficiency compared to healthy controls				**Results:** Nocturnal hypoglycemia associated with deepening of sleep; rapid glycemic change associated with greater number of awakenings	
Porter et al., 1996	Youth w/ T1DM (11-15 years old, *n* = 20)	**Method:** PSG, 1 night **Location:** Hospital	N/A	N/A	N/A	**Method:** Intravenous catheter plasma glucose; blood sampled every 30 minutes; hypoglycemia (<3.5 mmoL/L)	No significant difference in HbA_{1c} between participants who did and did not experience NH
		Results: Similar sleep and arousal indices observed in children with and without NH				**Results:** glycemic levels before sleep not predictive of nocturnal hypoglycemia	

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM Continued*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
Turner et al., 2016	High school seniors w/ T1DM (*n* = 236)	**Method:** Perceived sleep quality rated for 14 days as a part of 2-week sleep diary, calculated inconsistent sleep quality, calculated daily sleep quality deviations **Results:** Greater average sleep quality was associated with more consistent sleep quality Results from sleep diary not reported	N/A	N/A	**Method:** Daily frequency of blood glucose checks **Results:** No associations among frequency of blood checks, sleep quality, inconsistent sleep quality, and daily sleep quality deviations	**Method:** Calculated daily risk of high blood glucose **Results:** Greater average sleep quality was associated with lower risk of high blood glucose, inconsistent sleep quality was associated with increased risk of high blood glucose	N/A
Varni et al., 2009	Youth w/ T1DM (5-18 years old, *n* = 83), Parents of children (2-18 years old) with T1DM (*n* = 84) Youth with cancer (2-18 years old, *n* = 106) Parents (*n* = 181) Healthy youth (10-17 years old, *n* = 157) Parents (*n* = 157)	**Method:** PedsQL Multidimensional Fatigue Scale (general fatigue, sleep/rest fatigue, cognitive fatigue) **Results:** youth with T1DM reported significantly worse daytime fatigue than healthy controls (self-report) and comparable fatigue to controls with cancer (parent-report)	**Method:** PedsQL 4.0 Generic Core Scales (Emotional Functioning Subscale) **Results:** Greater sleep/rest fatigue associated with poorer emotional functioning	N/A	N/A	N/A	N/A

Table 1. *Overview of Research Examining Sleep, Internalizing Symptoms, Neurocognitive Functioning, and T1DM-related outcomes in Youth with T1DM Continued*

Study	Sample	Sleep	Internalizing Symptoms	Neurocognitive Functioning	Adherence	Blood Glucose	HbA_{1c}
Villa et al., 2000	Youth w/ T1DM (5-11 years old; *n* = 25), matched controls (*n* = 20)	**Method:** PSG, 1 night **Location:** sleep lab **Other:** pulmonary function using spirometry; apneic events using TCM3 **Results:** youth with T1DM experienced significantly more apneic events that lasted longer than controls	N/A	N/A	N/A	N/A	Children with T1DM, especially those with poor glycemic control experienced greater central sleep apneas, greater total apneic events, and longer duration of total apneic events; higher HbA_{1c} predicted increased frequency of total apnea and central apnea events
Yeshayahu & Mahmud, 2010	Youth w/ T1DM (12-18 years old, *n* = 75), matched controls (*n* = 54)	**Method:** Sleep timing on weekdays and weekends **Results:** Compared to controls, youth with T1DM slept longer on weekdays, but experienced less sleep increase on weekends	N/A	N/A	N/A	N/A	No associations among HbA_{1c}, average bed/wake times

Note. N/A = Not assessed; T1DM = type 1 diabetes mellitus, HbA_{1c} = hemoglobin A_{1c}, RLS = restless leg syndrome, PSG = polysomnography, REM = rapid eye movement sleep, TST = total sleep time NH = nocturnal hypoglycemia, †only methods and results for the adolescent sub-group are presented in the table

Examining the relationship between sleep and symptoms of depression within the context of diabetes is warranted as research suggests that youth with T1DM may be at increased risk for experiencing symptoms of depression (Blanz et al., 1993; Grey, Cameron, Lipman, & Thurber, 1995; Kovacs et al., 1997). For example, one study found that nearly one in seven youth (ages 10-18) with T1DM reported experiencing clinically significant symptoms of depression, which is nearly double the 12-month prevalence rate observed in youth in general (Avenevoli, Swendsen, He, Burstein, & Merikangas, 2015). Additionally, in a systematic review of research examining depression among adolescents and young adults with T1DM, Johnson and colleagues (2013) found consistent support for greater depressive symptoms being associated with higher HbA_{1c} levels, suggesting that youth with poorly controlled T1DM may be at even greater risk for difficulties associated with a depressed mood.

Several factors may contribute to the increased prevalence of depression in individuals with T1DM including adjustment to change in health status, management of complex medical regimens, fear of acute complications like hypo and hyperglycemia, and interference with one's family functioning and lifestyle (Hood et al., 2006; Kovacs et al., 1990).

Mechanisms. Given the known relationship between adherence to diabetes management tasks and metabolic control, adherence may be one possible mechanism through which depression impacts diabetes outcomes in adolescents with T1DM. Emerging evidence suggests that depressive symptoms interfere with adherence to diabetes management. For example, greater symptoms of depression have been found to be associated with less frequent blood glucose monitoring (Hood et al., 2006; McGrady, Laffel, Drotar, Repaske, & Hood, 2009), which is a vital aspect of diabetes management. Furthermore, difficulties with depression may impact illness management through increasing levels of cognitive burden, which may decrease adolescents' ability to concentrate while engaging in management activities (Grey, Whittemore, & Tamborlane, 2002; Hains, Berlin, Davies, Parton, & Alemzadeh, 2006; Herzer & Hood, 2010). Engaging in T1DM care activities requires sustained motivation, remembering to check ones' blood glucose, and accurately counting carbohydrate intake and dosing insulin. Numerous symptoms of depression such as difficulty concentrating, remembering details, decision-making, decreased motivation, and withdrawal may further exacerbate difficulties associated with non-adherence typically observed during adolescence,

resulting in even poorer adherence. Therefore, symptoms of depression may play a pivotal role in mediating the relationship between sleep and diabetes outcomes in youth with T1DM.

Anxiety. Research suggests that symptoms of anxiety negatively impact sleep; for example, greater levels of anxiety are associated with shorter sleep duration and daytime sleepiness among healthy adolescents (Moore et al., 2009; Sarchiapone et al., 2014). The directionality of the relationship between sleep and anxiety is poorly understood (Moore & Meltzer, 2008) as disrupted sleep is a symptom of anxiety and disrupted sleep appears to contribute to the impairment associated with anxiety (American Psychiatric Association, 2013). Longitudinal research suggests early childhood sleep problems predict the developmental of difficulties with anxiety during mid-childhood (Gregory et al., 2004). Examining the relationship between sleep and symptoms of anxiety within the context of diabetes is warranted as research has shown that anxiety disorders are common among adolescents with T1DM (Kovacs et al., 1997; Northam et al., 2004). For example, one study found that 36% of youth with T1DM experienced significant difficulty adjusting to their diagnosis and nearly 20% of youth met diagnostic criteria for an anxiety disorder 10 years later, most commonly generalized anxiety disorder (Kovacs et al., 1997). A recent study found that the rate of subthreshold anxiety symptoms/disorders in youth with T1DM has remained stable over time (approximately 20%; Northam et al., 2004).

Anxiety has been associated with poorer adherence and metabolic control (Bernstein et al., 2013). It has been suggested that extreme levels of anxiety (high or low) may negatively impact functioning such as memory, attention, and well-being (Deffenbacher, 1994; Hanoch & Vitouch, 2004), whereas moderate levels of anxiety may act in a protective manner to support functioning (Yerkes & Dodson, 1908). As such, there may be an identifiable level of anxiety that is “optimal” for promoting effective diabetes management. To this end, Herzer and Hood (2010) examined the relationship between anxiety and adherence to diabetes management tasks in youth with T1DM. Based on the Yerkes-Dodson model, a moderate level of anxiety should promote adherence better than both lower and higher levels of anxiety; however, Herzer and Hood (2010) found that as symptoms of anxiety increased, adherence decreased in a linear fashion. These results suggest that diabetes management may be negatively impacted by an increase in anxiety and that there may be no “optimal” level of anxiety for promoting adherence behaviors.

Alternatively, adolescents who experience high levels of anxiety may also experience co-occurring psychopathology, which may further interfere with adherence.

Mechanisms. Research has shown that worry about diabetes and negative affect negatively impact both illness management and glycemic control in youth with T1DM (Mortensen, 2002; Naar-King et al., 2006; Wiebe, Alderfer, Palmer, Lindsay, & Jarrett, 1994). Anxiety may decrease adolescents' ability to effectively manage their T1DM through its negative impact on memory, attention, and performance on tasks. Adolescents with T1DM who experience anxiety may be more likely to forget to carry out various management tasks (Herzer & Hood, 2010) and may count carbohydrates or dose insulin with less accuracy. Decreased ability to effectively engage in these and other illness management activities may subsequently negatively impact metabolic control.

Research examining internalizing symptoms and sleep in youth with T1DM. Elevated levels of internalizing symptoms are often associated with inadequate sleep in healthy youth. While research has demonstrated that youth with T1DM are at elevated risk for experiencing internalizing symptoms, a limited number of studies have considered how sleep may impact internalizing behaviors, specifically anxiety and depression, in youth with T1DM (Blanz et al., 1993; Caruso et al., 2014; Perfect et al., 2012; Varni et al., 2009). Initial research suggests that greater levels of internalizing symptoms are associated with poorer sleep outcomes, including more daytime fatigue (Blanz et al., 1993; Varni et al., 2009) and daytime sleepiness (Perfect et al., 2012). Using meditational modeling, Caruso and colleagues (2014) found that T1DM status (i.e., having a diagnosis of T1DM) predicted greater internalizing symptoms through greater difficulties with sleep among adolescents.

Additionally, emerging evidence suggests that alterations in sleep are associated with both increased internalizing symptoms and poorer diabetes outcomes. Perfect and colleagues (2012) found that youth who spent a greater proportion of time in stage 2 sleep experienced greater levels of depressed mood as well as higher average daily blood glucose values and poorer glycemic control. Notably, it is unclear how depressed mood may be associated with T1DM-related outcomes in this study; Perfect and colleagues (2012) did not report on this relationship.

Current research examining internalizing symptoms in the context of sleep and disease outcomes is limited. Although a number of studies have examined all three constructs, only one study has reported on

adolescents' sleep, internalizing symptoms, and T1DM-related outcomes (e.g., Caruso et al., 2014); however, their results should be interpreted with caution given the use of parent rather than adolescent report regarding adolescent sleep. Research suggests that poor sleep and greater levels of internalizing symptoms negatively impact adherence and metabolic control, and that poor sleep is associated with greater internalizing symptoms in healthy youth; yet research has yet to consider how sleep quality may influence diabetes-related outcomes through internalizing symptoms.

Sleep and neurocognitive functioning. Executive functioning (EF) is a broad cognitive term describing various meta-cognitive and behavioral regulation skills including problem solving, self-monitoring, working memory, initiation of behavior, emotional control, shifting cognitive set, attention, and inhibition (Donders, 2002; Gioia, Isquith, Guy, & Kenworthy, 2000). Three principal brain circuits appear to be responsible for EF including the dorsolateral prefrontal cortex, lateral orbital cortex, and anterior cingulate cortex. EF affords humans the ability to problem solve, adapt to the environment, and plan, execute, and evaluate goal-directed behavior. Executive dysfunction may result in various deficits including difficulties with the initiation and adaptation of behavior in order to meet environmental demands (Kinsella, Storey, & Crawford, 2006).

Children and adolescents with T1DM may be particularly vulnerable to neurocognitive deficits, which may be a function of disease-related processes (e.g., periodic fluctuations in blood glucose) that affect the brain's development (Desrocher & Rovet, 2004). Compared to their healthy peers, children and adolescents with T1DM have been found to experience various mild neurocognitive deficits including difficulties in executive functioning and inattention (Desrocher & Rovet 2004; Caruso et al., 2014; Gaudieri et al., 2008; Northam et al., 2006).

"Hot" versus "cold" assessment of executive functioning. Traditionally, EF has been assessed using "cold" tasks (i.e., tasks involving cognitive processes with little emotional salience and are thought to be less emotionally arousing; Chan, Shum, Toulopoulou, & Chen, 2008; Skogil, Egeland, Andersen, Hovik, & Oie, 2013). Examples of "cold" EF tasks include Stroop, Wisconsin Card Sorting Task, Trail Making Test, and verbal fluency tasks. Alternatively, cognitive processes in situations with stronger emotional salience (e.g., beliefs or desires) are often referred to as "hot" activities (Skogil et al., 2013). This may involve experiences of punishment and reward, regulation of interpersonal behavior, and decision-making

involving emotional and personal interpretation (Chan et al., 2008). An example of a "hot" EF task is the Iowa Gambling Task, in which individuals choose between decks of cards that yield either high immediate gain but larger future loss, or decks of cards that yield lower immediate gain but small future loss in order to optimize profit (Chan et al., 2008).

Hot and cold EF processes appear to activate different areas of the brain. Hot EF processes have been shown to activate areas of the brain associated with emotion regulation and reward processing (e.g., orbito-frontal cortex, ventral striatum, limbic system). Cold EF tasks appear to activate different areas of the brain, specifically the dorsolateral prefrontal cortex (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006).

Hot and cold executive functioning and T1DM management. Within the context of T1DM, effective disease management may involve both "hot" and "cold" EF abilities. Effective T1DM management may, in part, depend on adolescents' emotional regulation abilities (i.e., "hot" EF). These abilities may be important for management-related activities, such as negotiating responsibility sharing of management behaviors with the caregivers. Additionally, effective T1DM management likely depends on various "cold" EF abilities. These may include the ability to plan, organize, and initiate goal-directed behavior (e.g., counting carbohydrates, checking blood glucose, and accurately dosing insulin for the purpose of maintaining near-normal blood glucose levels), as well as to monitor progress towards reaching a goal. These management behaviors may tap into aspects of "cold" EF because they reflect more affect-neutral problem-solving behaviors. Notably, "cold" EF tasks associated with T1DM management often become "hot," as these activities occur within an emotionally-salient context (i.e., they are impacted by family dynamics and shared management negotiation).

While emerging evidence suggests that EF is associated with T1DM outcomes in children and adolescents (Bagner et al., 2007; McNally, Rohan, Pendley, Delamater, & Drotar, 2010; Miller et al., 2013), existing research has not examined the relative contributions of "hot" and "cold" EF to T1DM management. Current research examining EF in children and adolescents with T1DM has utilized the parent-report version of the Behavior Rating Inventory of Executive Functioning (BRIEF; Bagner et al., 2007; McNally et al., 2010; Miller et al., 2013). The BRIEF examines various latent aspects of adolescents' EF (e.g., planning, organization, inhibition, working memory, emotional control, etc.) using a list of

statements regarding adolescents' behaviors. Unlike performance-based neuropsychological tests, which typically assess only "cold" aspects of EF, Egeland and Fallmyr (2010) suggest that the BRIEF assesses both "hot" and "cold" aspects EF in children and adolescents. Specifically, Egeland and Fallmyr (2010) suggest that emotion regulation (i.e., emotional control and shifting) may uniquely represent "hot" aspects of EF, where as other aspects, such as behavioral regulation, may represent "cold" aspects of EF on the BRIEF. Therefore, the BRIEF may be uniquely positioned to examine both "hot" and "cold" aspects of EF simultaneously, while also providing valuable ecological insight into issues adolescents may be experiencing (Guy, Isquith, & Gioia, 2004).

To better understand the relationship between T1DM management and EF, it is important that assessment tools of EF examine both "hot" and "cold" aspects of EF processes. Assessment tools examining both aspects of EF, such as the BRIEF, may be more relevant to T1DM management than cold tasks alone, as cold tasks may be unable to capture the emotionally-laden aspect of T1DM management.

Mechanisms. Executive functioning abilities, such as problem solving, self-monitoring, and working memory, may play a key role in effective self-management in T1DM given the complexity involved in diabetes management (Bagner et al., 2007). For example, children and adolescents with executive dysfunction may have greater difficulty reflecting on and integrating previous experiences in order to improve their illness management. Additionally, management of T1DM may depend on specific EF abilities, such as creating and holding a goal in mind, creating a plan to achieve that goal, organizing and adjusting behavior in order to obtain that goal, and attending to relevant information while inhibiting non-relevant behaviors that may detract from pursuing that goal. Illness-related care activities likely depend upon these skills, such as remembering to check blood glucose regularly, adjusting insulin dosage based on blood glucose monitoring, tracking carbohydrate intake, accounting for physical activity, monitoring and addressing natural and unexpected fluctuations in blood glucose levels, and carrying and using quick acting sugar to treat low blood glucose levels. Research suggests EF skills may be particularly important for disease management and metabolic control in adolescents with T1DM. Executive dysfunction may impede the effective integration and coordination of various complex management activities, which may negatively affect adherence and metabolic control in adolescents with T1DM.

Research examining neurocognitive functioning and sleep in youth with T1DM. Emerging evidence has demonstrated that executive functioning may impact diabetes outcomes such as glycemic control through its effect on adherence to diabetes management tasks (Bagner et al., 2007; McNally et al., 2010). While executive dysfunction is associated with decreased adherence to diabetes management tasks (McNally et al., 2010) regardless of age (Bagner et al., 2007), EF abilities do not appear to be directly associated with glycemic control (McNally et al., 2010; Miller et al., 2013). Rather, McNally and colleagues (2010) demonstrated that adherence to diabetes management tasks mediates the relationship between EF and HbA_{1c} in children (ages 9 – 11) with T1DM, such that greater executive dysfunction predicted poorer adherence, which in turn predicted poorer glycemic control. Although this area of research is relatively new, initial findings lend support for the impact of EF on diabetes in outcomes in youth with T1DM and underscore the importance of EF to effective management of T1DM. Notably, published research examining EF in youth with T1DM has exclusively examined EF using the BRIEF, which is a parent-report measure assessing various domains of youths' EF based on observable behaviors. Research has yet to examine adolescents' perspectives of their own EF and how EF relates to T1DM outcomes.

Research has also shown that sleep may have undue influence on executive functioning, which may be particularly concerning for adolescents given the pervasiveness of insufficient sleep during this developmental period. In a review of correlational, case-control, quasi-experimental, and experimental studies examining cognitive, behavioral, and functional consequences of inadequate sleep in children and adolescent, Beebe (2011) concluded that difficulties with sleep are generally associated with both decreased executive functioning and increased inattention in typically developing children and adolescents. Longitudinal research suggests early- to mid-childhood sleep problems predict certain aspects of executive functioning during adolescence (Gregory, Caspi, Moffitt, & Poulton, 2009).

Although the relationship between sleep and EF is well documented, only one study has examined the relationship between sleep and EF within the context of pediatric T1DM (see Table 1; Caruso et al., 2014). Using mediational analyses, Caruso and colleagues (2014) demonstrated that youth with T1DM experienced greater deficits in meta-cognitive skills (i.e., initiation, working memory, planning/organizing, organization, and monitoring), which could be accounted for by poorer sleep in youth with T1DM. Conversely, sleep difficulties did not mediate the relationship between T1DM and behavior regulation (i.e.,

inhibition, shifting, emotional control) difficulties in youth with T1DM. Taken together, these findings suggest that poor sleep in youth with T1DM may uniquely account for meta-cognitive deficits but not behavioral regulation difficulties observed in this population. Although this study is the first study to consider the relationship between sleep and EF in the context of adolescents with T1DM, research has yet to consider how sleep may influence T1DM-related outcomes through EF in adolescents with T1DM.

Present Study

While sleep is extremely important for the development of children and adolescents, the majority of adolescents fail to sleep the recommended amount for their age. A coalescence of various biopsychosocial factors conspire to limit both the quality and quantity of sleep for many adolescents. Underlying disease processes, as well as other psychosocial and illness-related sequelae, are thought to further compound sleep difficulties among youth with chronic illness. Emerging evidence suggests that youth with T1DM experience more frequent and greater difficulties with sleep than healthy youth, which may be a function of the interaction between underlying disease processes associated with T1DM and bioregulatory mechanisms involved in sleep. Insufficient sleep appears to have various negative consequences for functioning in healthy adolescents, including increased internalizing behaviors like symptoms of depression and anxiety, as well as diminished neurocognitive functioning. Extent literature suggests early sleep problems predict increased difficulties with internalizing symptoms and executive functioning over the course of development among healthy youth (Gregory et al., 2009; Gregory et al., 2004; Gregory & O'Connor, 2002). Internalizing symptoms and neurocognitive functioning have been implicated in T1DM management and metabolic control (Bernstein et al., 2013; Hood et al., 2006; McGrady et al., 2009). Although research suggests that youth with T1DM are at increased risk for the development of internalizing symptoms and neurocognitive dysfunction, research has yet to consider how these processes may help to explain the potential relationships among sleep, illness management, and diabetes outcomes in youth with T1DM.

The current study focused on integrating our understanding of the complex relationships among sleep, internalizing symptoms, neurocognitive functioning, and T1DM-related outcomes. Upon careful review of the existing literature, there appears to be very limited research examining the relationships among adolescent-reported sleep quality (i.e., sleep quality, daytime sleepiness, and sleep quantity) and

T1DM-related outcomes (i.e., adherence and metabolic control). Furthermore, research has yet to examine internalizing symptoms (i.e., depression and anxiety) and neurocognitive functioning (i.e., executive functioning) as potential mediators of the relationship between sleep and T1DM-related outcomes. One might suppose internalizing symptoms and executive functioning influence the strength of the relationship between sleep and T1DM-related outcomes; however, based on a review of extent literature, examining internalizing symptoms and executive functioning as mediators (i.e., one that explains the relationship between variables of interest) appears to be most appropriate at this time. Therefore, sleep quality/quantity, internalizing symptoms, and neurocognitive functioning variables were examined within the context of the proposed mediation model (see Figure 3). Examination of the model enables improved understanding of the potential pathways through which aspects of sleep may be associated with treatment adherence and metabolic control in adolescents with T1DM. It is possible that adolescents' psychological and neurocognitive functioning may help to explain how aspects of sleep quality may impact T1DM-related outcomes. In the proposed model, aspects of sleep quality and sleep quantity are hypothesized to influence adherence and metabolic control through internalizing symptoms and neurocognitive functioning.

As the relationship between sleep and T1DM may be reciprocal in nature, sleep appears to be an important, clinically-relevant construct as it is a modifiable behavior that may be targeted for intervention. Additionally, given the relationship between sleep, internalizing behaviors, and neurocognitive functioning and the known impact of increased internalizing and neurocognitive deficits on illness management and outcomes, targeting sleep as a point of intervention in youth with T1DM may improve mood and neurocognitive functioning, as well as illness management and diabetes outcomes.

The present study aims to address numerous gaps in the research examining sleep in adolescents with T1DM:

1. To examine adolescents' perceptions of their sleep quality (i.e., sleep disturbances, fatigue/daytime tiredness, total sleep time).
2. To examine whether adolescents' sleep quality is related to T1DM-related outcomes (i.e., treatment adherence and metabolic control).

3. To examine the role of internalizing symptoms (i.e., symptoms of anxiety and depression) and neurocognitive functioning (i.e., executive functioning) in mediating the relationship between adolescent sleep quality and T1DM-related outcomes.

Hypotheses

1. Poorer **sleep quality** (i.e., adolescent-reported ASWS, CASQ) will be associated with poorer **treatment adherence** (i.e., caregiver- and adolescent-reported SCI-R scores).

2. Poorer **sleep quality** (i.e., adolescent-reported ASWS, CASQ) will be associated with poorer **metabolic control** (i.e., HbA_{1c} values).

3. Less **total sleep time** (i.e., adolescent-reported overall, weekday, and weekend TST on sleep diary) will be associated with poorer **treatment adherence** (i.e., caregiver- and adolescent-reported SCI-R scores).

4. Less **total sleep time** (i.e., adolescent-reported overall, weekday, and weekend TST on sleep diary) will be associated with poorer **metabolic control** (i.e., HbA_{1c} values).

5. Adolescents' **sleep quality** (i.e., adolescent-reported ASWS, CASQ) will influence **treatment adherence** (caregiver- and adolescent-reported SCI-R) because of the influence **sleep** has on adolescents' **executive functioning** (caregiver- and adolescent-reported BRIEF scores), which in turn influences **treatment adherence.**

6. Adolescents' **sleep quality** (i.e., adolescent-reported ASWS, CASQ) will influence **treatment adherence** (caregiver- and adolescent-reported SCI-R) because of the influence **sleep** has on the level of adolescents' **internalizing symptoms** (i.e., adolescent-reported BASC-2 Anxiety and Depression subscale scores), which in turn influences **treatment adherence.**

7. Adolescents' **sleep quality** (i.e., adolescent-reported ASWS, CASQ) will influence **metabolic control** (i.e., HbA_{1c}) because of the influence **sleep** has on adolescents' **executive functioning** (caregiver- and adolescent-reported BRIEF scores), which in turn influences **metabolic control.**

8. Adolescents' **sleep quality** (i.e., adolescent-reported ASWS, CASQ) will influence **metabolic control** (i.e., HbA_{1c}) because of the influence **sleep** has on the level of adolescents' **internalizing symptoms** (i.e., adolescent-reported BASC-2 Anxiety and Depression subscale scores), which in turn influences **metabolic control.**

9. Adolescents' **total sleep time** (i.e., adolescent-reported overall, weekday, and weekend TST on sleep diary) will influence **treatment adherence** (caregiver- and adolescent-reported SCI-R) because of the influence **total sleep time** has on adolescents' **executive functioning** (caregiver- and adolescent-reported BRIEF scores), which in turn influences **treatment adherence.**

10. Adolescents' **total sleep time** (i.e., adolescent-reported overall, weekday, and weekend TST on sleep diary) will influence **treatment adherence** (caregiver- and adolescent-reported SCI-R) because of the influence **total sleep time** has on the level of adolescents' **internalizing symptoms** (i.e., adolescent-reported BASC-2 Anxiety and Depression subscale scores), which in turn influences **treatment adherence.**

11. Adolescents' **total sleep time** (i.e., adolescent-reported overall, weekday, and weekend TST on sleep diary) will influence **metabolic control** (i.e., HbA_{1c}) because of the influence **total sleep time** has on adolescents' **executive functioning** (caregiver- and adolescent-reported BRIEF scores), which in turn influences **metabolic control.**

12. Adolescents' **total sleep time** (i.e., adolescent-reported overall, weekday, and weekend TST on sleep diary) will influence **metabolic control** (i.e., HbA_{1c}) because of the influence **total sleep time** has on the level of adolescents' **internalizing symptoms** (i.e., adolescent-reported BASC-2 Anxiety and Depression subscale scores), which in turn influences **metabolic control.**

Method

Participants

Eligible participants in the current study included male and female adolescents, ages 12-17 years old, and a primary caregiver/guardian. Inclusionary criteria for adolescents included1) fluency in English, 2) diagnosis of type 1 diabetes mellitus (T1DM) for at least one year prior to study participation, 3) having caregiver/guardian who is available to participate, and 4) having no reported history of intellectual disability or developmental disorder that would preclude them from reading or understanding study questionnaires. Adolescents could not be diagnosed with other chronic illnesses requiring additional treatment regimen that may alter their diabetes management. Eligibility criteria for caregivers/guardians included 1) residing in the same household as the adolescent, and 2) being fluent in English. Participants were recruited from Children's Hospital of Wisconsin (CHW) Department of Endocrinology (i.e. Diabetes Clinic).

Procedure

Eligible participants were recruited from the Diabetes Clinic at CHW. For recruitment purposes, demographic information (i.e. patient name, age, sex, medical diagnosis, address, phone number, and parent/guardian name) was obtained from clinic databases/medical records prior to obtaining informed consent. This information was gathered via a waiver of initial consent to screen records for potential participants at CHW**.** Authorized personnel, including staff members of the Diabetes Clinic and study personnel, identified potential participants who met eligibility criteria. Participants were informed of the study before or during a regularly scheduled appointment, during a Diabetes Clinic education class, or through mailings. Caregivers and adolescents were provided with a brief overview of the study and given the opportunity to complete consent procedure in the clinic or over the phone.

Participation was possible either in clinic or at home using paper-pencil questionnaires or online via Qualtrics. Caregivers and adolescents who completed questionnaires online received separate emails with instructions on how to complete questionnaires through Qualtrics. Online questionnaires were password protected. Passwords were provided in the email provided to participants completing questionnaires online. Participants were provided up to six auto emails to remind participants to complete

questionnaires through the Qualtrics system. Families were provided postage paid return envelopes to return paper-pencil questionnaires to Marquette University. Research assistants provided reminder calls for participants who chose to complete paper-pencil questionnaires. Of the complete dyads, where both caregivers and adolescents completed questionnaires, most caregivers and adolescents (64%) completed questionnaires online.

Adolescents were sent a $15 gift card to Target and a 5-night sleep diary with instructions after completing their questionnaires. Adolescents received an additional $5 gift card to Target after returning the 5-night sleep diary. Caregivers were mailed a $10 gift card to Target after completion of caregiver questionnaires.

Measures

Table 2 lists measures that were used in the present study, including assessed constructs and reporter information. Additional scale and subscale scores gathered as a part of the full protocol are not discussed here.

Demographic characteristics (caregiver and adolescent report). Caregivers and adolescents completed demographic questionnaires that included general demographic and illness-related information. Caregivers reported on their age, race/ethnicity, household composition, marital status, highest level of education obtained, occupational status, and family income. Adolescents reported on their age, race/ethnicity, grade, gender, and illness-related information (e.g., use of insulin pump and continuous blood glucose monitor).

Sleep.

Adolescent Sleep Wake Scale (ASWS; adolescent report). The ASWS is a 28-item self-report measure designed to assess overall sleep quality in adolescents ages 12-18 (LeBourgeois et al., 2005). The ASWS includes five behavioral dimensions associated with quality of sleep, including going to bed, initiating sleep, maintaining sleep, reinitiating sleep, and returning to wakefulness. The overall sleep quality score is derived from these five dimensions. Adolescents indicated how often they experienced certain sleep behaviors during the past month on a six-point Likert scale 1 (*Always*) to 6 (*Never*). Higher scores on the ASWS represent better sleep quality. The ASWS has demonstrated good internal consistency reliability

Table 2. Constructs and Measures Included in the Present Study

Construct	**Measure**	**Reporter**
Demographics	Demographic Characteristics	Caregiver, Adolescent
Sleep	Adolescent Sleep-Wake Scale	Adolescent
	Cleveland Adolescent Sleep Questionnaire	Adolescent
	Modified Consensus Sleep Diary – Core	Adolescent
Internalizing Symptoms	BASC-2 SRP-A (Anxiety and Depression subscale scores)	Adolescent
Executive Functioning	BRIEF	Caregiver
	BRIEF-SR	Adolescent
Treatment Adherence	Self-Care Inventory-Revised	Caregiver, Adolescent
Metabolic Control	Most recent HbA_{1c}	Medical Record Review

(Chronbach's alpha = 0.60 - 0.81; Essner, Noel, Myrvik, & Palermo, 2014). Internal consistency for each subscale in the present study was examined. Internal consistency ranged from .72 (initiating sleep subscale) to .79 (going to bed subscale). On the initiating sleep subscale, two poorly performing items were identified (i.e., When it's time to go to sleep… I feel sleepy and …I lie down, but then get up and come out of the bedroom) and removed from the subscale, resulting in improved internal consistency (α = .79). On the returning to wakefulness subscale, one item was identified as poorly performing (i.e., In general, I need help waking up in the morning). Internal consistency improved from .77 to .85 (Chronbach's alpha). A total of three items were removed from the questionnaire, resulting in good internal consistency (α = .89).

Cleveland Adolescent Sleep Questionnaire (CASQ; adolescent report). The CASQ is a 16-item adolescent self-report measure examining excessive daytime sleepiness in adolescents ages 11-17 (Spilsbury, Drotar, Rosen, & Redline, 2007). The overall sleepiness score is derived from four dimensions (i.e., sleep in sleep, awake in school, sleep in evening, and sleep during transport). Adolescents indicated how frequently they felt sleepy/fall asleep in various situations during the previous week using a five-point Likert-type scale: *never* (0 times per month) to *almost every day* (5 or more times per week). Higher scores on the CASQ reflect greater sleepiness. The CASQ has demonstrated good internal consistency reliability (α = 0.89) and is strongly correlated with other measures of sleepiness such as the School Sleep Habits Survey and Pediatric Daytime Sleepiness Scale among healthy adolescents and adolescents with sleep disordered breathing (Spilsbury et al., 2007). The current study found good internal consistency reliability for adolescent-reported daytime sleepiness (α = .88).

Modified Consensus Sleep Diary-Core (M-CSD-C; adolescent report). Adolescents completed a modified version of the CSD-C (Carney et al., 2012), a standardized, patient-informed sleep diary, for five days. Adolescents reported on various aspects of their sleep including time in bed, time fell asleep, nighttime awakenings, time of morning awakening, and time arising out of bed. Additionally, adolescents were asked to rate the quality of their sleep on a five-point Likert scale, ranging from 1 (*very poor*) to 5 (*very good*). Average total sleep time (TST; total time asleep) was calculated for weekday (Sunday – Thursday) and weekend (Friday – Saturday) sleep. Total sleep time was calculated by subtracting estimated amount of time to fall asleep and length of awakenings from maximum amount of possible sleep per night (i.e., time of final awakening in the morning minus time adolescent attempted to fall asleep). Although

adolescents tend to overestimate total sleep time and underestimate wake after sleep onset using sleep diaries compared to actigraphy (Honaker, 2015), sleep diaries are considered the "gold standard" for subjective sleep assessment (Carney et al., 2012). Adolescents completed analogue (i.e., paper-and-pencil) sleep diaries each morning upon awakening.

Psychological functioning.

Behavior Assessment System for Children, Second Edition, Self-Report of Personality, Adolescent (BASC-2 SRP-A; adolescent report). Adolescents completed the BASC-2 SRP-A (176 items), which is a "multimethod, multidimensional system used to evaluate the behavior and self-perception of children and young adults aged 12 through 21 years" (Reynolds & Kamphaus, 2004, p. 1). The BASC-2 assesses numerous aspects of behavior, including both adaptive and maladaptive behavior, and personality. Adolescents responded to a list of items that describe different situations, behaviors, and personality characteristics using a two-point format (adolescents indicate whether the statements are true or false about them), or a four-point Likert scale (adolescents indicate the degree to which the statements apply to them, 0 (*Never*) to 3 (*Always*); Reynolds & Kamphaus, 2004). For the purpose of this study, only adolescent reports were examined given that prior research suggests adolescents may be the most reliable reporters of their own internalizing symptoms (Angold et al., 1987).

For the purpose of this study, subscales of interest include Anxiety and Depression. Raw scores were converted to T-scores using gender and age-specific norms with higher scores representing poorer functioning. Previous literature has shown that internal consistency reliabilities for these two subscales among male and female adolescents 12 – 18 years of age were between 0.86 – 0.88. These subscales are highly correlated with other adolescent self-reports of anxiety and depression, such as the Achenbach System of Empirically Based Assessment Youth Self-Report, the Children's Depression Inventory, and the Revised Children's Manifest Anxiety Scale (Reynolds & Kamphaus, 2004). The current study found good internal consistency reliability for both adolescent-reported anxiety and depression ($\alpha = .86$).

Neurocognitive functioning.

Behavior Rating Inventory of Executive Functioning (BRIEF; caregiver report). The BRIEF (Gioia et al., 2000) is an 86-item parent-report measure assessing various domains of adolescents'

executive functioning. The measure consists of eight clinical scales assessing abilities related to flexibility in problem solving (Shift scale), setting goals and anticipation of future events (Plan/Organize scale), inhibition and impulse control (Inhibit scale), regulation of emotional responses (Emotional Control scale), initiation of behavior (Initiate scale), and assessing performance during or following a task (Monitor scale). Three indices are generated based on these scales: 1) Behavior Regulation Index (BRI; Inhibit, Shift, and Emotional Control), 2) Metacognition Index (MI; Initiate, Working Memory, Plan/Organize, Organization of Material, and Monitor scales), and 3) Global Executive Composite (GEC), which is derived from the BRI and MI scales and represents overall executive functioning (Gioia et al., 2000). Higher scores on the BRIEF represent poorer executive function.

The measure includes a list of statements that describes adolescents' behaviors. Parents indicated how frequently these behaviors are a problem for their adolescent on a three-point Likert scale (*Never, Sometimes, Often*). Research has demonstrated that the BRIEF is a reliable instrument with internal consistencies ranging from .80-.98 for parent and teacher reports (Gioia et al., 2000; McNally et al., 2010). The BRIEF has been found to be strongly correlated with other measures of behavioral and attention functioning, such as the Child Behavior Checklist, Behavior Assessment for Children, and Connors Rating Scale (Gioia et al., 2000). The current study found excellent internal consistency reliability for the Global Executive Composite ($\alpha = .98$).

Behavior Rating Inventory of Executive Functioning-Self Report (BRIEF-SR; adolescent report). The BRIEF-SR (Guy et al., 2004) is an 80-item adolescent-report measure assessing various domains of executive functioning in youth ages 11-18. The scales and indices for the BRIEF-SR are similar to those of the BRIEF. The BRIEF-SR includes a list of statements describing various behaviors with which adolescents may have difficulties. Adolescents indicated how frequently experience various difficulties on a three-point Likert scale (*Never, Sometimes, Often*). Higher scores on this measure indicate poorer executive functioning. The BRIEF-SR is considered a reliable instrument with internal consistencies ranging from .72-.96 (Guy et al., 2004), and BRIEF-SR scores are moderately to strongly associated with parent reports on the BRIEF (Walker & D'Amato, 2006). The current study found excellent internal consistency reliability for the Global Executive Composite ($\alpha = .96$).

Adherence.

Self-Care Inventory-Revised (C SCI-R and A SCI-R; caregiver and adolescent report).

Adolescents and their caregivers completed the Self-Care Inventory – Revised (Weinger et al., 2005), which is a 14-item questionnaire that measures adolescent adherence to a diabetes regimen over the previous two weeks. The SCI-R measures various aspects T1DM management, including blood glucose monitoring, insulin injections, and maintenance of prescribed diet and exercise recommendations of their physician. Participants responded to each item on a five-point Likert scale 1 (*never*) to 5 (*always*) with higher scores indicating better adherence. The SCI-R was scored by calculating the mean of all items for each participant, and, for ease of interpretation, the mean score was converted to a 0 to 100-point scale, with higher scores indicating a greater level of adherence (Weinger et al., 2005). Internal consistency ratings (Cronbach's alpha) for a sample of adults ≥18 years of age with T1DM was high ($\alpha = 0.87$). SCI-R is sensitive to differences in adherence between individuals with good versus poor metabolic control (Weinger et al., 2005). When comparing different methods of assessing adherence and glycemic control among youth with T1DM, Kichler and colleagues (2012) found that the adjusted global score on the SCI was a stronger predictor of HbA_{1c} than the 24-hour recall and blood glucose meter data. The current study demonstrated adequate internal consistency reliability for both caregiver- ($\alpha = .78$) and adolescent-reported adherence ($\alpha = .79$).

Medical Record Data

Metabolic control (HbA_{1c}). Hemoglobin A_{1C} (HbA_{1c}) measures blood glucose control during the previous two to three months. A medical record review was conducted to obtain HbA_{1c} values from the clinic visits one year prior to the day adolescents and caregivers consented to participate in the present study. Most recent HbA_{1c} values were used for this study. Higher values represent poorer metabolic control. It is recommended that adolescents maintain a value of 7.5% or less (American Diabetes Association, 2017).

Results

Data Analytic Plan

All data were screened for normality of distribution. Data were screened for patterns associated with missing data points. Data were missing at random. All composite scores across questionnaires were missing less than 25% of the data points required to calculate a given score. Therefore, missing values for each questionnaire were replaced by calculating each participant's average score for a given subscale or composite and imputing that value.

The distributions of scores were assessed for skewness and kurtosis, with transformations conducted as needed (Tabachnick & Fidell, 2007). Due to significant skew, HbA_{1c} values were transformed using log transformation. Adolescent-reported depression was highly skewed, but was not corrected for mediation analyses as the bias-corrected bootstrap approach to mediation does not make assumptions about the shape of the distribution of the indirect effect (i.e., the product of *ab* paths, see Figure 4; Hayes, 2013). Non-parametric analyses were conducted to identify potential covariates associated with adolescent-reported depression.

The impact of outliers was also assessed. Due to the differential impact of outliers on the distribution of adolescent-reported daytime sleepiness (i.e., CASQ), adolescent-reported behavioral regulation (i.e., BRIEF-SR BRI composite score), adolescent-reported depression (i.e., BASC2-SRP, Depression subscale score), adolescent-reported overall executive functioning (i.e., BRIEF-SR GEC composite score), and weekend total sleep time, five outliers, one for each measure, were truncated to 3 standard deviations from the mean of each respective samples composite score.

Multicollinearity among normally distributed independent variables (i.e., ASWS, CASQ, adolescent-reported Anxiety, and caregiver- and adolescent-reported BRIEF scores) was assessed using Pearson correlations and multicollnearity diagnostics (i.e., Tolerance and VIF). Composite scores (i.e., BRI, MI, and GEC) on caregiver- and adolescent-reported BRIEF were highly collinear (i.e., $r \geq .90$, Tolerance ≤ 0.1, and VIF ≥ 10). Therefore, only caregiver- and adolescent-reported Global Executive Composite scores were included in analyses examining adolescent neurocognitive functioning, where applicable.

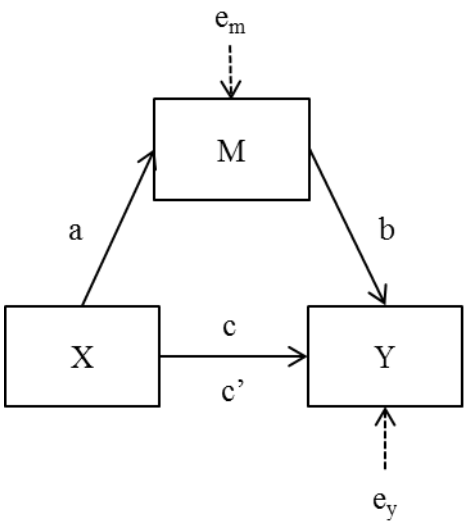

Figure 4. Conceptual model for simple mediation. X = Independent Variable, M = Mediator, Y = Dependent Variable, a path = effect of X on M, b path = effect of M on Y, while holding X constant, ab = indirect effect of X on Y through M, c' = estimates the direct effect of X on Y holding M constant, c = total effect of X on Y, in other words c' + ab.

Guidelines for required sample size for common statistical approaches to simple mediation models suggests a sample size of 80 participants provides sufficient power to detect a medium effect for *a* (*X* → *M*) and *b* (*M* → *Y*, controlling for *X*) pathways for a fully mediated model utilizing a bias-corrected bootstrap approach (Fritz & MacKinnon, 2007; see Figure 4). Biased-corrected bootstrap approach to mediation is considered the most robust approach for testing indirect effects for mediation analyses, though risk for Type I error increases with small sample sizes (Fritz & MacKinnon, 2007; MacKinnon et al., 2004). Despite these concerns, research demonstrates the bias-corrected bootstrap approach is the single best method for testing indirect effects (MacKinnon, Lockwood, & Williams, 2004) and is considered advantageous to normal theory approach as there are no assumptions regarding the shape of the sampling distribution for *ab* (Hayes, 2013).

All mediation analyses were conducted using bias-corrected bootstrap approach to simple and parallel multiple mediation (see Figure 5; Hayes, 2013). The constituent parts of a simple mediation model include estimates of the direct effect (*c'*) of a predictor variable (*X*) on an outcome variable (*Y*), holding the mediator (*M*) constant. The indirect effect of a predictor variable on an outcome variable through a mediator is the product of the *a* and *b* paths (Hayes, 2013). The PROCESS macro (version 2.16.3, 2016) for SPSS was utilized to calculate both direct and indirect effects for the mediation models. Mediation models were performed using ordinary least squares (OLS) path analysis. The PROCESS macro generates confidence intervals for each effect, where the significance of the effect is determined by the presence of zero within the confidence interval. Significance is observed when the confidence interval does not contain zero ($p < .05$; Vazsonyi et al., 2015).

There are numerous approaches for examining the indirect effect. Research has demonstrated one of the most robust approaches to estimating indirect effects is the bias-corrected bootstrap approach (Fritz & MacKinnon, 2007). The bootstrapping procedure is a part of a class of procedures that utilize resampling methods. With this approach, the original study sample size (*n*) is thought to represent the larger population from which it was drawn. Observations from the original sample are resampled with replacement a set number of times (ideally thousands of times) generating an empirically derived representation of the sampling distribution for the indirect effect. This representation is also utilized to develop confidence intervals for the indirect effect (Hayes, 2013). Based on previous research, bias-correct bootstrap

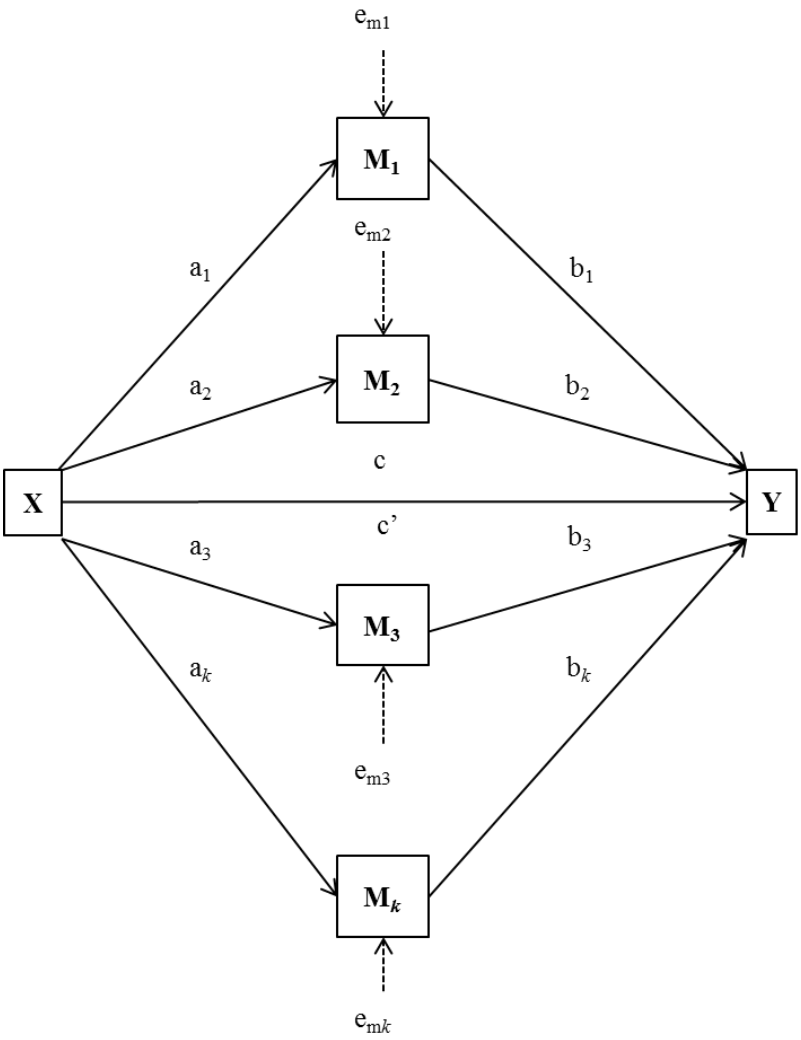

Figure 5. Conceptual model for parallel multiple mediation. X = Independent Variable, M = Mediator, Y = Dependent Variable, a path = effect of X on M, b path = effect of M on Y, while holding X constant, ab = indirect effect of X on Y through M, c' = estimates the direct effect of X on Y holding M constant, c = total effect of X on Y, in other words c' + ab.

confidence intervals are considered more accurate than the normal theory-based Sobel test because it does not make assumptions about the distribution of the sample (Fritz & MacKinnon, 2007; Hayes, 2013). The bias-corrected bootstrap approach was selected over the causal steps approach popularized by Baron and Kenny (1986) as it has been criticized for its ability to effectively detect mediation effects (Fritz & MacKinnon, 2007; Hayes, 2013; Vazsonyi et al., 2015). For the present study, all models were performed with 5,000 bootstraps, unless otherwise stated.

The impact of multivariate outliers on the bootstrapping approach to mediation analysis is largely unknown. In principle, multivariate outliers may have a substantial impact on model estimates, especially if the original sample size is very small. That is because an unusual case or two are likely to be resampled multiple times, which can distort results of analyses. However, research has yet to examine just how much outliers can impact bootstrap analyses (Hayes, 2013). For the present study, models were initially run to include multivariate outliers and compared to models with multivariate outliers removed. Multivariate outliers were identified using linear regression for predictor and mediator variables. Mahalanobis distance was determined for each combination of predictor and mediator variables and compared against the chi-square distribution. A significant cut-off point of $p < .001$ for the chi-square distribution was utilized to identify multivariate outliers (Tabachnick & Fidell, 2007). Exclusion of multivariate outliers did not significantly alter results of mediation models, therefore, only results of models including all available data, including multivariate outliers, are presented.

The present study proposed estimation of numerous simple mediation models; however, parallel multiple mediation is recommended when examining multiple mechanisms through which a given antecedent (*X*) may influence a consequent (*Y*). Parallel multiple mediation looks similar to simple mediation, except that it includes more than one mediator. While mediators are examined simultaneously, they are considered independent from one another (i.e., mediators do not causally influence one another; Hayes, 2013). When possible, parallel multiple mediator models are advantageous to simple mediation models as they are thought to increase power for tests of indirect effects and allow for comparison of indirect effect sizes of various mediators. Indirect effects of parallel multiple mediation models are interpreted in a similar fashion to simple mediation models. Similar to simple mediation models, only one indirect effect is interpreted at a time, but while holding all other mediators constant (Hayes, 2013). Simple

mediation models were performed for hypotheses examining single independent, dependent, and mediator variables.

Descriptive Analyses

One-hundred and thirty-three caregiver-adolescent dyads were recruited for the purpose of this study. Analyses were based on a sample of 81 caregiver-adolescent dyads. There were a total of five unpaired caregivers and adolescents. Adolescents who did not complete questionnaires or who were a part of an incomplete dyad (i.e., non-completers) were compared to adolescents who were part of an intact dyad (i.e., completers) on age and T1DM-related characteristics. Non-completers (M = 9.93, SD = 2.29, range = 6.50 – 15.00) had significantly poorer metabolic control than completers (M = 8.50, SD = 1.76, range 5.00 – 14.00), $t(73.49) = 3.63$, $p < .001$. Completers and non-completers did not significantly differ on age or other T1DM-related characteristics, such as length of diagnosis and age at diagnosis.

Descriptive statistics for primary caregiver demographic and household characteristics are displayed in Table 3. The majority of primary caregivers identified as biological mothers (84%). Primary caregivers ranged in age from 33 to 69 years (M = 46.22, SD = 6.29) and were primarily Caucasian (97.5%), married (88.9%), well-educated (46.9% had at least a 4-year college degree), and employed at least part-time (77.8%). More than half (59%) of the caregivers reported family earnings of at least $80,000 per year.

Descriptive statistics for adolescent participants are displayed in Table 4. Approximately half the sample consisted of male (49.4%) and female (48.1%) adolescents, with an additional two adolescents identifying as transgender or other (2.4%). Adolescents ranged in age from 12 to 17 years (M = 15.17, SD = 1.72). The majority of adolescents identified as Caucasian (95.1%). Most recent HbA_{1c} varied from 5% to 14% (M = 8.5, SD = 1.76), with higher scores representing poorer metabolic control. Nearly a third of adolescents (31%) were in good metabolic control (i.e., $HbA_{1c} < 7.5\%$). Adolescents' mean age at diagnosis was 10.56 years of age (SD = 3.38), and the mean length of diagnosis was 4.62 years (SD = 2.99). Over half of the adolescents reported dosing and administering their insulin via pump (56.8%), and nearly one-third of adolescents utilized a continuous blood glucose monitor (32.1%).

Descriptive data for aspects of sleep quality, caregiver- and adolescent-reported adherence to diabetes treatment regimen, anxiety, depression, and caregiver- and adolescent-reported executive

Table 3. Primary Caregiver Demographic and Household Characteristics (N = 81)

	n	%	Mean	SD	Range
Age (years)			46.22	6.29	33-69
Relationship to Adolescent					
Biological Mother	68	84			
Biological Father	10	12.3			
Adoptive Mother	1	1.2			
Grandmother	1	1.2			
Race/Ethnicity					
Caucasian	79	97.5			
Latino/Hispanic	1	1.2			
Asian/Pacific Islander	1	1.2			
Marital Status					
Married/Living with Partner	72	88.9			
Single/Never Married	4	4.9			
Divorced	2	2.5			
Separated	2	2.5			
Widowed	1	1.2			
Education					
Partial High School	2	2.5			
High School/GED	9	11.1			
Partial College (at least 1 year)	15	18.5			
Associates Degree	17	21.0			
≥ 4-year College Degree	38	46.9			
Occupational Status					
Employed Full Time	40	49.4			
Employed Part Time	23	28.4			
Unemployed	10	12.3			
Retired	1	1.2			
Not Working/Disabled	5	6.2			
Student	2	2.5			
Number of People in Household			4.68	1.29	2-9
Number of Siblings			2.01	1.46	0-10
Family Income					
≤ $20,000	4	4.9			
$20,000 – 49,000	7	8.6			
$50,000 – 79,000	20	24.7			
$80,000 – 109,999	16	19.8			
$110,000 – 139,999	9	11.1			
$140,000 – 169,999	10	12.3			
≥ $170,000	12	15.8			

Table 4. Adolescent Demographic Characteristics (N = 81)

	n	%	Mean	SD	Range
Age (years)			15.17	1.72	12.03-17.98
Gender					
Female	39	48.1			
Male	40	49.4			
Transgender	1	1.2			
Other	1	1.2			
Grade			9.35	1.74	6^{th}-13^{th}
Race/Ethnicity					
Caucasian	77	95.1			
Latino/Hispanic	2	2.5			
African American	1	1.2			
Biracial	1	1.2			
Diabetes Related Information					
Age at Diagnosis (years)			10.56	3.38	1.68-16.86
Length of Diagnosis (years)			4.62	2.99	1.10-13.76
Most recent HbA1C value			8.50	1.76	5.00-14.00
Adolescents who receive insulin via pump	46	56.8			
Adolescents who use continuous blood glucose monitor	26	32.1			

functioning are presented in Table 5. Approximately 9% and 24% of adolescents reported borderline to clinically significant levels of depression and anxiety, respectively. Notably, nine families were contacted because of concerns on self-report measures of symptoms of depression. Nearly 10% of adolescents and 16% of caregivers reported borderline to clinically significant concerns regarding global executive functioning.

A total of 51 adolescents completed a 5-night sleep diary. A series to t-tests, chi-squares, and Mann-Whitney U tests were conducted to examine differences in adolescents who did and did not complete sleep diaries. Adolescents who completed sleep diaries reported better adherence to diabetes management tasks than those who did not, $t(49.57) = -2.03$, $p < .05$. A chi-square test (χ^2) demonstrated a significant relationship between sleep diary completion and caregiver employment status, $\chi^2(1, N = 81) = 4.12$, $p < .05$. The odds of adolescents completing a sleep diary were 0.27 times higher if the participating caregiver was employed than if they were unemployed. Adolescents who completed sleep diaries did not significantly differ from adolescents who did not complete sleep diaries on other variables of interest.

On average, adolescents obtained approximately 8 hours and 18 minutes (*SD* = 1:09, range = 4:53 – 11:02) of sleep across five nights. There was a significant difference in the amount of sleep adolescents obtained on weekends (*M* = 8:42, *SD* = 1:31) compared to weekdays (*M* = 8:10, *SD* = 1:21), $t(44) = -2.02$, $p < .05$ (see Table 6). In the current study, 43% of 12-13 and 57% of 14-17 year olds reported obtaining the recommended amount of sleep for their age group (Overall TST). Approximately 36% of 12-13 and 43% of 14-17 year olds obtained the recommended amount of sleep for their age on weekdays. Nearly 42% of 12-13 and 70% of 14-17 year olds obtained the recommended amount of sleep for their age on weekends. The National Sleep Foundation recommends adolescents ages 12-13 obtain 9-11 hours of sleep per night and adolescents ages 14-17 obtain 8-10 hours of sleep per night (Hirshkowitz et al., 2015). Nearly 32% of all adolescents in the current study reported obtaining less than 8 hours of sleep over the course of five nights. Among participants ages 12-13, approximately 7% of adolescents reported obtaining less 8 hours of sleep on weekdays. This percentage increased to nearly 15% on weekends. Among 14-17 year olds, approximately 57% of adolescents reported obtaining less than 8 hours of sleep on weekdays. This decreased to approximately 27% on weekends (see Table 7). Bivariate correlations were performed to

Table 5. Means, Standard Deviations, and Ranges for Adolescent- and Caregiver-Report Measures (N = 81)

Variable	Mean	SD	Range
Daytime Sleepiness (CASQ)	32.82	9.79	16-66
Sleep Quality (ASWS)	4.24	0.72	2.5-5.81
Internalizing Symptoms (BASC2 SRP-A; T-scores)			
Anxiety	50.26	12.27	30-87
Depression	46.83	9.55	39-89
Executive Functioning (BRIEF; T-score)			
Behavioral Regulation Index (BRI)	53.32	11.99	37-85
Metacognition Index (MI)	51.56	10.91	37-79
Global Executive Composite (GEC)	52.86	12.01	36-84
Executive Functioning (BRIEF-SR; T-score)			
Behavioral Regulation Index (BRI)	48.88	9.84	33-82
Metacognition Index (MI)	49.93	11.09	31-83
Global Executive Composite (GEC)	49.48	10.74	30-85
Treatment Adherence (SCI-R)			
Caregiver	71.93	11.26	45.00-91.67
Adolescent	72.55	12.48	36.67-95.00

Table 6. Sleep Quantity Based on Five Night Sleep Diary (N = 51)

	Mean	SD	Range
Weekday Total Sleep Time	8:10	1:21	4:41-11:07
Weekend Total Sleep Time	8:42	1:31	5:11-14:50
Overall Total Sleep Time	8:18	1:09	4:53-11:02

Table 7. Percentage of Adolescents Obtaining Less Than 8 Hours of Sleep (N = 51)

		Age Group	
	Overall	12-13	14-17
Weekday Total Sleep Time	43.14	7.14	56.76
Weekend Total Sleep Time	23.53	14.29	27.03
Overall Total Sleep Time	31.37	0	43.24

Note. 12-13 year olds (n = 14), 14-17 year olds (n = 37)

examine the relationship between age and sleep quantity. Increasing age was associated with less sleep overall, $r = -.44$, $p < .01$ and less weekday sleep, $r = -.44$, $p < .01$ (see Table 8).

Preliminary Analyses

Preliminary analyses were conducted using parametric (i.e., t-test, Pearson correlation) and non-parametric (i.e., Spearman rho and Mann-Whitney U Test) statistical analyses to examine potential relationships among demographic characteristics (e.g. age, adolescent race/ethnicity, income), diabetes-related characteristics (e.g. most recent HbA_{1c}, treatment adherence, length of diagnosis, type of insulin administration), and study variables (e.g., sleep quality and quantity, executive functioning, anxiety, and depression) in order to identify potential covariates. There were two general demographic covariates (i.e., adolescent and caregiver age) and two diabetes-related covariate (i.e., length of diagnosis and insulin pump status) that were associated with constructs of interest.

Demographic covariates.

Age. Adolescent age was significantly associated with adolescent-reported daytime sleepiness, $r = .29$, $p < .01$, anxiety, $r = .30$ $p < .01$, executive functioning, $r = .23$, $p < .05$, and adherence, $r = -.36$, $p < .001$. Due to significant skew and kurtosis of adolescent-reported depression, Spearman rho correlations were performed to examine the relationship between symptoms of depression and variables of interest. Age was significantly associated with adolescent-reported depression, Spearman rho = .35, $p < .01$. Regarding adolescent-reported total sleep time, age was significantly associated with overall total sleep time, $r = -44$, $p < .01$, and average weekday sleep time, $r = -.44$, $p < .01$.

Caregiver age. Caregiver age was significantly associated with adolescent overall total sleep time, $r = -.34$, $p < .05$, and average weekday sleep time, $r = -.32$, $p < .05$. Caregiver age was not associated with aspects of adolescent-reported internalizing symptoms or parent- and adolescent-reported executive functioning, adherence to diabetes management tasks, or metabolic control.

Diabetes-specific covariates.

Length of diagnosis. Length of diagnosis was significantly associated with metabolic control, $r = .23$, $p < .05$, such that longer diagnosis was associated with poorer metabolic control. Length of diagnosis was also significantly associated with overall total sleep time, $r = -.31$, $p < .05$.

Table 8. Pearson Correlations of Adolescent Age and Total Sleep Time Variables (N = 51)

Variable	Age
Weekday Total Sleep Time	-.44**
Weekend Total Sleep Time	-.13
Overall Total Sleep Time	-.44**

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

Insulin pump status. Analyses revealed significant differences in adolescent-reported anxiety when comparing participants' method of insulin administration. Adolescents who reported use of an insulin pump reported greater symptoms of anxiety (M = 54.54, SD = 12.75) than adolescents who use daily insulin injections (M = 44.63, SD = 9.03), $t(78.65) = -4.10$, $p < .001$.

Correlations between adherence and metabolic control. Unlike previous research, which has generally found an association between treatment adherence and metabolic control, neither caregivers', r = -.11, *ns*, nor adolescents', r = -.18, *ns*, reports of adolescents' treatment adherence were significantly related to most recent HbA_{1c} values. There was a moderate level of agreement between caregiver and adolescent reports of adolescent treatment adherence as measured by the SCI-R, r = .62, $p < .001$.

Correlations among measures of aspects of sleep quality and quantity. Relationships among adolescent-reported sleep quality, daytime sleepiness, and total sleep time (overall, weekdays, and weekends) were examined utilizing Pearson correlations. Sleep quality was significantly associated with overall total sleep time, r = .30, $p < .05$, and weekday total sleep time, r = .34, $p < .05$. Better adolescent-reported sleep quality was associated with more overall and weekday sleep. Daytime sleepiness was negatively associated with overall total sleep time, r = -.31, $p < .05$, and weekday total sleep time, r = -.34, $p < .05$. Greater daytime sleepiness was associated with less overall and weekday total sleep time. Analyses revealed no statistically significant relationships among weekend total sleep time, sleep quality, and daytime sleepiness. The correlations for measures of sleep quality and quantity are presented in Table 9.

Hypotheses 1-4: Associations Among Adolescent-Reported Sleep Quality, Sleep Quantity, and Adolescent- and Caregiver-Reported Adherence to Diabetes Regimen and Metabolic Control

To examine associations among the first set of hypotheses, bivariate correlations were examined among adolescents' sleep quality and quantity variables, treatment adherence (as measured by caregiver and adolescent report), and metabolic control (as measured by adolescents' most recent HbA_{1c} values).

Associations among adolescent-reported sleep quality, daytime sleepiness, adherence, and metabolic control.

Sleep Quality. Bivariate associations among sleep quality variables, as measured by adolescent-reported sleep quality, daytime sleepiness, treatment adherence, and metabolic control are presented in Table 10. There were several significant associations among variables of interest. Daytime sleepiness was

Table 9. Pearson Correlations of Adolescent-Report Measures of Sleep Quality and Quantity (N = 51)

Variable	Sleep Quality (ASWS)	Daytime Sleepiness (CASQ)
Weekday Total Sleep Time	.34*	-.34*
Weekend Total Sleep Time	.05	-.05
Overall Total Sleep Time	.30*	-.31*

Note. *$p < .05$.

significantly associated with both caregiver reports, $r = -.33$, $p < .01$, one-tailed, and adolescent reports, $r = -.52$, $p < .001$, one-tailed, of adolescent treatment adherence. Specifically, greater daytime sleepiness was associated with poorer adherence to diabetes management tasks. Sleep quality was also significantly associated with both caregiver-, $r = .30$, $p < .01$, one-tailed, and adolescent- $r = .38$, $p < .001$, one-tailed, reported adolescent treatment adherence, such that poorer sleep quality was associated with poorer adolescent adherence to diabetes management tasks. Bivariate correlations revealed that there were no significant associations between metabolic control, daytime sleepiness, or sleep quality.

Sleep Quantity. Bivariate associations among sleep quantity variables, as measured by overall total sleep time, weekday total sleep time, and weekend total sleep time and treatment adherence and metabolic control are presented in Table 11. The only significant association observed among variables of interest was weekend total sleep time and caregiver-reported adolescent adherence to diabetes management tasks, $r = -.26$, $p < .05$. Greater weekend total sleep time was associated with poorer caregiver-reported adolescent treatment adherence. Metabolic control was not associated with sleep quantity.

Hypotheses 5-8: Mediation of Aspects of Sleep and T1DM-Related Outcomes by Internalizing Symptoms and Neurocognitive Functioning

Mediation analyses were used to determine if variables assessing adolescent-reported internalizing symptoms (i.e., anxiety and depression) and caregiver- and adolescent-reported neurocognitive functioning (i.e., global executive functioning) served as mediators to the relationships between adolescents' sleep quality (i.e., sleep quality and daytime sleepiness) and T1DM-related outcomes (i.e., treatment adherence and metabolic control). Several mediation models were examined to assess caregiver- and adolescent-reported measures of aforementioned constructs. Mediation models involving the prediction of metabolic control were not analyzed due to lack of significant associations among constructs of interest (i.e., adolescent-reported anxiety and depression, and caregiver- and adolescent-reported executive functioning) at the bivariate level (see Table 10).

Parallel multiple mediation of adolescent-reported sleep quality, daytime sleepiness, and treatment adherence through executive functioning, anxiety, and depression. For the present study, the first parallel multiple mediation model collapsed hypotheses 5 and 6 in order to examine if adolescent-reported executive functioning, anxiety, and depression mediated the relationship between adolescents'

Table 10. Pearson Correlations of Adolescent-Report Measures of Sleep Quality, Adherence, and Metabolic Control (N = 81)

Variable	Sleep Quality (ASWS)	Daytime Sleepiness (CASQ)
Treatment Adherence (SCI-R)		
Caregiver	.30**	-.33**
Adolescent	.38***	-.52***
HbA_{1c}	-.08	.07

Note. *$p < .05$. **$p < .01$. ***$p < .001$.

Table 11. Pearson Correlations of Sleep Quantity, Adherence, and Metabolic Control (N = 51)

Variable	Overall Total Sleep Time	Weekday Total Sleep Time	Weekend Total Sleep Time
Treatment Adherence (SCI-R)			
Caregiver	-.01	.08	-.26*
Adolescent	.12	.13	.00
HbA_{1c}	.01	.10	-.20

Note. *$p < .05$.

sleep quality, daytime sleepiness, and adolescent-reported treatment adherence. Parallel multiple mediation models were run separately for sleep quality (ASWS) and daytime sleepiness (CASQ).

Sleep quality. Sleep quality was entered as the predictor variable (*X*), adolescent-reported treatment adherence was entered as the outcome variable (*Y*), and adolescent-reported anxiety (M_1), depression (M_2), and executive functioning (M_3) were entered as mediators. Adolescents' age and insulin pump status were entered as covariates.

Results examining parallel multiple mediation demonstrated that adolescent-reported anxiety, depression, and executive functioning significantly mediated the association between sleep quality and adherence to diabetes management tasks. Results of the final model are presented in Table 12 and Figure 6.

Sleep quality had a significant indirect effect on treatment adherence through its effect on anxiety, while holding all other mediators constant. Participants who reported poorer sleep quality reported higher levels of anxiety (a = -4.63), and participants who reported higher levels of anxiety reported better adherence to diabetes management tasks (b = .39). A bias-corrected bootstrap confidence interval for the indirect effect (ab = -1.82) was entirely below zero, bootstrap 95% CI [-4.49 to -.41], indicating a significant indirect effect of sleep quality on adherence through level of anxiety.

Similarly, sleep quality was observed to indirectly influenced treatment adherence through its effects on depression, while controlling for other mediators. Adolescents who reported poorer sleep quality reported higher levels of depression (a = -4.91), and adolescents who reported higher levels of depression reported poorer adherence to diabetes management tasks (b = -.38). The bias-corrected bootstrap confidence interval for indirect effects for sleep quality and depression (ab = 1.84) was entirely above zero, bootstrap 95% CI [.24 to 3.91], indicating a significant indirect effect of sleep quality on adherence through level of depression.

Executive functioning was also found to significantly mediate the relationship between sleep quality and treatment adherence, while holding all other mediators constant. Adolescents who reported poorer sleep quality reported greater difficulties with executive functioning (a = -7.5) and adolescents who reported greater difficulties with executive functioning reported poorer adherence to diabetes management tasks (b = -.34). The bias-corrected bootstrap confidence interval for indirect effects for sleep quality and

Table 12. Regression Coefficients, Standard Errors, and Model Summary Information for the Sleep Quality Parallel Multiple Mediation Model Depicted in Figure 6

	Consequent															
	M_1 (Anxiety)				M_2 (Depression)				M_3 (GEC)				Y (Adherence)			
Antecedent		b	SE	p		b	SE	p		b	SE	p		b	SE	p
X (Sleep Quality)	a_1	-4.63	1.44	.002	a_2	-4.91	1.04	<.001	a_2	-7.50	1.47	<.001	c'	3.37	1.99	.10
M_1 (Anxiety)		-	-	-									b_1	.39	.20	.05
M_2 (Depression)		-	-	-									b_2	-.38	.19	.05
M_3 (GEC)		-	-	-									b_3	-.34	.17	.05
Constant	i_{m1}	29.16	13.97	.04	i_{m2}	44.36	9.39	<.001	i_{m3}	66.25	11.84	<.001	i_Y	.39	.20	.05
R^2		.37				.30				.31				.39		
F		19.09***				12.54***				10.39***				6.84***		

Note. Controlling for adolescent age and insulin pump status, GEC = Global Executive Composite

*p < .05. **p < .01. ***p < .001.

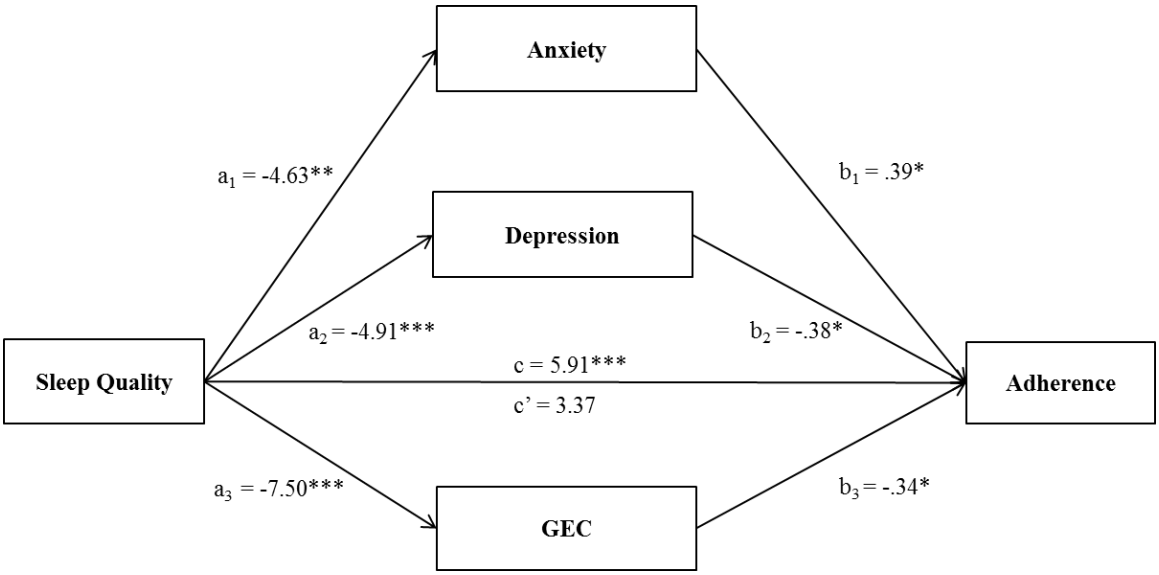

Figure 6. Parallel multiple mediation model examining the relationship between adolescent-reported sleep quality and adherence through anxiety, depression, and executive functioning (GEC)
*$p < .05$. **$p < .01$. ***$p < .001$.

executive functioning (*ab* = 2.52) was entirely above zero, bootstrap 95% CI [.12 to 4.99], indicating a significant indirect effect of sleep quality on adherence through executive functioning.

With regard to the overall parallel multiple mediation model, there was no evidence that sleep quality influenced treatment adherence independent of its effects on anxiety, depression, and executive functioning (*c'* = 3.37, *ns*).

Daytime sleepiness. A second parallel multiple mediation analysis examined the prediction of treatment adherence based on daytime sleepiness through internalizing symptoms and neurocognitive functioning. Daytime sleepiness was entered as the predictor variable (*X*), adolescent-reported treatment adherence was entered as the outcome variable (*Y*), and adolescent-reported anxiety (M_1), depression (M_2), and executive functioning (M_3) were entered as mediators. Adolescent age and insulin pump status were entered as covariates. Results of the final model are presented in Table 13 and Figure 7.

Results examining parallel multiple mediation demonstrated that only adolescent-reported anxiety significantly mediated the association between daytime sleepiness and adherence to diabetes management tasks. Daytime sleepiness had a significant indirect effect on treatment adherence through its effect on anxiety, while holding all other mediators constant. Participants who reported more daytime sleepiness reported higher levels of anxiety (*a* = .29), and participants who reported higher levels of anxiety reported better adherence to diabetes management tasks (*b* = .36). A bias-corrected bootstrap confidence interval for the indirect effect (*ab* = .10) was entirely above zero, bootstrap 95% CI [.001 to .31], indicating a significant indirect effect of sleep quality on adherence through level of anxiety.

Level of depression and executive functioning did not significantly mediate the relationship between daytime sleepiness and treatment adherence (see Table 13). With regard to the overall parallel multiple mediation model, there was evidence that daytime sleepiness influenced treatment adherence independent of its effects on anxiety, depression, and executive functioning (*c'* = -.41 $p < .01$), such that greater daytime sleepiness predicted poorer adherence to diabetes management tasks.

Simple mediation of adolescent-reported sleep quality, daytime sleepiness, caregiver-reported adolescent treatment adherence through caregiver-reported executive functioning. Two separate simple mediation models were conducted to assess if adolescents' sleep quality and daytime

Table 13. Regression Coefficients, Standard Errors, and Model Summary Information for the Daytime Sleepiness Parallel Multiple Mediation Model Depicted in Figure 7.

	Consequent															
	M_1 (Anxiety)				M_2 (Depression)				M_3 (GEC)				Y (Adherence)			
Antecedent		b	SE	*p*		b	SE	*p*		b	SE	*p*		b	SE	*p*
X (Daytime Sleepiness)	a_1	.29	.14	<.001	a_2	.42	.09	<.001	a_2	.62	.11	<.001	c'	-.41	.16	.01
M_1 (Anxiety)													b_1	.36	.21	.09
M_2 (Depression)													b_2	-.31	.18	.10
M_3 (GEC)													b_3	-.26	.17	.12
Constant	i_{m1}	1.62	10.96	.88	i_{m2}	14.60	6.99	.04	i_{m3}	20.89	9.82	.04	i_Y	122.79	10.87	.05
R^2		.35				.34				.36				.33		
F		17.07***				11.93***				14.89***				15.15***		

Note. Controlling for adolescent age and insulin pump status, GEC = Global Executive Composite

*$p < .05$. **$p < .01$. ***$p < .001$.

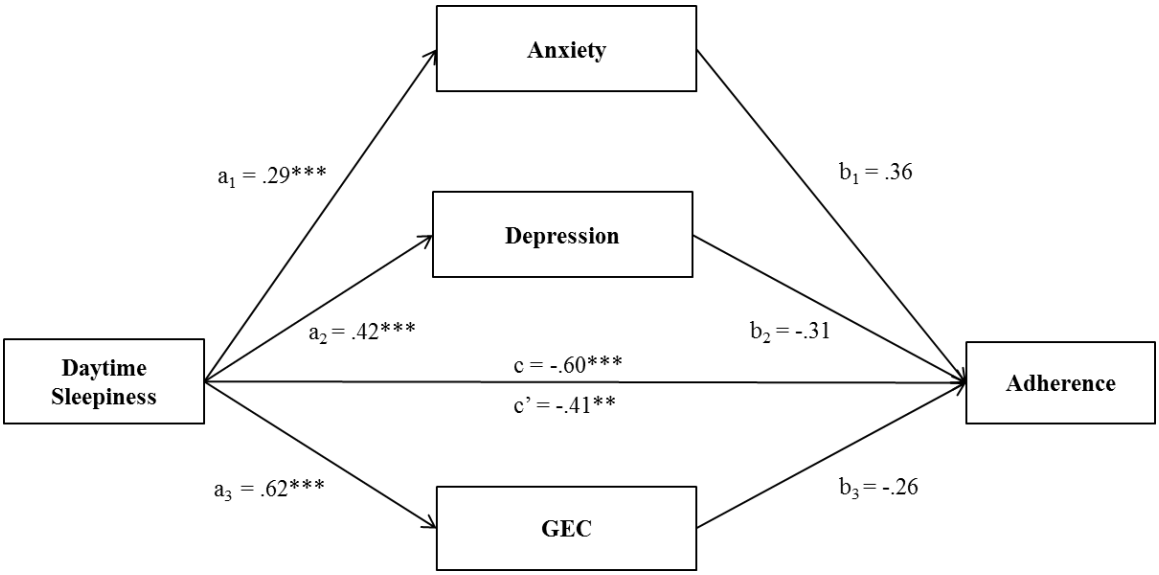

Figure 7. Parallel multiple mediation model examining the relationship between adolescent-reported daytime sleepiness and adherence through anxiety, depression, and executive functioning (GEC)
*$p < .05$. **$p < .01$. ***$p < .001$.

sleepiness predicted caregiver-reported adolescent treatment adherence through caregiver-reported executive functioning.

Sleep quality. Results of the first simple mediation model examining the relationship between adolescent-reported sleep quality and caregiver-reported treatment adherence through caregiver-reported adolescent executive functioning was significant. Sleep quality was found to indirectly predict caregiver-reported adolescent treatment adherence through caregiver-reported adolescent executive functioning. Greater adolescent-reported sleep quality predicted better executive functioning (a = -4.11) and, in turn, better executive functioning predicted better caregiver-reported adolescent adherence to diabetes management tasks (b = -.43). A bias-corrected bootstrap confidence interval for the indirect effect (ab = 1.78) was entirely above zero, bootstrap 95% CI [.34 to 3.83], indicating a significant indirect effect of sleep quality on adherence through executive functioning. Similar to the all adolescent-report model, there was no evidence that adolescent sleep quality influenced caregiver-reported adolescent adherence independent of its effect on caregiver perceptions of executive functioning (c' = 2.88, *ns*). Results of the final model are presented in Figure 8 and Table 14.

Daytime sleepiness. Results of the second simple mediation analysis demonstrated that caregiver-reported adolescent executive functioning did not mediate the relationship between adolescent-reported daytime sleepiness and caregiver perspective of adolescent adherence to diabetes management tasks (a = .19, b = -.43, ab = -.08, bootstrap 95% CI [-.24 to .02]). A direct effect for adolescent-reported daytime sleepiness on caregiver-reported adolescent treatment adherence was observed (c' = -.30, $p < .01$), such that greater daytime sleepiness predicted poorer adherence to diabetes management tasks. Results of the final model are presented in Figure 9 and Table 15.

Hypotheses 9-12: Mediation of Sleep Quantity and T1DM-Related Outcomes by Internalizing Symptoms and Neurocognitive Functioning

Although initially proposed, analyses examining if symptoms of anxiety and depression, as well as executive functioning mediated the relationship between sleep quantity and T1DM-related outcomes could not be performed due to limited sample size and power; estimations for mediation models could not be reliably interpreted.

Table 14. Simple Mediation Model for Adolescent-Reported Sleep Quality Predicting Caregiver-Reported Adherence, Through Caregiver-Reported Executive Functioning, Depicted in Figure 8.

		Consequent								
		M (GEC)					*Y* (Adherence)			
Antecedent		b	SE	*p*	95% CI		b	SE	*p*	95% CI
X (Sleep Quality)	*a*	-4.11	1.80	.02	[-7.69, -.53]	*c'*	2.88	1.80	.11	[-.70, 6.46]
M (GEC)		-	-	-	-	*b*	-.43	.08	<.001	[-.60, -.27]
Constant										
		$R^2 = .06$					$R^2 = .29$			
		$F(1, 78) = 5.23, p = .02$					$F(2, 77) = 18.80, p < .001$			

Note. GEC = Global Executive Composite

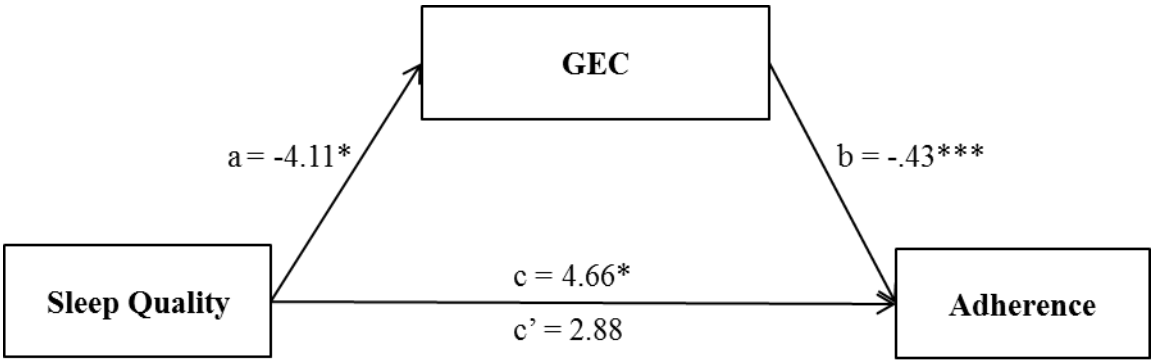

Figure 8. Simple mediation model examining the relationship between adolescent-reported sleep quality and caregiver-reported adherence through caregiver-reported executive functioning (GEC)
*$p < .05$. **$p < .01$. ***$p < .001$

Table 15. Simple Mediation Model for Adolescent-Reported Daytime Sleepiness Predicting Caregiver-Reported Adherence, Caregiver-Reported Executive Functioning, Depicted in Figure 9.

		Consequent								
		M (GEC)					*Y* (Adherence)			
Antecedent		b	SE	*p*	95% CI		b	SE	*p*	95% CI
X (Daytime Sleepiness)	*a*	.19	.16	.23	[-.13, .50]	*c'*	-.30	.11	.01	[-.52, -.08]
M (GEC)		-	-	-	-	*b*	-.43	.08	<.001	[-.59, -.27]
Constant										
		$R^2 = .02$					$R^2 = .32$			
		$F(1, 77) = 1.40, p = .24$					$F(2, 76) = 20.29, p < .001$			

Note. GEC = Global Executive Composite

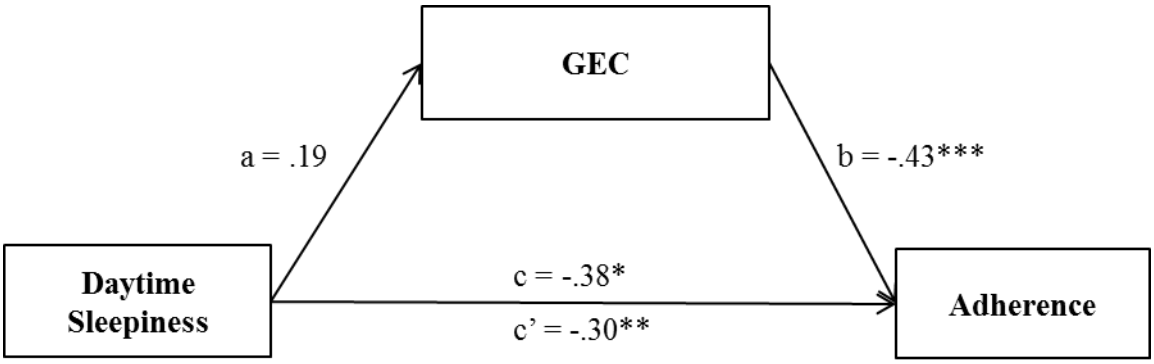

Figure 9. Simple mediation model examining the relationship between adolescent-reported daytime sleepiness and caregiver-reported adherence through caregiver-reported executive functioning (GEC) *$p < .05$. **$p < .01$. ***$p < .001$.

Exploratory Analyses

Parallel multiple mediation examining adolescent reported anxiety, depression, and treatment adherence through sleep quality and daytime sleepiness. Given the bidirectional nature of the relationship between sleep and internalizing symptoms (Moore & Meltzer, 2008; Moore et al., 2009), exploratory analyses were performed to examine alternative mediation models to determine if measures of sleep quality (i.e., sleep quality and daytime sleepiness) served as mediators to the relationship between internalizing symptoms (i.e., anxiety and depression) and adherence to diabetes management tasks. Two parallel multiple mediation models utilizing percentile bootstrap confidence intervals with 5,000 bootstraps were performed to examine measures of aforementioned constructs. Percentile bootstrap confidence intervals were utilized as bias-corrected bootstrapping resulted in unreliable estimates of indirect effects.

Anxiety. The first parallel multiple mediation analysis examined the prediction of adolescent-reported treatment adherence based on anxiety through sleep quality and daytime sleepiness. Anxiety was entered as the predictor variable (X), adolescent-reported treatment adherence (SCI-R) was entered as the outcome variable, and sleep quality (M_1) and daytime sleepiness (M_2) were entered as mediators. Adolescent age and insulin pump status were entered as covariates. Results of the final model are presented in Figure 10 and Table 16.

Analyses showed that only daytime sleepiness significantly mediated the association between anxiety and adherence to diabetes management tasks. Anxiety had a significant indirect effect on treatment adherence through its effect on daytime sleepiness, while holding sleep quality constant. Participants who reported higher levels of anxiety reported greater difficulty with daytime sleepiness (a = .23). Adolescents who reported greater daytime sleepiness in turn reported poorer adherence to diabetes management tasks (b = -.54). A percentile bootstrap confidence interval for the indirect effect (ab = -.13) was entirely below zero, bootstrap 95% CI [-.33 to -.002], indicating a significant indirect effect of anxiety on adherence through daytime sleepiness.

Sleep quality did not significantly mediate the relationship between anxiety and adherence to diabetes management tasks. With regard to the overall parallel multiple mediation model, there was no evidence that anxiety influenced treatment adherence independent of its effects of daytime sleepiness (c' = .23, p = .17).

Table 16. Regression Coefficients, Standard Errors, and Model Summary Information for the Exploratory Anxiety Parallel Multiple Mediation Model Depicted in Figure 10.

	Consequent											
	M_1 (Sleep Quality)				M_2 (Daytime Sleepiness)				Y (Adherence)			
Antecedent		b	SE	*p*		b	SE	*p*		b	SE	*p*
X (Anxiety)	a_1	-.02	.01	.01	a_2	.23	.13	.08	*c'*	.23	.17	.17
M_1 (Sleep Quality)		-	-	-		-	-	-	b_1	3.18	2.00	.12
M_2 (Daytime Sleepiness)		-	-	-		-	-	-	b_2	-.54	.19	.01
Constant	i_{m1}	5.72	.73	<.001	i_{m2}	4.30	8.34	.61	i_Y	94.70	15.03	<.001
R^2		.15				.16				.37		
F		4.38**				4.51**				8.47***		

Note. Controlling for adolescent age and insulin pump status

*$p < .05$. **$p < .01$. ***$p < .001$.

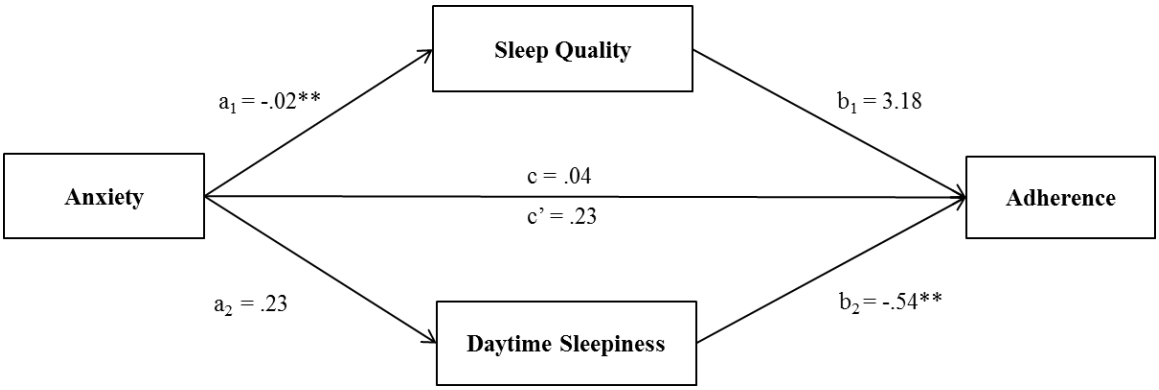

Figure 10. Parallel multiple mediation model examining the relationship between adolescent-reported anxiety and adherence through sleep quality and daytime sleepiness
*p < .05. **p < .01. ***p < .001.

Depression. A final parallel multiple mediation analysis was performed to examine whether the association between depression and adherence was mediated through sleep quality. Depression was entered as the independent variable (*X*), adolescent-reported adherence to diabetes management tasks was entered as the dependent variable (*Y*) and sleep quality (M_1) and daytime sleepiness (M_2) were entered as mediators. Age was entered as a covariate for the model. Results of the final model are presented in Figure 11 and Table 17.

Similar to the anxiety model, only daytime sleepiness significantly mediated the relationship between depression and treatment adherence. That is, depression had a significant indirect effect on adherence to diabetes management tasks through its effect on daytime sleepiness, while holding sleep quality constant. Participants who reported higher levels of depression reported greater daytime sleepiness (a = .55) and adolescents who reported greater daytime sleepiness reported poorer adherence to diabetes management tasks (b = -.43). A percentile bootstrap confidence interval for the indirect effect of anxiety through daytime sleepiness (ab = -.24) was entirely below zero, bootstrap 95% CI [-.50 to -.04]. Results suggest a significant indirect effect of depression on adherence through daytime sleepiness.

Sleep quality did not significantly mediate the relationship between depression and treatment adherence. There was no evidence that level of depression influenced treatment adherence independent of its effects of daytime sleepiness (c' = -.18, p = .18).

Table 17. Regression Coefficients, Standard Errors, and Model Summary Information for the Exploratory Depression Parallel Multiple Mediation Model Depicted in Figure 11.

	Consequent											
	M_1 (Sleep Quality)				M_2 (Daytime Sleepiness)				Y (Adherence)			
Antecedent		b	SE	*p*		b	SE	*p*		b	SE	*p*
X (Depression)	a_1	-.04	.01	.001	a_2	.55	.14	<.001	*c'*	-.18	.14	.18
M_1 (Sleep Quality)		-	-	-		-	-	-	b_1	1.63	1.89	.39
M_2 (Daytime Sleepiness)		-	-	-		-	-	-	b_2	-.43	.17	.01
Constant	i_{m1}	6.20	.71	<.001	i_{m2}	-3.20	8.27	.70	i_Y	110.93	15.52	<.001
R^2		.22				.31				.34		
F		7.65***				11.75***				11.85***		

Note. Controlling for adolescent age and insulin pump status

*$p < .05$. **$p < .01$. ***$p < .001$.

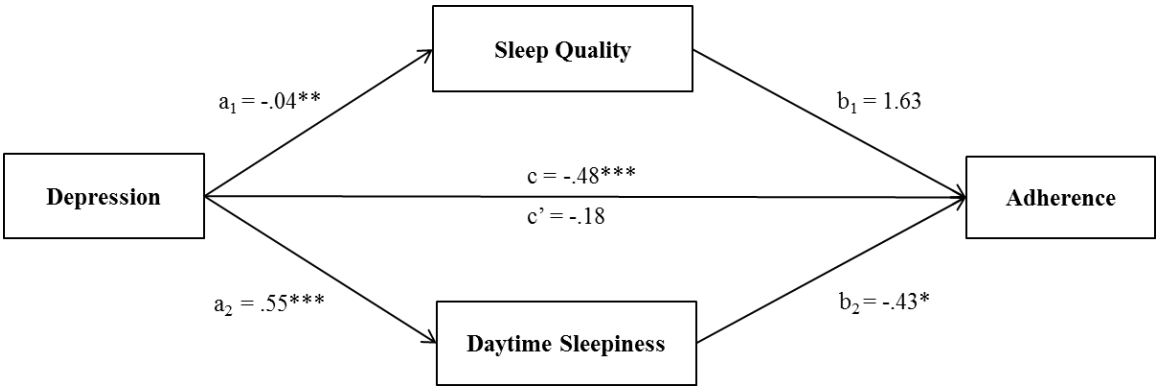

Figure 11. Parallel multiple mediation model examining the relationship between adolescent-reported depression and adherence through sleep quality and daytime sleepiness
*p < .05. **p < .01. ***p < .001.

Discussion

The current study is the first to explore adolescent-reported sleep quality and daytime sleepiness as it relates to T1DM-related outcomes (i.e., treatment adherence and metabolic control) utilizing validated and reliable self-report measures of sleep quality and adolescent-reported adherence behaviors in the same study. This study also examines relationships among adolescent-reported sleep quantity and T1DM-related outcomes of interest. Furthermore, the present study is the first to consider whether aspects of sleep quality predict T1DM-related outcomes through internalizing symptoms and neurocognitive functioning. Results partially supported our hypotheses. As predicted, poorer sleep quality and greater daytime sleepiness were associated with poorer adherence to diabetes management tasks. Although we initially hypothesized that poorer sleep quality and greater daytime sleepiness would be associated with poorer metabolic control, this hypothesis was not supported. Few associations were observed among aspects of sleep quantity (i.e., average weekday, weekend, and overall sleep across five-nights of sleep), adherence, and metabolic control. Results of mediation analyses suggest sleep quality indirectly affects treatment adherence through anxiety, depression, and executive functioning. In contrast, daytime sleepiness predicts adherence directly, as well as indirectly through anxiety. Although initially proposed, mediation models examining the prediction of metabolic control were not performed due to lack of significant associations among constructs of interest at the bivariate level. Additionally, analyses examining if anxiety, depression, and executive functioning mediated the relationship between sleep quantity and T1DM-related outcomes were not performed due to limited sample size and power. Results of exploratory mediation analyses suggests both anxiety and depression predict adherence to diabetes management tasks through daytime sleepiness and not sleep quality.

Relationships Among Aspects of Adolescents' Sleep Quality, Sleep Quantity, and Illness Management

Sleep quality, daytime sleepiness, and adherence. The first hypothesis explored associations among adolescents' sleep quality, daytime sleepiness, and treatment adherence. Sleep quality and daytime sleepiness were assessed with adolescent-report measures. Adherence was assessed using caregiver- and adolescent-report measures. Results demonstrated significant associations among adolescent-reported sleep quality, daytime sleepiness, and caregiver- and adolescent-reported adolescent treatment adherence, such

that poorer sleep quality and greater daytime sleepiness were associated with poorer caregiver- and adolescent-reported adherence to diabetes management tasks.

To our knowledge, this is the first study to assess aspects of sleep quality and adherence utilizing validated and reliable adolescent-report measures in the same study. Previous research examining the association between sleep quality and adherence has yet to utilize validated and reliable adolescent-report measures of both constructs in the same study. Previous studies examining this relationship typically focused on objective measures of adherence (i.e., frequency of blood glucose checks, frequency of insulin boluses; Jaser et al. 2016; McDonough et al., 2017; Turner et al., 2016) or assessed adolescent sleep using parent-report measures (Hazen et al., 2015). Although blood glucose monitoring is pivotal to effective diabetes management, operationalization of adherence as the frequency of blood glucose checks or insulin boluses does not provide information regarding other adherence behaviors critical to illness management (Riekert & Rand, 2002). To date, only one study has examined the relationship between sleep quality and adolescent-report adherence using a valid and reliable measure of treatment adherence (i.e., SCI-R); however, adolescent sleep quality was assessed using parent-reports on four items from the Child Behavior Checklist (i.e., Hazen et al., 2015; see Table 1). Reliance on parent reports of adolescents' sleep is problematic as caregivers are often unaware specific aspects of their child's sleep, resulting in inaccurate estimation/portrayal of sleep (Sadeh, 1996; Werner, Molinari, Guyer, & Jenni, 2008). Furthermore, parental reports fail to reflect adolescents own subjective experience of their sleep.

Sleep quality, daytime sleepiness, and metabolic control. The second hypothesis explored associations among adolescent-reported sleep quality, daytime sleepiness, and metabolic control. Sleep quality and daytime sleepiness were not significantly associated with most recent HbA_{1c} values. Previous research examining the relationship between aspects of sleep quality and metabolic control in youth with T1DM is equivocal. The inconsistent relationship between sleep quality and metabolic control is likely a function differing methodologies (e.g., operationalization and measurement approach to sleep quality, age range of sample, and parent- versus adolescent-reported parameters) across a small number of studies examining these constructs. Results of a recent systematic review and meta-analysis examining associations among sleep characteristics and glycemic control in children and adults suggests adults with T1DM experience poorer sleep quality than healthy controls, particularly when assessed by questionnaire, but not

when assessed using objective measures of sleep (i.e., PSG; Reutrakul et al., 2016). Based on analyses performed as a part of this meta-analysis, Reutrakul and colleagues (2016) found that adults with T1DM who reported good sleep quality had significantly lower HbA_{1c} scores by nearly 0.2% compared to adults who reported poor sleep quality. Similar analyses could not be performed on research examining sleep quality and metabolic control in youth with T1DM due to the limited data and number of published studies available for analysis.

Sleep quantity and adherence. The third hypothesis examined the association between adolescent-reported sleep quantity (based on a five-night sleep diary) and adherence to diabetes management tasks. Specifically, analyses examined relationships among adolescent-reported average overall, weekday, and weekend sleep time and caregiver- and adolescent-reported treatment adherence. Few associations among variables of interest were observed. The current study found that greater weekend sleep was associated with poorer caregiver-reported adolescent adherence to diabetes management regimen. Sleeping more on weekends may represent adolescents' attempt to address sleep debt accumulated throughout the week (Owens, 2014), resulting in an irregular sleep pattern known as oversleep (i.e., the difference in obtained weekday and weekend sleep; Owens, 2014). Although sleeping in on weekends provides some temporary relief from daytime sleepiness associated with insufficient weekday sleep, weekend oversleep may lead to disrupted sleep-wake cycles, exacerbation of normal circadian phase delay, and may lead to further difficulties with weekday alertness (Owens, 2014). Furthermore, there are several psychosocial consequences associated with oversleep and sleep loss that may have real-world consequences, including depressed mood (Moore et al., 2009), decreased judgement, decreased motivation, inattention, and affective dysregulation (Owens, 2014), which may negatively impact diabetes management.

Research examining the relationship between sleep duration and adherence is inconsistent. Previous research has demonstrated a negative relationship between sleeping more and poorer treatment adherence, specifically with regards to decreased frequency of blood glucose checks, implying adolescents may be asleep at times when diabetes cares are required (Hazen et al., 2015). Notably, generalizability of these findings is likely limited by sampling characteristics (i.e., adolescents specifically with poorly controlled diabetes) and reliance on secondary reports of adolescent sleep (i.e., parent reports; McDonough

et al., 2017). More recent research examining the relationship between sleep quantity and adherence has utilized adolescents' reports of their own sleep quantity using a 14-night sleep diary and found that longer sleep duration was associated with better adherence (i.e., more frequent blood glucose checks and daily insulin boluses; McDonough et al., 2017). This is inconsistent with findings of the current study, which suggest longer sleep duration, especially on weekends, is associated with poorer treatment adherence. Inconsistent findings may be associated with differing operationalization and measurement used to assess adherence, as well as length of sleep diary (i.e., five- versus 14-nights).

Sleep quantity and metabolic control. The fourth hypothesis examined the relationship between adolescent-reported sleep quantity (based on a five-night sleep diary) and metabolic control. Specifically, analyses examined relationships among adolescent-reported average overall, weekday, and weekend sleep time and most recent HbA_{1c} value. In general, estimates of sleep quantity were not significantly associated with metabolic control. Limited research has assessed the relationship between sleep duration and metabolic control among individuals with T1DM. In a study examining the impact of sleep on academic functioning in youth with T1DM, HbA_{1c} was significantly associated with adolescents' estimates of their average sleep time, such that less total sleep time was associated with poorer metabolic control (Perfect, 2014). The association between sleep duration and metabolic control in adolescents with T1DM is equivocal given the paucity of published research examining this relationship. Further, few studies have explored underlying mechanisms associated with the relationship between sleep and glycemic control (Farabi, 2016). Among healthy adults, research has shown that sleep disruption is associated with increased insulin resistance (Tasali et al., 2008). Among individuals with T1DM, Donga and colleagues (2010) found decreased insulin sensitivity after a single night of partial sleep restriction (i.e., four hours of sleep) versus a "normal" night of sleep (i.e., eight hours of sleep). Difficulties with insulin resistance may be compounded in adolescents with T1DM due to physiological changes associated with puberty (i.e., increased growth hormone resulting in increased insulin resistance). The relationship between sleep and glycemic control is further complicated by the effects of the "dawn phenomenon," which impacts approximately half of all individuals with T1DM, and may partially explain the need for increased insulin during adolescents (Carroll & Schade, 2005). Although an association between sleep duration and glycemic control was not

observed in the current study, there is emerging evidence to suggest sleep disruption, which are commonly observed during adolescents, may impact metabolic control through insulin resistance.

Mediations Models Predicting Treatment Adherence

A primary contribution of the present study has been to explore the potential influence of internalizing symptoms and neurocognitive functioning on the relationship between sleep and T1DM-related outcomes. The fifth and sixth hypotheses examined several models assessing the relationships between aspects of adolescent sleep quality and treatment adherence through symptoms of anxiety, depression, and executive functioning. Statistical analyses were performed using parallel multiple mediation for adolescent reports, which allowed for simultaneous testing of multiple mediators; thus, combining proposed analyses for the fifth and sixth hypothesis. Simple mediation analyses were performed to examine the relationship between aspects of adolescent-reported sleep quality and caregiver-reported adolescent treatment adherence through caregiver-reported adolescent executive functioning (BRIEF GEC).

Sleep quality. As predicted, mediation analyses indicated that the relationship between sleep quality and treatment adherence was influenced indirectly by internalizing symptoms and executive functioning. The simple mediation model examining caregiver-reported adolescent executive functioning and treatment adherence was consistent with results of the parallel multiple mediation model. Sleep quality did not directly predict treatment adherence after accounting for the influence of the mediators, suggesting the relationship between sleep quality and adherence to diabetes management tasks is fully mediated by symptoms of anxiety and depression and executive functioning abilities.

In the current study, results showed that poorer sleep quality predicts higher levels of anxiety, which in turn predicts better treatment adherence, suggesting that anxiety may act in a protective manner to support adherence. The direction of the relationship between sleep quality and adherence through anxiety is unexpected and inconsistent with previous research, which has shown a negative linear relationship between anxiety and frequency of blood glucose checks (i.e., as anxiety increases, blood glucose monitoring decreases; Herzer & Hood, 2010). Although Herzer and Hood (2010) suggest that there may be no “optimal” level of anxiety for promoting adherence, results of the current study indicate that increased levels of anxiety may help promote general adherence among adolescents experiencing better sleep quality.

One possible explanation for the current findings is that adolescence who experience better sleep quality, and therefore less anxiety, may be less motivated to engage in management behaviors. It also possible that adolescents who experience better sleep quality may be less vigilant to physiological symptoms associated with glycemic excursions (e.g., hyper- or hypoglycemia) and are therefore less likely to engage in management behaviors. The reverse may also be true, in which adolescents who experience poorer sleep quality may be more vigilant or sensitive to physiological cues associated with diabetes, and they are therefore more likely to engage in adherence behaviors.

Another possible explanation for the unexpected pattern of results is that the relationship between anxiety and treatment adherence may change from a linear to quadratic relationship with the addition of sleep quality. Furthermore, the observed relationship between sleep quality and adherence through anxiety may have been impacted by the relatively low (i.e., non-clinical) level of anxiety symptomatology in the current sample. Additional research examining the relationship between sleep quality and adherence among adolescents experiencing clinical levels of anxiety is needed. Finally, given the overlap between anxiety and other internalizing symptoms (e.g., depression, somatization), it is unclear to what extent results of the current study may be attributed to the shared variance associated with internalizing symptoms in general or to the unique variance associated with anxiety. Additional research is needed to better understand the unique quality of anxiety that may impact the relationship between sleep quality and adherence in adolescents with T1DM (e.g., fear of hypoglycemia, restlessness or feeling on edge).

Results also demonstrated that the relationship between sleep quality and adherence to diabetes management tasks was influenced indirectly by symptoms of depression. Poorer sleep quality predicted greater symptoms of depression, which in turn predicted poorer treatment adherence. These findings are consistent with previous research demonstrating that poorer sleep quality is associated with elevated rates of depressive symptoms (Morrison et al., 1992; Roberts et al., 2001) and that depressive symptoms are associated with poorer adherence behaviors in youth with T1DM (Hood et al., 2006). Extant literature suggests symptoms of depression may negatively impact illness management through increased cognitive burden, which may serve to diminish adolescents' ability to concentrate while engaging in management behaviors (Grey et al., 2002; Hains et al., 2006; Herzer & Hood, 2010). Numerous symptoms of depression such as difficulty concentrating, remembering details, and decision-making; decreased motivation; and

withdrawal may further exacerbate difficulties associated with non-adherence (e.g., remembering to check blood glucose levels, accurately counting carbs, engaging in regular physical activity) typically observed during adolescence, resulting in even poorer adherence. Results underscore the importance of considering the impact of sleep quality on mood, which in turn may negatively impact treatment adherence in adolescents with T1DM.

Results of analyses examining the relationship between sleep quality and caregiver- and adolescent-reported adherence through caregiver- and adolescent-reported adolescent executive functioning were consistent with the initial hypothesis. For both parallel multiple and simple mediation models, sleep quality was associated with adherence through executive functioning. Poorer sleep quality predicted greater executive dysfunction, which in turn predicted poorer adherence to diabetes management tasks. These findings are consistent with previous research examining the relationship between sleep quality and executive functioning, which showed that poorer sleep quality was associated with decreased cognitive and executive functioning in healthy adolescents (Beebe, 2011) and youth with T1DM (Caruso et al., 2014). Additionally, emerging evidence has demonstrated that greater executive dysfunction predicts poorer treatment adherence (McNally et al., 2010; Perez et al., 2017), regardless of age (Bagner et al., 2007). Research suggests executive dysfunction may negatively influence treatment adherence through decreased problem solving, self-monitoring, and working memory skills, which are critical to effective self-management in T1DM (Bagner et al., 2007). Additionally, poorer executive functioning may impact illness management through specific EF skills, such as adolescents' ability to hold a goal in mind, adjust and execute behaviors to obtain that goal, and attend to relevant information while simultaneously inhibiting non-relevant behavior that may otherwise detract from goal attainment. These skills likely underlie many critical illness-related care activities, such as remembering to check one's blood glucose regularly, adjusting insulin dosage based on blood glucose monitoring, tracking carbohydrate intake, accounting for physical activity, and monitoring and addressing natural and unexpected fluctuations in blood glucose levels. Results highlight the importance of considering the impact of sleep quality on executive functioning abilities, which in turn may negatively impact adherence to diabetes management tasks in adolescents with T1DM.

While previous research has established the relationship between the presence of T1DM and executive functioning through sleep quality in youth (ages 6-16; Caruso et al., 2014), to our knowledge, this is the first study to explore the relationship between sleep quality and adherence through executive functioning in adolescents with T1DM. While results underscore the importance of considering the influence of executive functioning on the relationship between sleep quality and adherence, additional research is needed to better understand how sleep impacts executive functioning in this population and which specific aspects executive functioning are critical to effective diabetes management.

Daytime sleepiness. Mediation analyses examining the relationship between daytime sleepiness and adherence were partially supported. Results indicated that the relationship between daytime sleepiness and treatment adherence was influenced indirectly by symptoms of anxiety and not depression or executive functioning. The simple mediation model examining caregiver-reported adolescent executive functioning and treatment adherence were consistent with results of the parallel multiple mediation model examining adolescent reports of constructs of interest. Daytime sleepiness was directly associated with caregiver- and adolescent-reported adherence after accounting for the influence of mediators in both models, suggesting the relationship between daytime sleepiness and adherence to diabetes management tasks is partially mediated by symptoms of anxiety. Similar to analyses examining the influence of anxiety on the relationship between sleep quality and adherence, results suggest that more daytime sleepiness predicts higher levels of anxiety, which in turn predicts better treatment adherence, again suggesting that anxiety may promote adherence in adolescents experiencing difficulties with daytime sleepiness.

To our knowledge, this is the first study examining the relationship between daytime sleepiness and adherence in adolescents with T1DM. Results of mediation analyses suggest daytime sleepiness may be a good predictor of adherence to diabetes management tasks, above and beyond internalizing symptoms and executive functioning in adolescents with T1DM. Daytime sleepiness may affect adherence through other facets of daytime functioning not examined in the current study, such as problem-solving, attention, and memory; however, research examining the relationship between these constructs and daytime sleepiness is limited in pediatric populations (Fallone, Owens, & Deane, 2002). Although adolescents in the current study reported similar levels of daytime sleepiness as healthy adolescents (Spilsbury et al., 2007), results underscore the significant role daytime sleepiness may play in adolescents' ability to effectively

adhere to diabetes management tasks. Given the limited research examining daytime sleepiness in adolescents with T1DM, additional research is critical better understand its effects on illness management.

Exploratory Analyses

Given the bidirectional nature of the relationship between sleep and internalizing symptoms (Moore & Meltzer, 2008; Moore et al., 2009), exploratory analyses were performed to examine alternative mediation models to determine if measures of sleep quality (i.e., sleep quality and daytime sleepiness) served as mediators to the relationship between internalizing symptoms (i.e., anxiety and depression) and adherence to diabetes management tasks (adolescent reports only). Results of exploratory mediation analyses demonstrated that symptoms of anxiety and depression are indirectly associated with treatment adherence through daytime sleepiness and not sleep quality. The mediational role of daytime sleepiness and its negative relationship with adherence may help to explain the potential adverse impact of anxiety and depression on diabetes management among adolescents with T1DM. Adolescents experiencing increased symptoms of anxiety or depression may need more sleep than individuals with better psychological functioning or require more energy to cope with everyday challenges (Moore et al., 2009), including diabetes management. It is also possible that adolescents experiencing increased levels of internalizing symptoms may have more negative perceptions of their sleepiness (Moore et al., 2009) and adherence behaviors.

Sleep Quantity in Adolescents with T1DM

In the present study, adolescents obtained an average of 8 hours and 18 minutes (i.e., 8.3 hours) of sleep over the course of five consecutive nights. Adolescents obtained significantly less sleep on weekdays (i.e., 8 hours and 10 minutes) than on weekends (i.e., 8 hours and 42 minutes). Observed sleep duration in the current study is somewhat lower than previously published research examining sleep in youth with T1DM. For example, based on four to six nights of sleep diary data, Perfect and colleagues (2014) found that average sleep duration for youth (ages 10-16) with T1DM was 8.76 hours. Similarly, based on 14 nights of sleep diary data, McDonough and colleagues (2017) found that average sleep duration was 8.57 hours among adolescents (ages 12-18) with T1DM.

Nearly 60% of 12-13 and 45% of 14-17 year olds obtained less than the recommended amount of sleep for their age (average overall TST; Hirshkowitz et al., 2015). Overall, nearly 32% of adolescents reported obtaining less than 8 hours of sleep on average across a five-night period. The percentage of adolescents who obtained less than the recommended amount of sleep increased across age groups (i.e., 12-13 and 14-17 year olds). In general, lower rates of insufficient sleep were observed among adolescents ages 12-13. The highest rates of insufficient sleep were observed among adolescents ages 14-17, in which nearly 57% of adolescents reported obtaining less than 8 hours of sleep on weekdays. The overall rate of insufficient sleep on weekends was nearly 25%, while weekdays was approximately 43%. Rates of insufficient sleep in the present study are somewhat lower than previously reported. For example, in a nationally representative sample of high school students, Eaton and colleagues (2010) found that nearly 69% of adolescents obtained less than 8 hours of sleep on school nights. This discrepancy may be associated with differences in measurement of sleep quantity used by Eaton and colleagues (2010) and the present study. Specifically, the current study assessed sleep quantity throughout the year (i.e., school year, summer break, holiday breaks) using a multi-night self-report sleep diary, whereas Eaton and colleagues (2010) quantified sleep duration by asking high school students to estimate the average amount of sleep they obtain on school nights. Response options included 4 hours or less, 5, 6, 7, 8, and 9 hours, or 10 hours or more.

Sleep duration may be overestimated in the present study. Research has demonstrated that sleep diaries may overestimate the amount of sleep adolescents obtain compared to actigraphic measures of sleep duration (Short, Gradisar, Lack, Wright, & Carskadon, 2012). Existing literature examining sleep duration in adolescents with T1DM suggests adolescents may overestimate the total amount of sleep obtained on self-report measures of sleep (e.g., sleep diaries, estimate of typical sleep duration on school and non-school nights) compared to actigraphy (Perfect et al., 2014). Despite these limitations, sleep diaries are considered the gold standard for the subjective measurement of sleep (Carney et al., 2012). Compared to PSG and actigraphy, sleep diaries are easy to use, less expensive, and readily available (Tremaine et al., 2010) to clinicians and clinical investigators, as well as the general population. Additionally, sleep diaries are simple to administer, score, and interpret. Although objective measures of sleep provide more reliable estimates of sleep duration (Buckhalt et al., 2009; Meltzer et al., 2012) than sleep diaries, interpretation of

PSG/actigraphy data in pediatric populations is limited by the lack of available age-appropriate norms (Griebel & Moyer, 2006; Meltzer et al., 2012).

Sleep Quality in Adolescents with T1DM

In the present study, adolescent-reported sleep quality appears to be consistent with previous reports of sleep quality (utilizing the ASWS) among Israeli adolescents with T1DM (Adler et al., 2016), healthy adolescents (Murray, Murphy, Palermo, & Clarke, 2012; Palermo, Fonareva, & Janosy, 2008; Palermo, Wilson, Lewandowski, Toliver-Sokol, & Murray, 2011; Walker, Johnson, Miaskowski, Lee, & Gedaly-Duff, 2010; Zafar, Ness, Dowdy, Avis, & Bashir, 2012), those undergoing treatment for cancer (Walker et al., 2010), and adolescents with multiple sclerosis (Zafar et al., 2012). Furthermore, sleep quality among adolescents with T1DM appears to be better than sleep quality among adolescents with diagnosed depressive disorders (Murray et al., 2012), as well as adolescents with chronic pain conditions (Palermo et al., 2008; Palermo et al., 2011). Similarly, adolescents in the current study reported comparable levels of daytime sleepiness as adolescents without known sleep disorders (Spilsbury et al., 2007). Poorer sleep quality and greater daytime sleepiness were associated with less overall and weekday sleep, but not weekend sleep, which is consistent with previous research examining the relationship between sleep quality and sleep duration (as measured by sleep diaries) among healthy adolescents (Short et al., 2012).

Adherence and Metabolic Control

Adolescent-reported adherence appears to be better than previously reported amongst adults with T1DM (Weinger et al., 2005). Adolescents demonstrated a broad range of metabolic control (i.e., from 5-14%), with nearly a third of the sample in "good" metabolic control (i.e., <7.5%, ADA, 2017). Caregiver- and adolescent-reported adherence to diabetes management tasks were not significantly associated with most recent HbA_{1c}. Although this is inconsistent with previous research (Weigner et al., 2005), the lack of relationship between adherence to diabetes management tasks and metabolic control may be a function of stress, metabolism (Gandhi, Vu, Eshtehardi, Wasserman, & Hilliard, 2015), and normal physiological changes associated with adolescents that are independent of adherence efforts (e.g., increased growth hormone, occurrence of the dawn phenomenon, and insulin resistance; Anderson et al., 1999; Carroll & Schade, 2005; Dabadghao et al., 2001; Moran, 2002; Wysocki et al., 2005). Furthermore, the lack of

association between HbA_{1c} and adherence in the present study may also be associated with discrepant measurement time frames as adherence was assessed over the previous 2 weeks from date of participation, whereas most recent HbA_{1c} value could have occurred up to 12 months prior to the date of participation. As such, for some adolescents, most recent adherence efforts may be discordant with previous adherence behaviors at the time of their most recent HbA_{1c} assay.

Clinical Implications

The present study findings have several potential clinical implications that may influence illness management among adolescents with T1DM. Although adolescents with T1DM appear to experience similar levels of sleep quality and daytime sleepiness as their otherwise healthy peers, the current study found that poorer sleep quality and daytime sleepiness are associated with poorer treatment adherence. Results suggest sleep quality predicts adherence through anxiety, depression, and executive functioning. Additionally, daytime sleepiness predicts treatment adherence directly and through anxiety. Further, exploratory analyses suggest anxiety and depression appear to impact treatment adherence through daytime sleepiness. Results of the current study highlight that it is important for diabetes providers to better understand how sleep may impact adolescents' ability to care for their diabetes. Providers should consider assessing sleep quality, daytime sleepiness, internalizing behaviors, and executive functioning to identify adolescents who may be at risk for poorer diabetes management and potential difficulties with glycemic control. In fact, as of 2017, the American Diabetes Association Standards of Care recommends providers assess sleep patterns and duration, as well as psychosocial functioning (e.g., symptoms of anxiety and depression) as part of comprehensive medical evaluations. It may be beneficial for clinics to consider utilizing brief assessment measures of sleep quality (e.g., ASWS or CASQ), internalizing symptoms, and executive functioning in the future. There are number of well-validated measures that can be used to assess youth's perspective regarding sleep (see Lewandowski et al., 2011), internalizing symptoms (see Klein, Dougherty, & Olino, 2010; Silverman & Ollendick, 2010), and executive functioning (e.g., BRIEF and BRIEF-SR; Gioia et al., 2000; Guy et al., 2004).

Diabetes care teams should consider providing education and counseling to adolescents regarding sleep hygiene and the importance of sleep for illness management and in general (Hazen et al., 2015; McDonough et al., 2017). Education and counseling could take place during regularly scheduled clinic

appointments and/or during period diabetes education classes. Based on emerging evidence of the relationship between sleep and diabetes management, there are new efforts to develop a clinically relevant sleep modification protocol for youth with T1DM (Perfect et al., 2016). Adolescents with T1DM experiencing sleep difficulties may benefit from support services focused on identifying and addressing barriers to sleep, as well as difficulties associated with internalizing behavior and executive functioning, which may negatively impact illness management.

Limitations and Future Directions

Several aspects of the current study may limit the generalizability of the findings. One limitation of the study was the cross-sectional design, thus only providing data regarding sleep quality, anxiety, depression, executive functioning, and diabetes management from one point in time. Results generally provide information regarding relationships among constructs of interest, rather than demonstrate causal relationships. Given the paucity of research examining sleep in adolescents with T1DM, examining relationships longitudinally and with multiple methods (i.e., subject and objective measures of sleep, psychosocial functioning, and T1DM-related outcomes) will allow for a better understanding of complex relationships among sleep, internalizing symptoms, executive functioning, and T1DM-related outcomes. Examining constructs of interest over time may also further clarify the developmental course, determinants, and impact of sleep disturbances on mental health, cognitive functioning, and illness management in this population.

Although sleep quality is an accepted clinical construct, it represents a complex and multifaceted phenomenon that is not readily defined. Previously published research examining sleep quality in adolescents T1DM varies widely in terms of the operationalization of sleep quality. The operational definition used in the present study is not necessarily equivalent to the operationalization used in previously published research examining sleep quality in youth with T1DM (e.g., Caruso et al., 2014; Hazen et al., 2015; Perfect et al., 2014; Pillar et al., 2003; Varni et al., 2009). For example, sleep quality has been operationalized as sleep disturbances (Caruso et al., 2014), alterations in sleep architecture (Pillar et al., 2003), fatigue (Varni et al., 2009), and sleep hygiene/habits (Perfect et al., 2014). Additionally, research is highly variable in terms of measurement of sleep quality, including use of objective (i.e., PSG and actigraphy) and subjective (i.e., sleep diary and self-report questionnaires) measures of sleep in adolescents

with T1DM. Given the paucity of research examining sleep in this population, additional research utilizing mixed-methods, including objective and subjective self-reports of various aspects of sleep quality and quantity, is necessary. Use of both objective and subjective sleep measures would also decrease shared variance associated with relying only on subjective self-reports of sleep quality and quantity.

To our knowledge, this is the first study to consider both caregiver- and adolescent-reported adolescent adherence to diabetes management tasks in relation to sleep in adolescents with T1DM. Given the paucity of research examining the relationship between sleep and adherence, additional research is needed to better understand the relationship between sleep and adherence. Future research should integrate additional measures of adherence, including both objective (i.e., data from CGM's and insulin pumps) and subjective measures (e.g., frequency of blood glucose checks or 24-hour recall interviews).

As previously noted, another limitation of the current study is the discordant time frames used across measures of sleep quality, internalizing symptoms, executive functioning, adherence to diabetes management tasks, and most recent HbA_{1c}. For example, the most recent HbA_{1c} value represents glycemic control from up to 12 months before date of consent. Regarding sleep, adolescents were asked to report on sleep quality during the previous four weeks and daytime sleepiness during a "usual week" (Splisbury et al., 2007). Internalizing symptoms were assessed during the "past several months" (Reynolds & Kamphaus, 2004) and difficulties with executive functioning were assessed during the previous 6 months (Gioia et al., 2000). As such, the measurement time frame for constructs of interest may have limited to no overlap, which may have impacted results. The use of measures with similar timeframes may elucidate relationships among aspects of sleep quality, internalizing symptoms, neurocognitive functioning, and illness management in future research.

Generalizability of the present study may be limited due to issues associated with relative homogeneity of the sample (i.e., Caucasian, highly educated parents). Adolescents who consented but did not complete questionnaires had poorer metabolic control compared to adolescents who completed questionnaires. Therefore, the generalizability of the current findings to populations with greater diversity and poorer metabolic control may be limited. Future research should examine the relationships among variables of interest in more diverse samples with greater variability in racial, ethnic, and socioeconomic characteristics. Further, utilization of an age-matched control group without chronic illness would allow for

direct comparison of sleep parameters, internalizing symptoms, and executive functioning and help to highlight potential characteristics unique to adolescents with T1DM that may impact illness management.

Finally, several initially proposed analyses could not be performed. Analyses examining the relationship between aspects of adolescent sleep quality and metabolic control through anxiety, depression, and executive functioning were not performed due to limited bivariate correlations among variables of interest. Additionally, analyses examining the relationship between sleep quantity and T1DM-related outcomes through anxiety, depression, and executive functioning could not be performed due to limited sample size and power. Future research is needed to further clarify the complex relationships among sleep quality, quantity, and T1DM-related outcomes of interest through internalizing symptoms and executive functioning.

Conclusion

The current study provides new insights into the relationships among adolescent sleep quality, daytime sleepiness, and disease management among adolescents with T1DM. Observed sleep quality and daytime sleepiness in the current sample are similar to the levels previously reported among healthy adolescents and are better than previously reported by adolescents with chronic pain conditions and depressive conditions. Poorer sleep quality, greater daytime sleepiness, and longer weekend sleep duration were found to be associated with poorer adherence to diabetes management tasks, but not metabolic control. Sleep quality was associated with illness management through anxiety, depression, and executive functioning. Additionally, daytime sleepiness was found to be associated with adherence through anxiety and has a direct effect on adherence independent of anxiety, depression, and executive functioning. Difficulties with anxiety and depression were found to be associated with adherence through daytime sleepiness, but not sleep quality. Given the paucity of research examining sleep in youth with T1DM, additional research is needed to better understand the interaction between T1DM disease processes and the bioregulatory mechanisms involved in sleep. Furthermore, additional research is needed to elucidate the relationship between sleep and illness management and outcomes among youth with T1DM. Results underscore the importance of considering the role of sleep quality and quantity in adolescent's adherence behaviors.

FOOTNOTES

[1] The term “youth” or “youths” is used to represent both children and adolescents as a group.

[2] Stage 2 sleep, constitutes approximately 50% of sleep, considered less restorative than stages 3 and 4.

[3] Stage 3 sleep, deep restorative sleep, typically comprises 15-20% of sleep in combination with stage 4 sleep.

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