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Caffeine Use and Associations with Sleep in Adolescents with and without ADHD

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Abstract

Objective
The objective of this study was to compare caffeine consumption in the morning, afternoon, and evening in adolescents with and without ADHD and examine associations with sleep functioning.

Methods
Participants were 302 adolescents (ages 12-14) with (*n*=140) and without (*n*=162) ADHD. Adolescents wore actigraph watches to assess total sleep time and wake after sleep onset and reported on sleep-wake problems and the number of caffeinated beverages consumed per day in the morning, afternoon, and evening. Parents reported on adolescents' difficulties initiating and maintaining sleep. Chi-square analyses, odds ratios, and path analyses were conducted.

Results
Analyses controlled for sex, medication status, and pubertal development. Adolescents with ADHD were 2.47 times more likely to consume caffeine in the afternoon and evening than adolescents without ADHD. Path analyses indicated significant associations between afternoon caffeine use and more self-reported sleep problems for adolescents with and without ADHD, and an association between evening caffeine use and self-reported sleep problems only in adolescents with ADHD. Afternoon caffeine use was associated with parent-reported sleep problems in adolescents with ADHD but not in adolescents without ADHD. Caffeine use was not associated with actigraphy-assessed sleep.

Conclusions
This is the first study to show that adolescents with ADHD consume more caffeine than peers during later times of the day. Additionally, caffeine use is more consistently associated with poorer subjective sleep functioning in adolescents with ADHD compared to adolescents without ADHD. Pediatricians and mental health professionals should assess for caffeine use in adolescents with ADHD and co-occurring sleep problems.

Key words: caffeine; attention-deficit/hyperactivity disorder; sleep; adolescents

Introduction

Caffeine use is highly prevalent during adolescence (Temple, 2019). Caffeine intake is often initiated during childhood in low doses through soda and tea, but increases during adolescence with more caffeinated soda consumption in addition to coffee and energy drinks (Ahluwalia & Herrick, 2015). Experimental research examining the impact of caffeine use in adolescents has found some evidence supporting positive effects of caffeine usage (Heatherley, Hancock, & Rogers, 2006), however there may also be negative consequences associated with caffeine use, such as disrupted sleep (Temple, 2009).

Caffeine Use and Sleep

Adolescents with high levels of caffeine consumption report increased difficulty sleeping and more disturbed sleep compared to adolescents with lower levels of caffeine consumption. For example, Pollak and Bright (2003) surveyed the caffeine consumption patterns of adolescents ages 12-15 years old and found that higher caffeine use was associated with decreased sleep duration and increased interruptions in sleep and daytime sleepiness. Similarly, Orbeta and colleagues (2006) examined sleep functioning in high versus low caffeine consumers ages 11-17 years old. They found that high consumers were almost 2 times more likely to report difficulties sleeping and feeling tired in the morning than those classified as low consumers (Orbeta et al., 2006).

There is also evidence to suggest that the time of day caffeine is consumed plays an important role in determining whether there is a negative impact on sleep functioning (Drake et al., 2013). Research in adults has found that caffeine consumed later in the day, particularly around bedtime, is associated with increased sleep onset latency, decreased sleep efficiency, and decreased total sleep time (Drapeau et al., 2006). Adolescents are more likely than adults to consume caffeine throughout the day, compared to adults who are more likely to consume caffeine simply in the morning (Martyn et al., 2018), making it especially important to understand the link between caffeine use and sleep among adolescents. However, despite studies showing an association between greater caffeine use and poorer sleep among adolescents, most studies have examined general caffeine consumption and have not looked at specific time-of-day differences that may be important when evaluating whether, and to what extent, caffeine use is associated with poorer sleep. A study by Galland and colleagues (2017) found caffeine consumption after dinner to be associated with adolescents reporting increased daytime dysfunction on the Pittsburgh Sleep Quality Index. However, the authors did not assess caffeine use throughout the day and therefore were unable to examine differential associations with various aspects of sleep quality (Galland et al., 2017).

ADHD, Sleep, and Caffeine Use

In considering caffeine use and sleep problems in adolescents, a population that may be particularly at risk is adolescents with Attention-Deficit/Hyperactivity Disorder (ADHD). ADHD is a neurodevelopmental disorder characterized by developmentally inappropriate levels of inattentiveness and/or hyperactivity-impulsivity (American Psychiatric Association, 2013). Behavioral sleep disturbances in youth with ADHD are well-documented (Cortese, Faraone, Konofal, & Lecendreux, 2009). Becker, Langberg, Eadeh, Isaacson, and Bourchtein (2019) compared the sleep patterns of 162 adolescents comprehensively diagnosed with ADHD with 140 comparison adolescents (ages 12 – 14 years old). They found that those with ADHD experienced shorter school night sleep duration assessed via both sleep diary and actigraphy (Becker et al., 2019). Additionally, adolescents with ADHD had significantly higher rates of adolescent- and parent-reported daytime sleepiness and parent-reported difficulties initiating and maintaining sleep, and total sleep disturbance (Becker et al., 2019).

Typically developing adolescents are already at risk for poor sleep functioning due to a variety of biological, social, and contextual factors that emerge during adolescence (Becker, Langberg, & Byars, 2015). Many factors are compounded in adolescents with ADHD, who tend to experience difficulties in domains that may lead to later bedtimes and sleep disturbance. For example, adolescents with ADHD experience higher rates of homework problems (Coghill et al., 2008) and increased technology use (Bourchtein et al., 2019). Adolescents with ADHD may use caffeine as a way to "self-medicate" when their ADHD medications wear off in the afternoon and evening hours. Understanding how caffeine use may impact sleep functioning in this population is crucial as there are clear associations between sleep problems and negative outcomes in adolescents with ADHD, such as poorer school performance (Langberg et al., 2013) and mental health symptoms (Becker, Langberg, & Evans, 2015).

Despite the fact that ADHD is characterized by attention problems and sleep disturbance, there has been minimal research on caffeine use and ADHD and this has therefore been identified as a research priority (Mulraney, Sciberras, & Becker, 2020). In particular, very little research has examined naturalistic behaviors, habits, or consequences of caffeine use in adolescents with ADHD (i.e., outside of the context of a treatment study). Only one study (Walker et al., 2010) has examined caffeine use behaviors in adolescents with ADHD, finding that adolescents with ADHD were almost two times more likely to consume high levels of caffeine in comparison to adolescents without ADHD. However, this study did not evaluate the association between caffeine use and sleep outcomes and did not assess for time of day when caffeine was consumed. Whether caffeine use is associated with sleep problems in adolescents with ADHD has yet to be examined. It is critical for pediatricians and mental health professionals to understand the extent to which caffeine use is a risk factor for sleep problems in this population. Unlike many risk factors for poor sleep (e.g., health conditions, early school start times), caffeine use may be feasible to address quickly through psychoeducation.

Present Study

As summarized above, adolescents with ADHD are at increased risk for behavioral sleep problems and there is some evidence indicating these individuals are more likely to use caffeine. However, there is little information about the nature of caffeine use in adolescents with ADHD and how it compares to adolescents without ADHD. Additionally, whether caffeine use is uniquely associated with sleep problems in adolescents with ADHD is unknown. Caffeine use is oftentimes associated with sleep onset disruptions and decreased sleep quality (Temple et al., 2017). Specifically, the presence of caffeine in the body may inhibit sleep onset, contribute to increased sleep problems throughout the night, and subsequently lead to more sleepiness during the day. These difficulties may also result in a lower total sleep time and increased wake after sleep onset (WASO; Clark & Landolt, 2017; Drake et al., 2013). Accordingly, the present study used a multimethod, multi-rater approach to assessing sleep, including adolescent-report, parent-report, and actigraphy. Specifically, sleep problems were assessed through adolescent-report of sleep-wake problems, parent-report of initiating and maintaining sleep difficulties, and actigraphy-derived total sleep time and WASO.

The first aim of this study was to build upon previous research examining caffeine use behaviors in adolescents with and without ADHD. Differences in caffeine consumption at various times of the day (morning, afternoon, and evening) were evaluated. Medication status was included as a covariate in all models. Sex and pubertal development were also included as covariates in order to account for developmental differences in caffeine metabolism and gender differences in subjective and physiological responses to caffeine (Temple & Ziegler, 2011). Given previous research by Walker and colleagues (2010), it was hypothesized that adolescents with ADHD in this sample would be more likely to consume caffeine at all times of the day.

The second aim of the study was to assess whether caffeine use is uniquely associated with sleep functioning in adolescents with ADHD compared to adolescents without ADHD. Given the focus on sleep problems, analyses examined afternoon and evening caffeine use, when caffeine is still in the system. These analyses evaluated whether caffeine use in the afternoon and the evening is associated with sleep functioning, controlling for sex, pubertal development, and medication status. These covariates were chosen given the established differences in sleep that emerge during pubertal maturation between males and females (Johnson et al., 2006), as well as to control for any effects of pharmacological treatments that may impact sleep. Given the prediction that adolescents with ADHD consume significantly more caffeine in the afternoons and evenings, it was also hypothesized that there will be significant associations between caffeine and sleep for adolescents with ADHD but not for the comparison group.

Methods

Participants

Participants were 302 adolescents (167 male, 135 female) in eighth grade (ages 12-14 years). Approximately half of the participants (53.6%; *n*= 162) were diagnosed with ADHD (57 female, 105 male). In the comparison group (46.4%; *n*= 140), there were 78 females and 62 males. In the overall sample, most participants identified as White (81.8%), with the remaining participants identifying as Black (5.3%), Asian (4.6%), American Indian/Alaska Native (0.3%), or Biracial/Multiracial (7.9%). 4.6% of participants identified as Hispanic/Latino. Regarding medication use, 31.1% of the ADHD group and 0% of the comparison group were taking medication for ADHD. Additionally, 7.3% of the ADHD group and 2.3% of the comparison group were taking medication for other emotional or behavioral difficulties. For more information on sample characteristics, please see the supplementary materials (Table S1) and Becker and colleagues (2019) which analyzed group differences in sleep functioning in the same sample. Of note, Becker and colleagues (2019) found that adolescents in the ADHD group displayed significantly higher self-reported sleep-wake problems, parent-reported initiating and maintaining sleep problems, and shorter total sleep time (see Table S2). For more information about group differences on all sleep functioning variables examined in the parent study, see Becker et al. (2019).

Procedures

All procedures were approved by the Institutional Review Boards where the study was conducted. Participants were recruited during the fall of their eighth-grade year at two sites in the United States. Potential participants were recruited via emails sent out by school administrators. Written informed consent was obtained from the parents/guardians of the adolescents who served as participants. Additionally, verbal assent from the adolescents was also obtained.

The study sought to recruit approximately equal numbers of adolescents with and without ADHD. Those meeting the screening criteria were scheduled for an evaluation to determine eligibility. Recruitment materials targeted towards individuals with ADHD specified that participants may either have a previous diagnosis of ADHD or symptoms of ADHD. To be eligible for the ADHD group, participants had to meet full Diagnostic and Statistical Manual, Fifth Edition (DSM-5) diagnostic criteria for either ADHD Predominantly Inattentive Presentation or ADHD Combined Presentation based on a structured clinical interview (Children’s Interview for Psychiatric Syndromes, Parent Version [P-ChIPS]; Weller, Weller, Fristad, Rooney, & Schecter, 2000) conducted during the initial evaluation. Specifically, this required: (1) six or more symptoms of inattention at clinically significant levels; (2) presence of ADHD symptoms prior to age 12 years; (3) presence of ADHD symptoms in two or more settings (e.g., home, school); (4) evidence that symptoms contribute to impairment in home, academic, and/or social functioning according to the P-ChIPS or parent or teacher report on the Impairment Rating Scale (IRS; Fabiano et al., 2006), wherein scores ≥ 3 indicate impairment; and (5) symptoms of ADHD were not better explained by another mental disorder (e.g., anxiety, depression). Participants meeting criteria for ADHD Predominantly Hyperactive-Impulsive Presentation were not included given the low prevalence of this presentation in adolescence and ongoing concerns about its validity after early elementary school (Willcutt et al., 2012). To be eligible for the comparison group, participants were required to have fewer than four symptoms of ADHD in each domain (i.e., inattention and hyperactivity/impulsivity). To be eligible for either group, participants had to have an estimated IQ ≥ 80, take core classes in a regular education setting, and could not have a diagnosis of autism, bipolar disorder, a dissociative disorder, a psychotic disorder, or an organic sleep disorder. For additional details, see Becker et al. (2019).

Measures

Caffeine Use. The Caffeine Use Questionnaire is a self-report measure assessing the frequency of caffeine consumption in the past 30 days. This measure was adapted from questions used by Walker and colleagues (2010), which were originally derived from the standard items from the Centers for Disease Control and Prevention's Youth Risk Behavior Survey on adolescent diet (Brener et al., 2002). Participants were asked to select the average number/range of caffeinated beverages they consumed per day in the morning ("before 12 PM"), afternoon (“between 12 and 4 PM”), and evening (“after 4 PM”) during the past 30 days.

Sleep Habits Survey. The Sleep Habits Survey (SHS; Wolfson & Carskadon, 1998) is a self-report measure of sleep functioning validated for use in youth ages 10-19 years old (Wolfson et al., 2003). For the present study, the 10-item sleep-wake problems subscale was used, which specifically assesses the frequency of a number of sleep-related problems, such as daytime sleepiness and difficulties falling asleep, in the past two weeks. Ten items are rated on a 5-point Likert scale (1 = *never*; 5= *every day/night*) and summed to create a scale where higher scores indicate more sleep/wake problems (α = .76).

Sleep Disturbance Scale for Children. The Sleep Disturbance Scale for Children (SDSC; Bruni et al., 1996) is a 26-item parent-rated measure of sleep functioning validated in youth ages 6-15 years old. For the present study, the difficulties initiating and maintaining sleep subscale was used, which specifically assesses the frequency of a number of sleep-related behaviors in the past 6 months, such as typical total sleep time, sleep onset latency, and difficulties falling and staying asleep (5-point Likert scale, 1 = *never*; 5= *always*). The subscale demonstrated adequate internal consistency in the present sample, α = .77.

Actigraphy. Participants wore ActiGraph GT9X Link on their non-dominant wrist continuously for approximately two weeks. Data were downloaded using Actilife software version 6. Sixty-second epoch lengths were used to score the actigraph data. Data were first validated using the wear-time sensor and a validation algorithm, and then sleep scores were calculated with the Sadeh sleep scoring algorithm (Sadeh et al., 1994) by individually adding sleep periods to each night the device was worn for each participant. The first actigraph variable used in the present study is total sleep time, which was calculated by assessing the total time from sleep onset to offset. This methodology has been shown to be the most accurate approximation of actigraphy-derived measure of total sleep (Short et al., 2012). The second actigraph variable included in the analyses is wake after sleep onset (WASO), which assesses the amount of time in minutes spent awake after falling asleep on a given evening.

Covariates

Pubertal Development. The Physical Development Scale (Petersen et al., 1988) is a validated self-report measure assessing pubertal development in adolescents. There are separate forms for males and females to complete (six items on each); a mean score of five items pertaining specifically to physical indicators of puberty was calculated for analyses ($\alpha = .70$ and .76 for females and males, respectively).

Medication Use. A modified version of the Services for Children and Adolescents - Parent Interview (Jensen et al., 2004) was used, which is a clinician-administered interview. In the present study, a single variable for current medication use for attention, emotional/behavioral difficulties, and/or sleep difficulties was included as a covariate.

Analytic Plan

The caffeine measure assesses how many caffeinated beverages were consumed per day in the past 30 days. The response choices are ordered categorical, with some of the response choices representing range (e.g. “4 or more per day”), preventing the scale from being evaluated continuously. For each time period (i.e. morning, afternoon, evening), caffeine use variables were categorized into “no caffeine per day”, “less than 1 drink per day”, or “1 or more drinks per day”. Responses were categorized in this manner to allow for comparison with Walker et al. (2010) which followed similar procedures. For the first aim, chi-square tests were calculated in order to compare adolescents with and without ADHD on the number of caffeinated consumed per day during the three times of day (morning, afternoon, and evening). Odds ratios and 95%

confidence intervals were computed using logistic regression analyses to determine the change in likelihood of adolescent caffeine use at various times of the day and whether it is associated with ADHD status. Sex, pubertal development, and medication status were included as covariates.

For the second aim, multi-group path analyses were conducted in Mplus Version 7 (Muthén & Muthén, 1998). Two models were run to examine the effects of caffeine use on sleep functioning, the first model examining caffeine use in the afternoon and the second examining caffeine use in the evening, with both models predicting the four sleep functioning outcomes. Group status was used as the grouping variable for each path analysis. Sex, pubertal development, and medication status were included as covariates. Model fit statistics compared the models with paths free to vary across the groups (i.e., examining differential relations between caffeine use and sleep outcomes across the two groups) versus fixed to be equal across groups (i.e., assuming these relations to be the same for the two groups). A nonsignificant chi-square change statistic indicates that the fixed model should be retained in favor of parsimony. Model fit was examined for the retained models using several indices: Comparative Fit Index (CFI), the root mean square error approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). CFI values greater than .90 suggest good fit. RMSEA values less than .06 indicate good fit and values less than .10 indicate adequate fit. SRMR values less than 1.00 suggest good fit (Brown, 2015; Hu & Bentler, 1999).

Results

Missing data were minimal, with less than 2% of data missing with the exception of total sleep time, which had 3.6% missing data. Assumptions of normality were met for all variables with all skewness values less than 2 and kurtosis values less than 7 (Kim, 2013).

Caffeine Use Comparison based on Group Status

Chi-square tests compared adolescents with and without ADHD on the number of caffeinated beverages consumed during the three times of day (Table 1). Caffeine use in the morning did not significantly differ between groups, $\chi^2(2)=4.92$, $p=.086$. However, adolescents with ADHD were more likely to consume one or more caffeinated beverages in the afternoon, $\chi^2(2)=14.94$, $p=.001$, and evening, $\chi^2(2)=7.81$, $p=.020$ than adolescents without ADHD. Logistic regression analyses controlling for sex, pubertal development, and medication use, revealed that there were no significant increases in likelihood of caffeine consumption based on group status when examining no caffeine consumption or less than one beverage per day for morning, afternoon, or evening (Table 1). However, when examining use in the afternoon and evening for consuming at least one caffeinated beverage, adolescents with ADHD were 2.47 times more likely than adolescents without ADHD to consume at least one caffeinated beverage per day in the afternoon (95% confidence interval: 1.04-5.85) and at least one caffeinated beverage per day in the evening (95% confidence interval: 1.07-5.69). Approximately 81% of the participants with ADHD who consumed one or more caffeinated beverages in the afternoon also consumed one or more beverages in the evening.

Caffeine Use and Associations with Sleep Functioning

In the path analysis examining caffeine use in the afternoon and evening in relation to sleep functioning, model fit statistics confirmed that allowing paths to be free across groups resulted in significantly better fit than fixing these paths across groups, $\Delta\chi^2(4) = 138.80$, $p<.001$, and $\Delta\chi^2(4) = 144.91$, $p<.001$, respectively. Model fit for the afternoon was good on one index (SRMR = 0.04) and adequate on two indices (RMSEA = 1.00, CFI = 0.90). Model fit for the evening was good on all three indices (SRMR = 0.03, RMSEA = .035, CFI = 0.99).

For adolescents in both the ADHD and comparison groups, consuming at least one caffeinated beverage per day in the afternoon was associated with higher levels of self-reported sleep-wake problems (Figure 1). For adolescents in the ADHD group, consuming at least one caffeinated beverage in the afternoon was also associated with higher levels of parent-reported initiating and maintaining sleep difficulties. This association was not significant for adolescents in the comparison group. Caffeine consumption in the afternoon was not significantly associated with actigraphy total sleep time or WASO for either group.

For adolescents in the comparison group, consuming at least one caffeinated beverage per day in the evening was not associated with any sleep functioning outcomes (Figure 2). For adolescents in the ADHD group, caffeine use in the evening was significantly associated with higher levels of self-reported sleep-wake problems.

Given the potential for clinically relevant associations between medication use and caffeine use, we explored the impact of medication further. First, we assessed whether there were differences in caffeine consumption between participants who took ADHD medication versus participants who did not take ADHD medication. Chi-square tests did not reveal any significant differences. In terms of the role of medication as covariate in the caffeine to sleep models for adolescents with ADHD, medication use as a covariate was only significant for the paths between afternoon and evening caffeine use and WASO, with medication use being positively associated with greater WASO; afternoon, .100 (.048), $p = .039$, and evening, .106 (.048) $p = .029$.

Discussion

This study builds on prior literature by comparing rates of caffeine use at various times of the day in adolescents with and without ADHD and evaluating whether caffeine use is uniquely associated with sleep functioning in adolescents with ADHD. In this sample, adolescents with

ADHD were 2.47 times more likely than adolescents without ADHD to consume one or more caffeinated beverages in the afternoon and evening. Notably, these findings are consistent with the only other study to evaluate caffeine use in adolescents with ADHD, which reported that adolescents with ADHD were 2.08 times more likely to consume high levels of caffeine as compared to adolescents without ADHD (Walker et al., 2010). However, previous research only evaluated caffeine use broadly across the day (Walker et al., 2010). The results of the present study demonstrate that time of day and the specific amount of caffeine consumption is important when considering differences in caffeine use habits. Specifically, group differences were only found when examining consumption of one or more drinks per day during the afternoon and evening periods. There were no significant between group differences during the morning hours or when examining rates of consumption of less than one caffeinated beverage per day or no caffeine per day. The American Academy of Pediatrics (AAP) recommends that adolescents not exceed more than 100 mg of caffeine per day, which is equivalent to approximately one cup of coffee, and advises against the consumption of any quantity of energy drinks (CDC, 2016). Different types of caffeine consumption were not directly assessed in this study, however, consumption of one or more of any caffeinated beverages per day points towards problematic amounts of caffeine for over 20% of adolescents with ADHD in this study. Importantly, there was 81% overlap in the participants with ADHD who consumed high amounts of caffeine in both the afternoon and evening, which implies a pattern of problematic use that occurs in the middle of the day and continues into the evening. This highlights the importance of identifying adolescents with ADHD who are regular consumers of caffeine and further understanding patterns of use.

Interestingly, the greatest difference in time of day of consumption was found during the afternoon period. The afternoon is likely a time where teens' caffeine consumption is not directly supervised by parents and adolescents are in a position where they have more freedom to choose the beverages they consume (e.g. during lunchtime or between classes). During the evening, adolescents are more often in the company of their caregivers and may have more restrictions placed on how much caffeine they consume. Further, the afternoon and evening are times of day when there are high demands to pay attention, during class or while completing homework. It is possible that these adolescents with ADHD are using caffeine as a form of self-medication in order to increase concentration. Research in a normative sample of adolescents found that the teens were most likely to consume caffeine as a means to "get through the day" and were most likely to consume their first beverage of the day around 2 PM (Bryant Ludden & Wolfson, 2010). Adolescents with ADHD struggle with sustained attention and may be more likely to turn to caffeine use to increase attention in the afternoon and evening hours.

This was the first study to examine associations between caffeine use and sleep functioning in adolescents with ADHD. Results demonstrate that caffeine use in the afternoon is associated with adolescent-reported sleep-wake problems in both adolescents with and without ADHD. Interestingly, there were associations between afternoon caffeine use and parent-reported initiating and maintaining sleep problems only for adolescents in the ADHD group. Similarly, when examining the association between evening caffeine use and sleep, there were only significant associations for adolescent-reported sleep-wake problems in the ADHD group. It may be that due to the increased consumption of caffeine during the later parts of the day, caffeine is having a stronger negative impact on sleep functioning in these individuals. However, it is important to note that the overall magnitude of the effects were small, which may be a reflection of the low number of adolescents who consumed one or more caffeine drinks in the afternoon or evening. The adolescents in this sample were in eighth grade, and it will important to evaluate these associations in older adolescents with higher rates of caffeine use.

There were no significant associations between caffeine use in the afternoon or evening and actigraphy derived total sleep time or WASO for either adolescents with or without ADHD. These results are partially consistent with previous research which examined sleep functioning based on adolescent-report and actigraphy in a sample of 14 adolescents with ADHD compared to 21 healthy controls (Mullin et al., 2011). Although the authors noted low power in their analyses, they did not find any significant differences on actigraphy or self-reported total sleep time between the ADHD group and the control group (Mullin et al., 2011). Taken together, it may be that caffeine consumption is not impacting the total hours slept, but rather, is impacting subjective experiences of sleep and/or behavioral sleep functioning. Despite literature suggesting associations between caffeine use and increased WASO (Clark & Landolt, 2017), this study did not find significant associations in either the comparison or ADHD group. In a sample of adolescents, Pollack and Bright (2003) found associations between caffeine use and WASO. This may be because the sample in that study reported higher levels of caffeine consumption as compared to the present sample. Additional research utilizing samples of adolescents who are frequent and regular caffeine consumers is needed in order to more fully understand problematic caffeine use and the complex relationship with sleep.

The present study has several strengths, including a large samples size, well-defined groups, and multiple informants of sleep. However, the measure of caffeine use utilized in this study is limited in that the item choices are ordered categorical and do not assess the exact number of caffeinated beverages consumed continuously. Further, it also does not provide detailed information about which specific types of caffeine (e.g., soda, coffee, energy drinks) are being consumed by adolescents with and without ADHD. Research suggests that milligrams of caffeine per beverage impacts the effects of caffeine on the body and impact sleep functioning (Lodato et al., 2013). An additional limitation with the caffeine measure is that it does not allow data to be collapsed across times of the day (i.e., morning, afternoon, and evening) because some of the response choices represent a range. It may be important to assess global usage in additional to use at specific times of the day in order to evaluate the cumulative impact of caffeine consumption across the day on sleep. Future research should examine the different types of caffeine consumed by adolescents with ADHD and both global and specific time of day use in order to develop a more comprehensive understanding of caffeine and its effect on sleep in this population.

Due to the cross-sectional nature of this study, no assumptions can be made about the directionality of the associations. It is unclear whether increased caffeine use precedes sleep problems or whether individuals with worse sleep may be more likely to turn to caffeine. It has been suggested that that there may be a cyclic relationship between caffeine use and sleep problems (Temple, 2019). Caffeine use during the day disrupts sleep, which therefore causes more caffeine use the following day, which disrupts sleep, and so on (Temple, 2019). Longitudinal research in this area is needed in order to understand the direction of this association more clearly.

Finally, the impact of medication use on the association between caffeine use and sleep in adolescents with ADHD should be further explored. In the path analyses examining caffeine use and sleep functioning it was found that medication use was associated with WASO for individuals in the ADHD group. However, chi-square analyses found no significant differences in caffeine consumption based upon ADHD medication status. Taken together, these results suggest that medication use could serve as a moderator between caffeine use and sleep and future research is needed to explore this possibility.

Overall, the results of this study suggest that adolescents with ADHD are consuming more caffeine than their non-ADHD peers in the afternoon and evening, and that there are unique associations between caffeine use and adolescent and parent-reported sleep problems in this population. Becker and colleagues (2019) found that adolescents with ADHD in this sample experienced significantly worse sleep functioning across multiple domains compared to adolescents without ADHD, highlighting the importance of understanding factors that may negatively impact sleep in this population. These findings also suggest a need for parents and health care providers to educate adolescents about AAP caffeine use recommendations and consider implications for sleep.

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Table 1.
Chi-Square Tests and Odds Ratios for Number of Caffeinated Beverages Drank Per Day in Past 30 Days

			No caffeine	Less than one	One or more	χ^2
Morning						
	Comparison	*n*	70	55	15	
		(%)	(50.0%)	(39.3%)	(10.7%)	4.92
	ADHD	*n*	70	58	32	
		(%)	(43.8%)	(36.3%)	(20.0%)	
		Odds Ratio	1.08	0.754	1.53	
Afternoon						
	Comparison	*n*	65	65	10	
		(%)	(46.4%)	(46.4%)	(7.1%)	14.94**
	ADHD	*n*	56	67	37	
		(%)	(35.0%)	(41.9%)	(23.1%)	
		Odds Ratio	0.80	0.84	2.47*	
Evening						
	Comparison	*n*	70	58	12	
		(%)	(50.0%)	(41.4%)	(8.6%)	7.81*
	ADHD	*n*	69	59	32	
		(%)	(43.1%)	(36.9%)	(20.0%)	
		Odds Ratio	0.91	0.71	2.47*	

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

Note. Sex, pubertal developmental, and medication status were entered as covariates for odds ratios. Additionally, although the objective of our study was to examine differences in caffeine consumption between adolescents with and without ADHD, we also explored differences based on ADHD subtype. There were no significant differences in caffeine consumption based on ADHD subtype.

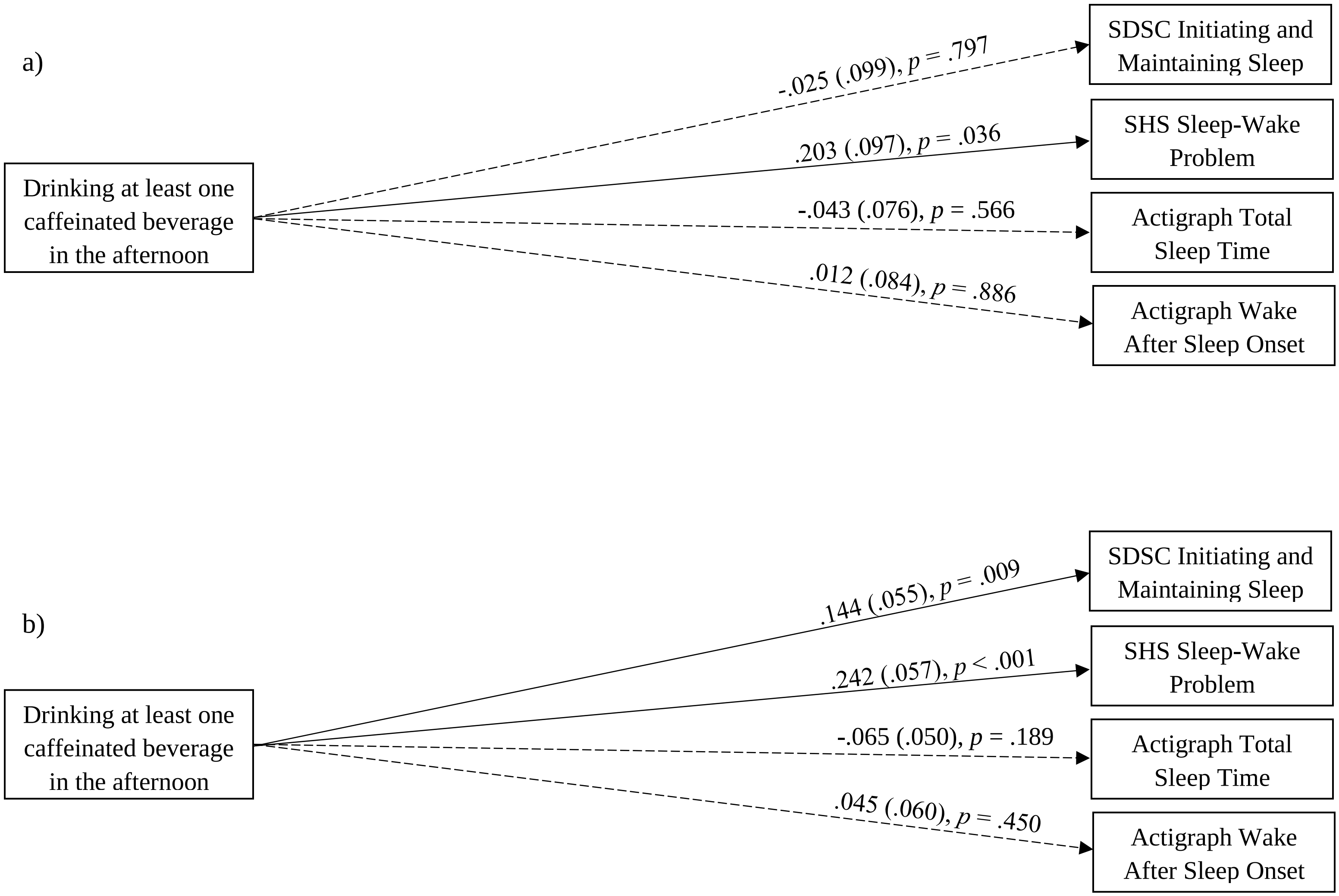

Figure 1. Relations between drinking caffeinated beverages in the afternoon and sleep problems for the a) Comparison and b) ADHD Group. SHS = Sleep Habits Survey. SDSC = Sleep Disturbance Scale for Children. Standardized coefficients shown outside parentheses; standard errors are shown inside parentheses. Dashed paths are nonsignificant. Covariances are not included for readability.

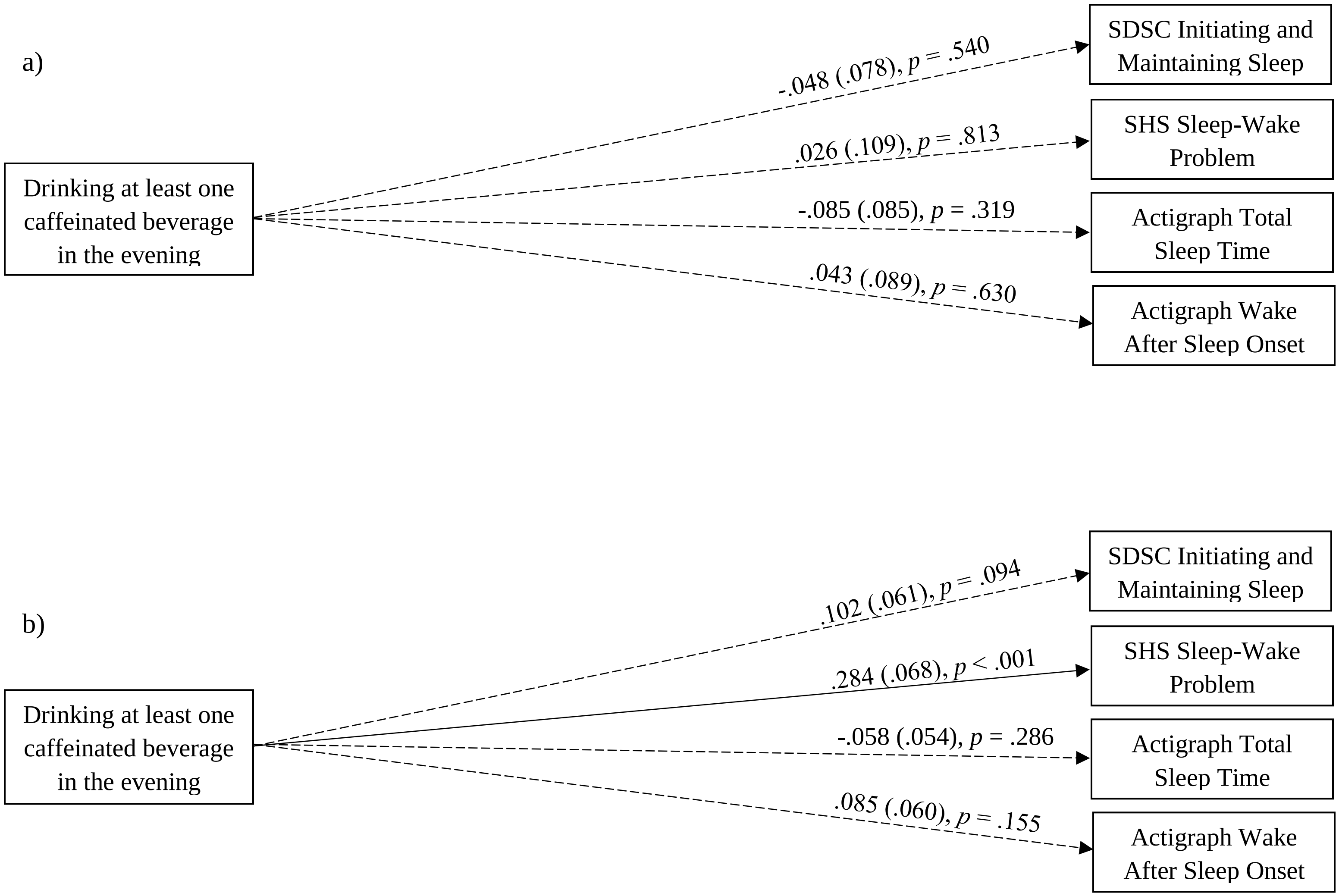

Figure 2. Relations between drinking caffeinated beverages in the evening and sleep problems for the a) Comparison and b) ADHD Group. SHS = Sleep Habits Survey. SDSC = Sleep Disturbance Scale for Children. Standardized coefficients shown outside parentheses; standard errors are shown inside parentheses. Dashed paths are nonsignificant. Covariances are not included for readability.

Table S1. Sample characteristics

	Total Sample (*N* = 302) *M* ± *SD*	ADHD Group (*N* = 162) *M* ± *SD*	Comparison Group (*N* = 140) *M* ± *SD*
Age	13.17 ± 0.40	13.17 ± 0.41	13.18 ± 0.40
Pubertal Development			
Female	3.07 ± 0.62	3.11 ± 0.57	3.05 ± 0.66
Male	2.34 ± 0.58	2.31 ± 0.56	2.39 ± 0.61
Primary Household Income	93,073 ± 34,856	84,875 ± 35,864	102,500 ± 31,213
	N (%)	*N* (%)	*N* (%)
Sex			
Male	167 (55.3)	105 (64.8)	62 (44.3)
Female	135 (44.7)	57 (35.2)	78 (55.7)
ADHD Presentation			
Predominantly Inattentive	-	120 (74.1%)	-
Combined	-	42 (25.9%)	-
Race			
White	247 (81.8)	129 (79.6)	118 (84.3)
Black	16 (5.3)	12 (7.4)	4 (2.9)
Asian	14 (4.6)	4 (2.5)	10 (7.1)
American Indian/Alaskan	1 (0.3)	1 (0.6)	0 (0)
Biracial/Multiracial	24 (7.9)	16 (9.9)	8 (5.7)
Hispanic/Latinx	14 (4.6)	7 (4.3)	7 (5.0)
Highest Maternal Education			
HS degree or less	14 (4.3)	10 (6.2)	4 (2.9)
Partial college/vocational	56 (18.5)	33 (20.4)	23 (16.4)
College graduate	126 (41.7)	73 (45.1)	53 (37.9)
Graduate/professional degree	106 (35.1)	46 (28.4)	60 (42.9)
Medication Use			
ADHD (any)	96 (31.8)	96 (59.3)	0 (0)
Methylphenidate	48 (15.9)	48 (29.6)	0 (0)
Amphetamine[a]	47 (15.6)	47 (29.0)	0 (0)
Nonstimulant[b]	20 (6.6)	20 (12.3)	0 (0)
Other Psychiatric (any)	29 (9.6)	22 (13.6)	7 (5)
Antidepressant	24 (7.9)	18 (11.1)	6 (4.3)
Antianxiety	2 (0.7)	1 (0.6)	1 (0.7)
Antipsychotic	3 (1.0)	3 (1.9)	0 (0)
Sleep (any)	32 (10.6)	23 (14.2)	9 (6.4)
Melatonin	31 (10.3)	22 (13.6)	9 (6.9)
Other sleep medication	1 (0.3)	1 (0.6)	0 (0)
Other psychiatric diagnoses[c]	107 (35.4)	74 (45.7)	33 (23.6)
Any externalizing (ODD/CD)	41 (13.6)	35 (21.6)	6 (4.3)
Any anxiety	73 (24.2)	46 (28.4)	27 (19.3)
Any depression	24 (7.9)	16 (9.9)	8 (5.7)

Note. SD= Standard Deviation. ODD= Oppositional Defiant Disorder. CD= Conduct Disorder. Income presented in US dollars. Table adapted from Becker, S. P., Langberg, J. M., Eadeh, H. M., Isaacson, P. A., & Bourchtein, E. (2019). Sleep and daytime sleepiness in adolescents with and without ADHD: Differences across ratings, daily diary, and actigraphy. *Journal of Child Psychology and Psychiatry*, *60*(9), 1021-1031.

[a]Includes amphetamine and mixed amphetamine salts.

[b]Includes guanfacine, atomoxetine, and clonidine.

[c]Presence of comorbid mental health diagnosis based on parent or adolescent report (only parents were administered ODD and PTSD modules) during the diagnostic interview.

Table S2. Group differences in sleep functioning

	ADHD	Comparison	Group differences		
	M ± *SD*	*M* ± *SD*	*t*	*p*	*d*
Adolescent SHS ratings:					
Sleep/wake problems[a]	18.23 ± 6.08	15.87 ± 4.77	3.77	<.001	.43
Parent SDSC ratings:					
Initiating and maintaining sleep problems[a]	66.73 ± 14.31	56.94 ± 11.27	6.65	<.001	.76
Actigraphy:					
Total sleep time (minutes)	374.81 ± 42.71	385.47 ± 37.23	2.26	.02	.27
Wake after sleep onset (minutes)	86.09 ± 26.79	87.12 ± 28.20	.31	.75	.04

Note. SHS = Sleep Habits Survey. SDSC = Sleep Disturbance Scale for Children. Table adapted from Becker, S. P., Langberg, J. M., Eadeh, H. M., Isaacson, P. A., & Bourchtein, E. (2019). Sleep and daytime sleepiness in adolescents with and without ADHD: Differences across ratings, daily diary, and actigraphy. *Journal of Child Psychology and Psychiatry*, *60*(9), 1021-1031.
[a]See Becker et al. (2019) for scale details.