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A multi-method examination of sluggish cognitive tempo in relation to adolescent sleep, daytime sleepiness, and circadian preference

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Background: The field's understanding of the association between sluggish cognitive tempo (SCT) and sleep is severely limited by the lack of multi-method and multi-informant research designs that move beyond global ratings, often focused on a limited number of sleep-related domains, such as daytime sleepiness. The current study begins to address these limitations by using actigraphy, daily sleep diary, and self- and parent-report global ratings of sleep in adolescents, a developmental period marked by changes in SCT, sleep, and circadian function. As SCT and sleep are also associated with ADHD symptoms, we tested these associations in a sample of adolescents with and without ADHD. **Methods:** Adolescents (N = 302; M age = 13.17 years, 44.7% female) with (n = 162) and without ADHD (n = 140) and parents completed global ratings of sleep and daytime sleepiness, and adolescents completed a measure of circadian preference. Adolescents also wore actigraphs for approximately two weeks, during which daily diaries were completed. **Results:** Above and beyond demographic characteristics (i.e., sex, race, and family income), pubertal development, medication use, and ADHD group status, adolescents' self-reported SCT symptoms were uniquely associated with shorter sleep duration and later sleep onset per both actigraphy and daily diary. SCT symptoms were also uniquely associated with longer sleep onset latency and poorer overall sleep (per daily diary), more sleep/wake problems and daytime sleepiness (per adolescent rating), more difficulties initiating and maintaining sleep (per parent rating), and later eveningness preference (per adolescent rating). Nearly all significant effects remained in sensitivity analyses controlling for adolescent- or parent-reported ADHD symptom dimensions. **Conclusions:** Findings provide the strongest evidence to date for SCT being uniquely linked to poorer sleep, greater daytime sleepiness, and a later evening circadian preference across subjective and objective measures. Longitudinal studies are needed to evaluate predictive and bidirectional associations. **Keywords:** ADHD; adolescence; circadian function; circadian preference; daytime sleepiness; sluggish cognitive tempo; sleep.

Introduction

Sluggish cognitive tempo (SCT) is a collection of behaviors characterized by excessive mind-wandering, daydreaming, mental fogginess, hypoactivity, and drowsiness. SCT has been shown to be distinct from, yet strongly related to, attention-deficit/hyperactivity disorder inattentive (ADHD-IN) symptoms in youth samples (Barkley, 2014; Becker, Leopold, et al., 2016). Furthermore, studies have linked SCT to a host of academic and socio-emotional impairments above and beyond ADHD-IN symptoms (for reviews, see Barkley, 2014; Becker & Barkley, 2018). One domain that has received comparatively less empirical attention is sleep. Notably, no study has comprehensively examined the association between SCT and sleep and circadian function in adolescence, a developmental period with higher levels of SCT than childhood (Leopold et al., 2016) and when substantial changes in sleep and circadian function occur (Crowley, Wolfson, Tarokh, & Carskadon, 2018). Given studies demonstrating strong associations between SCT and ADHD symptoms (Becker, Leopold, et al., 2016), the possibility that SCT may be linked to functioning differentially among youth with and without ADHD (Barkley, 2014), and a robust literature documenting high rates of co-occurring sleep problems, daytime sleepiness, and evening preference in adolescents diagnosed with ADHD (Becker, Langberg, Eadeh, Isaacson, & Bourchtein, 2019; Lunsford-Avery, Krystal, & Kollins, 2016), we tested SCT in relation to sleep in a sample of adolescents with and without ADHD.

SCT, sleep, and daytime sleepiness

When considering the nature of SCT (e.g., hypoactivity, drowsiness, and mental fogginess), it is unsurprising that research has proposed a link between SCT and poor sleep (Becker, Leopold, et al., 2016; Becker, Pfiffner, Stein, Burns, & McBurnett, 2016; Cortese, Faraone, Konofal, & Lecendreux, 2009). Research in adult (primarily college student) samples has shown SCT to be uniquely associated with self-reported poor sleep

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and greater daytime sleepiness above and beyond ADHD symptoms (Becker, Luebbe, & Langberg, 2014; Fredrick, Burns, Langberg, & Becker, 2021; Langberg, Becker, Dvorsky, & Luebbe, 2014). These findings have been replicated in samples of children. In a sample of school-aged children with sleep disorders, parent-reported SCT was uniquely associated with multiple measures of parent-reported sleep problems and daytime sleepiness, above and beyond demographics, ADHD symptoms, and internalizing symptoms (Becker Garner, & Byars, 2016). Two recent studies also found SCT symptoms to be associated with parent ratings of child daytime sleepiness (O'Hare et al., 2021) and disturbed sleep and excessive sleep duration (Mayes, Waschbusch, Fernandez-Mendoza, & Calhoun, 2021). Similarly, studies have found higher parent-reported sleep problems in children with SCT, with or without ADHD, than children with ADHD only (Burns & Becker, 2021; Rondon, Hilton, Jarrett, & Ollendick, 2020). To date, only three studies have examined SCT and sleep in adolescents. Smith, Eadeh, Breaux, and Langberg (2019) found self-reported SCT to be distinct, yet strongly related to, daytime sleepiness in adolescents with ADHD. Using an experimental sleep restriction/extension protocol, two studies found shortened sleep duration to be causally linked to increased SCT symptoms in adolescents with (Becker, Epstein, et al., 2019) and without (Garner et al., 2017) ADHD. Importantly, exceptions have also been noted with a few studies not finding a robust or consistent association between parent- or teacher-rated SCT with children's sleep problems (Becker, Pfiffner, et al., 2016; Koriakin, Mahone, & Jacobson, 2015; Lee, Burns, & Becker, 2017), notably in studies using robust measures of SCT.

SCT and circadian preference

Preliminary work also suggests that SCT may be associated with circadian function, specifically a greater eveningness preference. Defined as the component of the sleep/wake cycle reflecting an individual's preference for timing of waking activities and sleep (Jenni, Achermann, & Carskadon, 2005), there has been growing interest in the role of circadian factors as a contributor and maintenance of sleep problems, daytime sleepiness, and psychopathology in youth (Arns, Kooij, & Coogan, 2021). Two studies have examined SCT in relation to circadian preference in adults. First, in a sample of college students, self-reported SCT was bivariately correlated with greater eveningness preference (Voinescu, Szentagotai, & David, 2012). Another study in adults seeking an ADHD evaluation found SCT symptom severity to be associated with eveningness preference above and beyond demographics, comorbidities, and ADHD symptoms (Lunsford-Avery, Sweitzer, Kollins, & Mitchell, 2020). Given that adolescents' self-reported evening preference is linked to poorer sleep quality, daytime impairments, daytime sleepiness, and inattention (Hennig, Krkovic, & Lincoln, 2017; Martin, Gaudreault, Perron, & Laberge, 2016; Vollmer et al., 2017), which are all associated with SCT, one might expect SCT to also be associated with later eveningness preference in adolescence.

Toward a comprehensive understanding of SCT and sleep in adolescence

The current study aims to advance a more comprehensive understanding of the link between SCT and sleep in three major ways. First, adolescence is referred to as the "the perfect storm" for poor sleep due to the substantial biopsychosocial factors impacting sleep regulation and circadian shifts toward eveningness, coupled with a mismatch in early waking demands and later social activities (Crowley et al., 2018). Nevertheless, very few studies have focused on SCT and sleep in adolescence, and it is important to identify whether SCT is associated with poor sleep, daytime sleepiness, and circadian preference during this distinct developmental period. Second, there is growing interest in conceptualizing SCT as an internalizing rather than externalizing psychopathology (Becker & Willcutt, 2019; Smith et al., 2019), making self-report of SCT important (Sáez, Servera, Burns, & Becker, 2019). Yet with few exceptions, most of the studies reviewed above relied on parent-report of youths' SCT symptoms. Third, existing studies have primarily examined daytime sleepiness (Smith et al., 2019) or sleep duration (Becker, Epstein, et al., 2019; Garner et al., 2017). Other domains (e.g., sleep onset latency, bed/wake times, and circadian preference) are important to assess to gain a more comprehensive understanding of SCT and sleep. In addition, almost all studies have relied on subjective, global ratings of sleep, with the one study to date using polysomnography (PSG) finding no significant associations between parent-reported SCT symptoms and 14 PSG indexes of sleep in a large sample of school-aged youth (Mayes et al., 2021). There is, thus, no evidence to date of an association between SCT and objectively measured sleep function. Considered together, the studies examining SCT and sleep in adolescence are limited in both number and scope.

The current study used an optimal adolescent self-report measure of SCT and multiple methods for assessing sleep, including global adolescent and parent ratings, adolescent daily sleep diary, and actigraphy. Additionally, the current study controlled for key covariates that have been associated with sleep and circadian rhythm, including medication use (Lunsford-Avery et al., 2016), sex (Arns et al., 2021), pubertal development (Foley, Ram, Susman, & Weinraub, 2018), and family income (Sivertsen, Bøe, Skogen, Petrie, & Hysing, 2017). A sample of adolescents with and without ADHD was included to examine whether self-reported SCT is associated with poor sleep above and beyond the influence of ADHD group status (primary analyses) or ADHD symptom severity (sensitivity analyses). We hypothesized that adolescent self-reported SCT symptoms would be uniquely associated with greater sleep problems. Furthermore, building on the previous study linking adolescents' self-reported SCT symptoms to greater daytime sleepiness (Smith et al., 2019), we expected SCT to be uniquely associated with greater self- and parent-reported daytime sleepiness. Although no study has tested SCT and circadian preference in youth samples, we hypothesized that higher SCT symptoms would be uniquely related to self-reported evening preference following the two previous studies in adults (Lunsford-Avery et al., 2020; Voinescu et al., 2012). Drawing from studies using subjective measures, we expected SCT symptoms to be associated with later bedtime (possibly representing greater eveningness circadian preference), lower sleep efficiency (an index of sleep quality), and shorter sleep duration. We also explored ADHD group status as a possible moderator of any associations between SCT and sleep. Finally, we tested whether SCT symptoms would remain associated with sleep outcomes when controlling for self- and parent-reported ADHD symptoms.

Methods

Participants

Participants were 302 adolescents between the ages 12–14 ($M = 13.17$, $SD = 0.40$; 44.7% females). Parents identified adolescents' race as European–American/White (81.8%), Biracial/Mixed Race (7.9%), Black/African–American (5.3%), Asian (4.5%), and American Indian/Alaskan (0.3%) and adolescents' ethnicity as Hispanic/Latinx (4.5%). Slightly more than half of participants (53%) had a reported family income of $100,000 or higher, 31.2% between $50,000 and $100,000, and 14.5% less than $50,000. Around 40% of adolescents were currently taking any medication for ADHD, emotional problems (e.g., depression, anxiety), or sleep. For purposes of the larger study, recruitment targeted an approximately equal number of adolescents with and without ADHD ($n = 162$ diagnosed with DSM-5 ADHD; 120 with Inattentive Presentation, and 42 with Combined Presentation). Further description of the sample and comparisons can be found elsewhere (Becker, Langberg, et al., 2019).

Procedure

This study was approved by the Institutional Review Boards (IRB) at Cincinnati Children's Hospital Medical Center and Virginia Commonwealth University. Data in the current study were collected at the initial baseline visit of a broader study of adolescents with and without ADHD (Becker, Langberg, et al., 2019). Parents contacted the research staff in response to recruitment materials and were administered a phone screen to determine study eligibility. Inclusion criteria included (a) enrollment in eighth grade, (b) estimated Full-Scale IQ ≥ on the Weschler Abbreviated Scale of Intelligence, Second Edition (WASI-II) (Wechsler, 2011), and (c) meeting criteria for either the ADHD or comparison group as defined below. Exclusion criteria included (a) past or current diagnoses per parent-report of autism spectrum disorders, bipolar disorder, or schizophrenia disorder, and (b) previous diagnosis per parent-report of an organic sleep disorder.

ADHD diagnosis. ADHD diagnosis was established based on the parent version of Children's Interview for Psychiatric Syndromes (P-ChIPS; Weller, Weller, Rooney, & Fristad, 1999), with adolescents required to meet criteria for either the ADHD Combined Presentation or Predominantly Inattentive Presentation on the P-ChIPS. Adolescents were in the comparison group if the parent endorsed <4 symptoms of ADHD in both domains (i.e., inattention, hyperactivity/impulsivity) on the P-ChIPS.

Measures

Child concentration inventory, second edition (CCI-2). Adolescents' self-reported SCT was measured with the CCI-2 (Sáez et al., 2019). The scale includes 15 items that reflect symptoms of SCT (e.g., "My mind feels like it is in a fog") rated on a four-point scale (0 = *never*; 3 = *always*). Thirteen of the 15 CCI-2 items have demonstrated strong convergent validity and discriminative validity from ADHD-IN symptoms and were used in the current study (Becker, Burns, Smith, & Langberg, 2020). In the present study, internal consistency was $\alpha = .92$.

ADHD Self-Report Scale (ASRS). Adolescents' self-reported DSM-5 ADHD symptoms were assessed with the 18-item ASRS (Kessler et al., 2005). Items assess the frequency of inattentive and hyperactive-impulsive symptoms on a four-point scale (0 = *never*; 3 = *very often*). The ASRS has well-documented internal validity and convergent validity with interview-assessed ADHD symptoms (Sonnby et al., 2015). In the present study, internal consistencies for inattention and hyperactivity/impulsivity were $\alpha s = .86$ and.84, respectively.

Vanderbilt ADHD Diagnostic Rating Scale (VADRS). Parents report of adolescents' ADHD symptoms was measured with the VADRS (Wolraich, 2003). Similar to the ASRS, the frequency of each symptom is rated on a four-point scale (0 = *never*; 3 = *very often*). Scores on the VADRS have demonstrated strong internal consistency, factor structure, and concurrent validity with other ADHD assessment instruments (Wolraich, 2003). In the present study, internal consistencies for inattention and hyperactivity/impulsivity were $\alpha s = .95$ and .90, respectively.

Sleep Habits Survey (SHS). The SHS (Wolfson & Carskadon, 1998) is a self-report measure of sleep difficulties, daytime sleepiness, and circadian preference. The 10-item sleep/wake problem subscale assesses the frequency of trouble falling and staying asleep (1 = *never*; 5 = *every day/night*), and the 10-item daytime sleepiness subscale includes situations where an adolescent may experience sleepiness (1 = *no*; 4 = *both struggled to stay awake and fallen asleep*), with one item about falling asleep while driving removed due to age of participants. The 10-item circadian preference subscale assesses preference for morningness or eveningness, with lower scores indicating greater eveningness preference. In the present study, internal consistencies for sleep/wake problems, daytime sleepiness, and circadian preference were $\alpha s = .76$, .79, and .77, respectively.

Sleep Disturbance Scale for Children (SDSC). The SDSC (Bruni et al., 1996) is a 26-item parent-report measure of youth sleep. The difficulties initiating/maintaining sleep (seven items) and daytime sleepiness (five items) subscales were used. Items are rated on a 5-point scale (1 = *never*; 5 = *always*). In the present study, internal consistencies for difficulties initiating/maintaining sleep and daytime sleepiness were αs = .77 and .79, respectively.

Daily sleep diary. Adolescents completed sleep diaries every morning for approximately two weeks following the in-person assessment. Individual items for night-time sleep were averaged across weekdays (given the low number of weekend days with diary data and number of variables being examined, we did not examine weekend diary data). Participants were asked to indicate their (a) bedtime and wake time in hours and minutes, (b) how many minutes it took to fall asleep (i.e., SOL), (c) how many hours they slept (i.e., sleep duration), (d) how many minutes they spent awake after waking up at night (i.e., WASO), and (e) how many times they woke up during the night. Last, participants were asked about the overall quality of their sleep (1 = *very good*; 5 = *very bad*).

Actigraphy. Participants wore an ActiGraph GT9X Link on their non-dominant wrist during the same period that they completed sleep diaries to measure sleep onset and offset time (actigraph device registered the participant as asleep or awake, respectively), time in bed (total time from sleep onset to offset), which has been shown to be the most accurate approximation of actigraphy-derived measure of total sleep in adolescents (Short, Gradisar, Lack, Wright, & Carskadon, 2012); and sleep efficiency (the ratio of time spent asleep to total time spent in bed). Data were downloaded using Actilife software version 6. 60-s epoch lengths were used to score the actigraph data. They were first validated using both the wear-time sensor built into the device and in combination with a validation algorithm (Troiano, 2007) to maximize the accuracy of when the actigraph was physically being worn by finding the times of non-wear based on a threshold of consecutive zeros. Once data were validated, sleep scores were calculated with the Sadeh sleep scoring algorithm (Sadeh, Sharkey, & Carskadon, 1994), and by individually adding sleep periods to each night the device was worn for each participant, with adolescent daily diaries used alongside the actigraph scoring.

Covariates. Adolescents completed the 6-item Physical Development Scale (Petersen, Crockett, Richards, & Boxe r, 1988), which has separate forms for male and female adolescents. A mean score of five items specific to physical indicators of puberty was calculated (αs = .70 and .76 for females and males, respectively). Parents were administered an adaptation of the Services Use in Children and Adolescents–Parent Interview (SCA-PI) (Hoagwood et al., 2004) to assess medication use (for ADHD, sleep [including melatonin], and/or an emotional/behavioral problem [e.g., anti-depressants]). Parents reported on family income and their child's sex and race.

Analyses

Adolescents with <five nights of weekday daily diary ($n = 21$) and actigraphy ($n = 18$) data across the two-week assessment were excluded from analyses with those variables, given reliability evidence (Short, Arora, Gradisar, Taheri, & Carskadon, 2017). Participants with complete daily diary data had a higher family income ($p < .01$), and those with complete weekday actigraphy data were more likely to be White and had a higher family income (ps < .05). SPSS version 26 was used for all analyses. Significance was set at $p < .05$ for analyses. Due to the present study being the first to evaluate SCT and sleep using multiple informants and methodologies, preliminary analyses included zero-order correlations among SCT and sleep variables. Second, for our primary analyses, we conducted a series of multiple regressions to determine whether the associations between SCT and sleep outcomes remained above and beyond several covariates. We also explored whether any associations between SCT and sleep outcomes were moderated by ADHD group status. Finally, as sensitivity analyses, we re-ran the regression models with adolescent- or parent-reported ADHD inattentive and hyperactive-impulsive symptoms to determine whether the pattern of results obtained in the primary analyses with ADHD group status was similar when ADHD symptom severity was used instead.

Results

Bivariate correlations of SCT and sleep outcomes

Intercorrelations among study variables are presented in Table S1 (Table S2 provides correlations of covariates with SCT and sleep variables). Associations were generally medium-to-large for global ratings, small-to-medium for daily sleep diary ratings, and negligible-to-small for actigraphy variables. Specifically, adolescents' self-reported SCT was bivariately correlated with each of the self- and parent-reported rating scales and daily diary variables, with the exception of diary-assessed wake time ($r = -.03$, $p = .626$). SCT was significantly correlated with actigraphy measures of later sleep onset ($r = .15$, $p = .009$) and shorter sleep duration ($r = -.21$, $p < .001$), though unrelated to actigraphy measures of sleep efficiency ($r = .07$, $p = .280$) or wake time ($r = -.04$, $p = .680$).

Primary regression analyses examining associations between SCT and sleep

SCT in relation to global ratings of sleep, sleepiness, and circadian preference. As presented in Table 1, SCT was uniquely related to self-reported sleep/wake problems ($\beta = .53$, $p < .001$, $sr^2 = .49$), parent-reported difficulties initiating/maintaining sleep ($\beta = .13$, $p = .023$, $sr^2 = .12$) self ($\beta = .46$, $p < .001$, $sr^2 = .43$), parent-reported daytime sleepiness ($\beta = .19$, $p = .002$, $sr^2 = .17$), and self-reported evening preference ($\beta = -.41$, $p < .001$ $sr^2 = -.38$), above and beyond sex, race, income, puberty development, medication status, and ADHD group status.

SCT in relation to daily diary ratings. As shown in Table 2, SCT was uniquely associated with later bedtime ($\beta = .14$, $p = .032$, $sr^2 = .13$), longer sleep onset latency ($\beta = .19$, $p = .002$, $sr^2 = .18$), greater number of night wakings ($\beta = .24$, $p < .001$ $sr^2 = .22$), longer duration of wake after sleep onset ($\beta = .24$, $p < .001$ $sr^2 = .22$), shorter sleep duration ($\beta = -.14$, $p = .024$, $sr^2 = -.13$), and greater difficulty waking in the morning ($\beta = .39$, $p < .001$ $sr^2 = .36$). However, SCT was not uniquely associated with ratings of morning wake time.

SCT in relation to actigraphy parameters. As shown in Table 3, SCT was uniquely associated with

Table 1 Adolescent SCT in relation to self- and parent-reported global rating scales

	b	*SE*	*β*	*t*	sr^2
DV = Self-reported Sleep/Wake Problems					
Sex	−.35	.65	−.03	−.54	−.03
Race	−.72	.72	−.05	−1.00	−.05
Income	−.19	.16	−.06	−1.16	−.06
Med Use	.81	.67	.07	1.21	.06
Puberty	.52	.46	.06	1.12	.05
Group	.18	.69	.02	.27	.01
SCT	5.41	.53	.53	10.24***	.49
DV = Parent-reported Initiate/Maintain Sleep					
Sex	.32	.57	.04	.57	.03
Race	−.28	.62	−.07	−.45	−.02
Income	−.11	.14	−.03	−.80	−.04
Med Use	1.40	.58	−.05	2.39*	.13
Puberty	.03	.40	.16	.07	.00
Group	1.96	.60	.22	3.26**	.18
SCT	1.05	.46	.13	2.28*	.12
DV = Self-reported Daytime Sleepiness					
Sex	−.82	.46	−.11	−1.77	−.09
Race	−.67	.51	−.07	−1.31	−.07
Income	.05	.11	.02	.41	.02
Med Use	−.37	.48	−.05	−.78	−.04
Puberty	.33	.33	.06	1.01	.05
Group	.51	.49	.07	1.03	.05
SCT	3.13	.38	.46	8.33***	.43
DV = Parent-reported Daytime Sleepiness					
Sex	−.06	.53	−.01	−.12	−.01
Race	−.38	.58	−.04	−.66	−.04
Income	−.10	.13	−.05	−.77	−.04
Med Use	.28	.54	.04	.52	.03
Puberty	.03	.37	.01	.09	.01
Group	1.27	.56	.16	2.28**	.13
SCT	1.32	.43	.19	3.09***	.17
DV = Self-reported Circadian Preference					
Sex	1.08	.66	.11	1.65	.09
Race	.80	.72	.06	1.10	.06
Income	.02	.16	.01	.14	.01
Med use	−.19	.67	−.02	−.28	−.02
Puberty	.02	.46	.00	.03	.00
Group	.50	.69	.05	.72	.04
SCT	−3.72	.53	−.41	−7.03***	−.38

For sex, 0 = male, 1 = female. For race, 0 = non-White, 1 = White. Med Use = medication use. For Group, 0 = control, 1 = ADHD. SCT = self-reported sluggish cognitive tempo.
*$p < .05$. **$p < .01$. *** $p < .001$.

a later sleep onset time ($\beta = .16$, $p = .017$, $sr^2 = .14$) and fewer minutes in bed ($\beta = -.16$, $p = .011$ $sr^2 = -.15$). SCT was not uniquely related to sleep efficiency, wake time, or wake after sleep onset.

Sensitivity analyses

To determine whether effects remained when controlling for ADHD symptom dimensions instead of ADHD group status, analyses were re-run controlling for adolescent and parent ratings of ADHD symptoms separately (see Tables S3–S8). Regarding rating scales, all significant effects remained, except for SCT no longer being uniquely associated with parent-report of difficulties initiating/maintaining sleep and daytime sleepiness. Additionally, SCT symptoms remained uniquely associated with all daily diary ratings except for sleep onset latency when controlling for self-report of ADHD symptoms, though SCT remained uniquely related to longer sleep onset latency ($\beta = .18$, $p = .005$, $sr^2 = .16$) above and beyond parent ratings of ADHD symptoms. Finally, SCT remained uniquely associated with later sleep onset time and fewer minutes in bed as measured via actigraphy when either adolescent- or parent-reported ADHD symptom dimensions were in the model. Finally, we explored whether any effects were moderated by ADHD group status, and all interaction models were non-significant.

Discussion

Using a multi-method, multi-informant design, the current study is the most comprehensive examination to date of the association between SCT and sleep. In a sample of adolescents with and without ADHD, adolescents' self-reported SCT symptoms were uniquely associated with (a) later sleep onset time as measured with diary and actigraphy, (b) longer sleep onset latency via diary, (c) shorter sleep duration with diary and actigraphy, (d) more night wakings according to the diary, (e) more self- and parent-reported sleep/wake problems, (f) difficulties waking in morning according to the diary, (g) greater self and parent-reported daytime sleepiness, and (h) later self-reported evening preference, above and beyond adolescent demographics, medication status, pubertal development, and ADHD status. Nearly, all unique effects remained except for parent-reported sleep problems and daytime sleepiness and diary-assessed sleep onset latency when controlling for self- or parent-reported ratings of ADHD symptoms instead of ADHD group status. Findings provide compelling evidence for SCT symptoms being uniquely associated with poor sleep in adolescents with and without ADHD.

Findings across subjective and objective ratings advance the current state of the SCT literature in several key ways. First, actigraphy data corroborated findings from daily sleep diary ratings and showed that adolescents' SCT was uniquely associated with a later sleep onset time and shortened sleep duration. Second, findings expanded on the two prior studies in adults (Lunsford-Avery et al., 2020; Voinescu et al., 2012) by being the first to demonstrate a unique association between SCT and self-reported eveningness preference in youth. Finally, our findings linking SCT to daily diary ratings of difficulty waking in morning and self-reported daytime sleepiness are consistent with the one study in adolescents to date documenting significant associations between self-reported SCT and daytime sleepiness (Smith et al., 2019). Notably, these effects remained when controlling for several factors that have been linked to sleep functioning and circadian rhythm. For instance, self-reported SCT symptoms remained associated with poor sleep above and

Table 2 Adolescent SCT in relation to daily sleep diary ratings

	b	*SE*	*β*	*t*	*sr²*		*b*	*SE*	*β*	*t*	*sr²*
			DV = Bedtime						DV = Sleep Onset Latency		
Sex	.08	.12	.05	.68	.04	Sex	−1.78	2.20	−.06	−.81	−.05
Race	−.20	.13	−.10	−1.56	−.09	Race	.92	2.51	.02	.37	.02
Income	.03	.03	.07	1.06	.06	Income	−.08	.56	−.01	−.15	−.01
Med Use	−.04	.12	−.03	−.37	−.02	Med Use	6.87	2.26	.21	3.04**	.18
Puberty	.04	.08	.04	.52	.03	Puberty	1.10	1.55	.05	.71	.04
Group	−.11	.12	−.07	−.92	−.06	Group	−1.39	2.30	−.04	−.60	−.04
SCT	.20	.09	.14	2.16*	.13	SCT	5.42	1.77	.19	3.07**	.18
			DV = Times Awake						DV = Wake after Sleep Onset		
Sex	.14	.09	.11	1.61	.09	Sex	.92	1.23	.05	.74	.04
Race	−.17	.10	−.10	−1.71	−.10	Race	−1.82	1.41	−.08	−1.29	−.06
Income	−.03	.02	−.09	−1.54	−.09	Income	−.00	.31	−.02	−.01	−.00
Med Use	.04	.09	.03	.49	.03	Med Use	1.83	1.27	.10	1.44	.08
Puberty	−.02	.06	−.02	−.26	−.02	Puberty	.66	.87	.05	.76	.04
Group	−.01	.09	−.01	−.15	−.02	Group	.15	1.30	.01	.11	.01
SCT	.27	.07	.24	3.84***	.22	SCT	3.82	.99	.24	3.84***	.22
			DV = Sleep Duration						DV = Sleep Quality		
Sex	−.14	.13	−.08	−1.10	−.06	Sex	.09	.09	.07	1.04	.06
Race	.10	.15	.04	.63	.04	Race	−.04	.10	−.02	−.39	−.02
Income	.05	.03	.10	1.64	.09	Income	−.02	.02	−.04	−.68	−.03
Med Use	−.11	.13	−.06	−.81	−.05	Med Use	.01	.09	.01	.08	.00
Puberty	−.14	.09	−.11	−1.55	−.09	Puberty	.12	.06	.13	2.00*	.11
Group	−.18	.14	−.10	−1.36	−.08	Group	.01	.09	.01	.12	.01
SCT	−.24	.10	−.14	−2.34*	−.13	SCT	.47	.07	.39	6.72***	.36
			DV = Waketime						DV = Difficulty to Wake		
Sex	.01	.08	.00	.01	.00	Sex	.16	.10	.11	1.61	.09
Race	−.21	.10	−.14	−2.24*	−.13	Race	.11	.11	.05	.94	.05
Income	.02	.02	.06	1.03	.06	Income	−.00	.03	−.01	−.11	−.01
Med Use	.03	.09	.02	.34	.02	Med Use	−.03	.10	−.01	−.25	−.01
Puberty	−.06	.06	−.07	−.99	−.06	Puberty	.07	.07	.07	1.07	.06
Group	−.22	.09	−.19	−2.56*	−.15	Group	−.03	.10	−.00	−.06	−.00
SCT	.05	.07	.04	.67	.04	SCT	.53	.08	.39	6.65***	.36

N = 284. For group, 0 = non-ADHD, 1 = ADHD. For sex, 0 = male, 1= female. For race, 0 = non-White, 1 = White. For Group, 0 = control, 1 = ADHD. SCT = self-reported sluggish cognitive tempo. *p <.05. **p <.01. *** p <.001.

beyond the influence of self- and parent-reported ADHD symptoms. As ADHD symptoms are linked to later sleep onset, shortened sleep, greater daytime sleepiness, and evening preference (Becker, Langberg, et al., 2019; Lunsford-Avery et al., 2016), these findings highlight the importance of considering SCT behaviors when understanding adolescents' sleep functioning. As adolescence represents a period marked by disruptions in sleep–wake regulation and circadian preference (Crowley et al., 2018), our study highlights the importance of considering adolescents' own ratings of SCT in studies investigating sleep and circadian functioning.

These novel findings underscore several remaining questions and important future directions. Given that SCT is associated with shortened sleep duration and experimental studies link shortened sleep to increased SCT behaviors (Becker, Epstein, et al., 2019; Garner et al., 2017), is SCT an attentional and behavioral consequence of shortened or insufficient sleep? Although the magnitude of the correlations between shortened sleep and daytime sleepiness with adolescents' self-reported SCT ratings were in the small-to-medium range and do not suggest redundant constructs (consistent with other studies; Becker, Epstein, et al., 2019; Smith et al., 2019), longitudinal studies are needed to understand directionality of associations. Additionally, due to the unique association of SCT with greater self-reported eveningness preference and later objective sleep onset time, it will be important to evaluate whether SCT represents an underlying circadian phase delay, in turn resulting in shortened sleep duration, difficulties waking in the morning, and greater daytime sleepiness. In line with this possibility, in a recent qualitative study in youth with clinically-elevated SCT, parents most frequently selected difficulties with the morning routine as being negatively impacted by SCT behaviors (Becker et al., 2021). It is possible that there are subgroups of youth with SCT whose poor sleep and/or circadian preference is the primary contributor to SCT-related behaviors. It

Table 3 Adolescent SCT in relation to actigraphy parameters

	b	*SE*	*β*	*t*	*sr*^{2}
		DV = Sleep Onset			
Sex	-.05	.12	-.03	-.41	-.03
Race	-.30	.14	-.13	-2.16**	-.13
Income	.05	.03	.10	1.61	.10
Med Use	.01	.12	.01	.12	-.01
Puberty	.04	.09	.03	.47	.03
Group	-.02	.13	-.01	-.18	-.01
SCT	.23	.10	.16	2.40*	.14
		DV = Total Minutes in Bed			
Sex	-.39	6.07	-.00	-.06	-.01
Race	11.78	7.01	.10	1.68	.10
Income	-.46	1.50	-.02	-.30	-.02
Med Use	-1.73	6.26	-.02	-.28	-.02
Puberty	-3.74	4.32	-.06	-.89	-.05
Group	-6.87	6.40	-.08	-1.07	-.06
SCT	-12.26	4.92	-.16	-2.49*	-.15
		DV = Sleep Efficiency			
Sex	2.21	.76	.21	2.92**	.17
Race	-1.04	.87	-.07	-1.19	-.07
Income	.25	.19	.09	1.35	.08
Med Use	-1.35	.78	-.12	-1.74	-.10
Puberty	.23	.54	.03	.43	.03
Group	.68	.80	.06	.85	.05
SCT	.72	.61	.08	1.18	.07
		DV = Waketime			
Sex	-.04	.08	-.04	-.53	-.03
Race	-.14	.09	-.10	-1.59	-.10
Income	.05	.02	.16	2.52*	.15
Med Use	-.04	.08	-.04	-.54	-.03
Puberty	-.02	.05	-.02	-.35	-.02
Group	-.15	.08	-.14	-1.91	-.11
SCT	.04	.06	.05	.71	.04

For group, 0 = non-ADHD, 1 = ADHD. For sex, 0 = male, 1= female. For race, 0 = non-White, 1 = White. For Group, 0 = control, 1 = ADHD. SCT = self-reported sluggish cognitive tempo.
*p <.05. **p <.01. *** p <.001.

is also possible that sleep/circadian function contribute more strongly to a specific set of SCT symptoms. Latent profile analysis would be one fruitful avenue in this area. Finally, consistent with suggestions for investigating SCT and the arousal/circadian domain of the Research Domain Criteria (RDoC) framework (Becker & Willcutt, 2019), these findings may be an initial starting point to ongoing investigation of eveningness, circadian rhythm, and underarousal as potential biomarkers of SCT (Becker & Willcutt, 2019; Lunsford-Avery et al., 2020).

Limitations and future directions

The current study includes many strengths, notably the multi-informant, multi-method inclusion of self- and parent-reported rating scales, daily diary ratings, and actigraphy data. The study also used a sample of adolescents with and without ADHD, as well as an optimal adolescent self-report measure of SCT. However, some limitations are worth noting. Primarily, we were unable to determine whether SCT predicts, or is preceded by, sleep disturbances, daytime sleepiness, and circadian preferences due to the cross-sectional nature of our data. Further understanding of directionality and mechanisms linking SCT to sleep problems and circadian preferences will be an important area of future research to identify targets for treatment (Becker & Langberg, 2017). Second, although global ratings, daily diary, and actigraphy are notable strengths of the current study, actigraphy data may be unable to sufficiently identify the transition from sleep and wake states (Short et al., 2012), and global ratings/daily diaries are subject to retrospective recall (Lunsford-Avery et al., 2016). Future research utilizing polysomnography and the multiple sleep latency test (MLST) as an assessment of sleep architecture and daytime sleepiness are important next steps. Finally, the daily diary and actigraphy data used in the current study did not include weekend or daytime sleep, and future research is encouraged to examine SCT across the 24-hour period during the week and weekend.

Conclusions

The current study is the first to examine SCT in relation to sleep functioning, daytime sleepiness, and circadian preference, using rating scales, daily diary data, and actigraphy data in a sample of adolescents. Across findings, adolescents' self-reported SCT was uniquely associated with multiple types of sleep onset and maintenance problems, self-reported circadian preference, and self-reported daytime sleepiness, controlling for several factors previously linked with poor sleep and ADHD group status. These findings underscore the need to incorporate SCT in studies investigating the links between ADHD, sleep, daytime sleepiness, and circadian preference.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Table S1. Interrelations, means, and standard deviations of key study variables.
Table S2. Interrelations of covariates with SCT and sleep variables.
Table S3. Adolescent self-reported ADHD symptoms in relation to self- and parent-reported global rating scales.
Table S4. Adolescent self-reported ADHD symptoms in relation to daily sleep diary ratings.
Table S5. Adolescent self-reported ADHD symptoms in relation to actigraphy parameters.

Table S6. Parent-reported adolescent ADHD symptoms in relation to self- and parent-reported global rating scales.

Table S7. Parent-reported adolescent ADHD symptoms in relation to daily sleep diary ratings.

Table S8. Parent-reported adolescent ADHD symptoms in relation to actigraphy parameters.

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Key points

- No study has tested self-reported SCT in relation to adolescent sleep using rating scales, daily diary ratings, and actigraphy data.
- Adolescents self-reported SCT was uniquely related to later sleep onset time, shortened sleep duration, difficulty waking in morning, greater daytime sleepiness, and eveningness preference.
- Nearly all findings remained above and beyond ADHD symptom dimensions.
- SCT is an important set of behaviors that negatively impact sleep, daytime sleepiness, and eveningness preference.
- Future studies using longitudinal data and objective indices, including polysomnography and multiple sleep latency tests, are critical.

Note

1. As a post hoc test, we removed two items on the CCI-2 reflecting poor sleep/tiredness (e.g., "I feel sleepy or drowsy during the day" and "I get tired easily") to ensure that results were not attributable to some overlap between the SCT variable and the sleep variables. When regression analyses were re-run, all significant unique effects for SCT remained with the exception of marginal effects on parent-reported difficulties with initiating/maintaining sleep (β = .11, p = .064) and daily diary ratings of bedtime (β = .12, p = .056).

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