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Sluggish Cognitive Tempo and Processing Speed in Adolescents with ADHD: Do Findings Vary Based on Informant and Task?

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Abstract

Few studies have examined whether behavioral sluggish cognitive tempo (SCT) symptoms are related to speeded task performance. Mixed findings in existing research could be due to previous studies using a broad conceptualization of processing speed, not including self-report of SCT symptoms, and relying on non-optimal measures of SCT. Using a multi-informant design with both parent- and adolescent-reported SCT symptoms, the present study provides a preliminary test of the hypothesis that SCT symptoms would be associated with slower performance on tasks having greater graphomotor and fine motor demands. Participants were 80 adolescents (ages 13–17 years; 71% male) with attention-deficit/hyperactivity disorder (ADHD). Adolescents and parents completed ratings of SCT. Adolescents were administered the Wechsler Symbol Search and Coding subtests and the Grooved Pegboard Test. When adjusting for age, sex, and ADHD symptom severity, parent-reported SCT symptoms were not significantly associated with Symbol Search or Coding scores but were significantly associated with slower Grooved Pegboard time. Adolescent-reported SCT symptoms were not significantly associated with Symbol Search but were significantly associated with lower Coding scores and slower Grooved Pegboard time. Findings provide preliminary support for the hypothesis that SCT may be more clearly associated with processing speed task performance as motor demands increase and provide a potential explanation for the mixed literature on SCT in relation to processing speed by demonstrating that the presence and magnitude of associations vary by informant and task.

Keywords

adolescence; attention-deficit/hyperactivity disorder; graphomotor; motor speed; neurocognition; sluggish cognitive tempo

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Sluggish cognitive tempo (SCT), characterized by behavioral symptoms that include excessive daydreaming, mental confusion and foggy, lethargy, and slowed behavior/ thinking, are distinct from, yet related to, symptoms of attention-deficit/hyperactivity disorder (ADHD) [1]. Approximately 25–40% of children with ADHD have elevated SCT symptoms [2–5]. In addition, a growing body of research has found SCT symptoms to be associated with poorer adjustment in youth diagnosed with ADHD, including increased internalizing symptoms [2,6,7], social withdrawal [2,3,8,9], and poorer academic functioning [6,9–11]. Despite these findings supporting the internal and external validity of the SCT construct, surprisingly few studies have examined the neurocognitive correlates of SCT.

The term ‘sluggish cognitive tempo’ emerged in the 1980s as a label for a symptom factor that included items assessing sluggishness, apathy, lethargy, and drowsiness [12]. Given the SCT terminology and its associated symptoms, it is often assumed that SCT is related to slowed neurocognitive processes. However, little research has examined the relation between behavioral symptoms of SCT and processing speed, with mixed findings reported. Several studies have found SCT to be associated with slower processing speed, above and beyond ADHD symptoms. In a sample of 566 clinically-referred children (ages 6–16 years) parent-reported SCT symptoms were associated with slower processing speed as assessed using the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV) Processing Speed Index (PSI), though effects were stronger for younger children compared to older children [13]. Similarly, using several tasks designed for preschool-aged children (including individually-administered and computerized executive function tasks), teacher-reported SCT symptoms, though not parent-reported SCT symptoms, were associated with slower processing speed in a sample of 61 four-year-old children at-risk for ADHD [14]. Further support for the association between SCT and slower processing speed was reported in a sample of 721 youth (ages 8–16 years) with and without ADHD, whereby combined parent- and teacher-reported SCT symptoms were significantly associated with slower performance on a composite measure of processing speed [9]. Importantly, each of these studies included ADHD symptoms in their analyses to demonstrate a unique association between SCT and slower processing speed, though these studies also suggested that findings may be somewhat inconsistent across development, informants, and processing speed measure.

Complicating the picture, some studies found no association between SCT and slower processing speed. Willard and colleagues [15] found no association between parent-reported SCT symptoms and WISC-IV processing speed scores in survivors of pediatric brain tumors or leukemia. In a sample of 140 children (ages 6–11 years) with and without elevated ADHD symptoms, neither parent- nor teacher-reported SCT symptoms were associated with WISC PSI above and beyond ADHD symptoms and child demographics [16]. Similarly, the one study that has examined SCT and processing speed in adults did not find an association between SCT and college students’ processing speed [17]. In a population-based sample of 976 twins, Becker et al. [18] reported a modest but significant bivariate correlation between parent-rated SCT symptoms in childhood and slower WISC PSI in adolescence, though the association was not significant in analyses that controlled for ADHD symptoms. A recent study used computational modeling and found significant evidence against an association

between parent- or teacher-rated SCT symptoms and global information processing speed (drift rate) [19].

The mixed findings from these studies have led researchers to question “what precisely is the ‘sluggish cognitive’ nature of SCT” [18, p. 1101]. Clarifying what, if any, association is present between SCT symptoms and processing speed is important for advancing theory regarding the etiology and clinical correlates of SCT. Further, it is important to consider potential reasons for the mixed findings reported in extant research. There are several possible reasons for the inconsistent findings to date regarding any association between SCT and processing speed, including (1) an overly broad conceptualization of processing speed, (2) informant differences, especially the potential importance of self-reported SCT, and (3) the use of non-optimal SCT measures.

SCT and Processing Speed: Do Motor Demands Matter?

Processing speed is the “underlying cognitive efficiency at understanding and acting upon external stimuli, which includes integrating low level perceptual, higher level cognitive, and output speed” [20], p. 586]. Thus, processing speed tasks include cognitive, fine motor, and visual-spatial demands to varying degrees based on the task [21,22]. Although it may be assumed that SCT is associated with slower processing speed, as reviewed above the evidence for this assumption is mixed. We hypothesize that SCT symptoms are associated with slower performance on neurocognitive tasks as graphomotor/fine motor demands increase. This novel hypothesis is based on three separate areas of research.

First, youth with ADHD have slower processing speed compared to typically developing peers [23,24]. There is evidence that the magnitude of processing speed differences between children with and without ADHD is greater for processing speed tasks with graphomotor demands (e.g., WISC Coding) compared to tasks with less graphomotor demands (e.g., WISC Symbol Search) [22,25–28]. Further, systematic reviews indicate that ADHD inattentive symptoms are more strongly correlated than ADHD hyperactive-impulsive symptoms with slower processing speed [29], and inattention is also more clearly associated with fine motor skill impairment in children with ADHD [30]. However, most studies examining graphomotor and fine motor skills in youth with ADHD have not considered SCT, which is strongly associated with ADHD inattention [1] and may at least in part contribute to poorer performance on tasks with greater graphomotor/fine motor demands in youth with ADHD.

Second, it has been hypothesized that SCT may be a form of maladaptive mind wandering [31,32]. Although studies are needed to directly address this possibility, “daydreams” is the most frequently used behavioral item for assessing SCT [1] and is also a key feature of mind wandering [33,34]. Further, both mind wandering [35] and SCT symptoms [36] are associated with altered default mode network connectivity. A small but growing body of research has linked mind wandering to poorer motor task performance [37]. For instance, Kam and colleagues [38] found that participants made more motor tracking errors during mind wandering periods compared to on-task periods during a timed task which required participants to continuously track a moving target across the computer screen using a

joystick. These findings led the authors to conclude that “mind wandering does impair the precision at which we control our motor behavior on a moment-to-moment basis” (p. 3). Although mind wandering and SCT are not interchangeable, they have striking conceptual similarities and these empirical findings lend credence to the possibility that SCT symptoms will be associated with poorer performance on speeded tasks with greater motor demands.

Third, the first neuroimaging study investigating associations between SCT symptoms and neural substrates found SCT symptoms to be uniquely associated with hypoactivity in the superior parietal lobe in response to visual cues above and beyond inattentive symptoms [39]. The superior parietal lobe is often associated with visual-spatial input from one’s hand [40,41]. Hypoactivity in the superior parietal lobe and altered default mode network connectivity could potentially explain why SCT symptoms would be especially associated with slower speed on tasks with greater motor demands.

By including multiple measurements of processing speed, we can examine if the relation between SCT and processing speed is more clearly evident on tasks that have greater graphomotor and fine motor skill demands. Consistent with the studies reviewed above, the most commonly used measure of processing speed is the WISC PSI. The WISC PSI is based on two tasks—Coding and Symbol Search. Coding (which requires the participant to identify a symbol that matches a number from a key and reproduce the symbol in a grid below) has more graphomotor demands than Symbol Search (which requires participants to identify if there is a matching symbol or not in a row of symbols) [21,42,43]. Accordingly, Coding has been referred to as a test of motor or writing speed, whereas Symbol Search has been referred to as a test of visual mental speed [26,42]. We are aware of only two studies that separated out Coding and Symbol Search when examining processing speed correlates of SCT. First, Wood et al. [17] found identical, negligible associations between college students’ self-reported SCT symptoms and both Coding and Symbol search (both $r_s = -.05$). However, college students are likely less neuropsychologically impaired than a clinical sample or the general population, which may have obfuscated possible associations [17,44]. Second, Becker et al. [18] found a slightly stronger correlation of childhood SCT symptoms with Coding scores compared to Symbol Search scores in adolescence, though the magnitude of the difference was small ($r_s = -.29$ and $-.24$, respectively). However, the authors used a limited SCT symptom set and noted that “studies using measures with more items tapping performance speed/mental confusion may be better poised to examine whether, and under what conditions, SCT is associated with processing speed” (p. 1101).

One neuropsychological task assessing fine motor speed is the Grooved Pegboard Test, which is a manipulative dexterity test during which an individual fits small pegs into precise keyholes as quickly as possible. Of note, exploratory factor analysis has found Coding and Grooved Pegboard to load together on the same factor [45]. Only one study to date has examined SCT and Grooved Pegboard performance. Hinshaw and colleagues [46] examined neuropsychological performance in a sample of girls (ages 6–12 years) with and without ADHD. Although girls with ADHD predominantly inattentive type and co-occurring SCT symptoms did not differ from other girls with ADHD across most neuropsychological domains, they did perform significantly worse (slower) on the Grooved Pegboard Test than both comparison girls and girls with ADHD predominantly inattentive type but without SCT

symptoms. These findings support the possibility that SCT symptoms may be associated with poorer performance on speeded tasks of fine motor dexterity. However, no study to date has examined processing speed performance across tests with increasing motor demands (e.g., WISC Symbol Search → WISC Coding → Grooved Pegboard Test). The present study included these three separate measures as a preliminary test of the hypothesis that SCT symptoms are increasingly associated with slower task performance as fine motor requirements for successful performance increase.

Self-Report Assessment of SCT

Another possible reason for the mixed findings in previous studies examining the association between SCT symptoms and performance speed is the sole reliance on parent and teacher ratings of SCT. SCT symptoms are strongly associated with internalizing symptoms but are typically unassociated or *negatively* associated with externalizing behaviors [9,13,18,47–49]. In addition, SCT does not fit within a general disruptive behavior factor [50] and is associated with conflicted shyness [5,51], punishment sensitivity [52], and behavioral inhibition system sensitivity and neuroticism [53]. Thus, it has been hypothesized that SCT may be best conceptualized as falling under the internalizing dimension of psychopathology [31]. Given the importance of using self-report ratings when assessing internalizing constructs, investigators have begun to validate self-report measures of SCT symptoms [6,54–57]. Self-report ratings of SCT symptoms may more clearly relate to individual performance on neurocognitive tasks as it is increasingly being understood to relate to internalizing behaviors. As noted above, a study with young adult college students did not find an association between self-reported SCT symptoms and processing speed [17]. The current study is the first to examine youth self-reported SCT symptoms in relation to processing speed.

Measurement of SCT

A third possible reason for the inconsistent findings among previous studies examining the association between SCT and processing speed is that, until relatively recently, researchers have had to rely on short, non-validated measures of SCT. Most previous studies examining SCT and processing speed have used SCT scales comprised of 3–6 items [9,14–16,18]. In contrast, Jacobson et al. [13] used a longer SCT-specific rating scale and found a significant association between SCT symptoms and slower processing speed as measured by the WISC-IV PSI, though the association was stronger for younger children compared to older children. In the present study, we used a validated SCT rating scale based on meta-analytic findings of optimal SCT items [1]. Further, the scale used in this study has parallel parent- and self-report versions that allowed us to evaluate whether there are informant differences when examining the association between SCT and processing speed.

The Current Study

The current study builds upon previous research examining the link between SCT and processing speed in several ways. First, separate tests of processing speed were used that have increasing motor demands (WISC Symbol Search → WISC Coding → Grooved

Pegboard Test). Second, a multi-informant design with both parent- and adolescent-reported SCT symptoms was used to examine possible informant differences of the association between SCT and processing speed and to add to the growing literature examining the external validity of youth self-reported SCT. Third, we used a reliable and validated measure of SCT that was developed based on meta-analytic findings of optimal SCT items. Using a sample of adolescents diagnosed with ADHD, we tested the hypotheses that (1) SCT symptoms would be more clearly associated with slower processing speed as motor demands increased, and (2) adolescent self-reported SCT symptoms would be more clearly associated than parent-reported SCT symptoms with slower processing speed.

Methods

Participants

Participants were 80 adolescents (57 males, 23 females) ages 13–17 years ($M = 14.99$, $SD = 1.09$) diagnosed with ADHD using the DSM-5 Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children (K-SADS) [58,59] interview conducted with the adolescent's parent ($n = 61$ with ADHD predominantly inattentive presentation, $n = 19$ with ADHD combined presentation). All participants had an IQ ≥ 80 ($Range = 83$ – 132 ; $M = 103.80$, $SD = 11.91$) based on the Kaufman Brief Intelligence Scale, Second Edition (KBIT-2) [60]. Approximately three-quarters of the adolescents were non-Hispanic White ($n = 62$; 77.5%), and the remaining participants were Black ($n = 8$; 10.0%), Asian ($n = 1$, 1.3%), Hispanic ($n = 1$; 1.3%), or multiracial ($n = 8$; 10.0%). Based on the K-SADS interview conducted separately with the adolescent and their parent, 7 participants (8.8%) met criteria for generalized anxiety disorder, 6 participants (7.5%) met criteria for oppositional defiant disorder, 2 participants (2.5%) met criteria for post-traumatic stress disorder, 1 participant (1.3%) met criteria for conduct disorder, and 1 participant (1.3%) met criteria for persistent depressive disorder. Approximately one-third of the adolescents were prescribed stimulant medication for ADHD ($n = 29$, 36.3%), though all participants were unmedicated on the day of testing.

Procedures

This study was approved by the Institutional Review Board (IRB). Multiple strategies were used to recruit participants over a two-year period, including letters distributed through schools and flyers/emails distributed at the institution where the study was conducted. Recruitment materials described a study examining sleep in adolescents with ADHD, though the study was not specific to (nor did it target) adolescents with sleep problems. Parents who contacted the research staff in response to these recruitment activities were given additional information and administered a phone screen to assess initial eligibility. At the inclusion/exclusion evaluation, all parents signed informed consent, and youth provided signed assent. All adolescents were required to meet full DSM-5 criteria for ADHD predominantly inattentive presentation or ADHD combined presentation on the K-SADS interview conducted with the parent to be eligible. Exclusion criteria for the primary study included ADHD predominantly hyperactive-impulsive presentation, autism, bipolar disorder, obsessive-compulsive disorder, or psychosis; possible presence of sleep-disordered breathing, periodic limb movement disorder, or restless leg syndrome; history of epilepsy or

head trauma resulting in loss of consciousness; regular high caffeine use (more than one coffee/energy drink or three caffeinated soft drinks per day); highly atypical sleep duration (routinely obtaining <6 hours of >9.5 hours on school nights); or obligations that required a bedtime later than 10:00PM or waking prior to 6:00AM. Data used in the present study were collected during the inclusion visit of the primary study (see [61] for additional details and a flow diagram).

Measures

Vanderbilt ADHD Diagnostic Parent Rating Scale (VADPRS).—The VADPRS [62] includes all nine inattentive (ADHD-IN) and nine hyperactive-impulsive (ADHD-HI) DSM ADHD symptoms. Each item is rated on a four-point scale (0 = *never*, 3 = *very often*). The factor structure, internal consistency, and reliability of the VADPRS is acceptable and consistent with DSM and other accepted measures of ADHD [63–65]. In the present study, mean scale scores were calculated (ADHD-IN $\alpha = .90$, ADHD-HI $\alpha = .90$) and included as covariates in the regression analyses to ensure findings were not attributable to ADHD symptom severity.

SCT symptoms.—The Child and Adolescent Behavior Inventory (CABI) [66] and the Child Concentration Inventory, Second Edition (CCI-2) [67] were used to assess parent- and adolescent-reported SCT symptoms, respectively. The same 15 items (e.g., daydreams, gets lost in own thoughts, slow behavior) are included on the CABI SCT module (0 = *almost never*, 5 = *almost always*) and CCI-2 (0 = *never*, 3 = *always*), are internally consistent, and demonstrate discriminant validity from ADHD symptoms [5,51,57]. Mean scale scores were calculated (CABI $\alpha = .92$; CCI-2 $\alpha = .88$).

Wechsler Processing Speed Index (PSI).—The Symbol Search and Coding subtests of the WISC-IV [43] were administered to participants ages 13–16 years and these subtests of the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV) [68] were administered to participants age 17 years¹. Symbol Search requires participants to quickly scan, discriminate and identify if there are matching symbols for each line. On the left side of the row there are two symbols and participants have to determine, as quickly as they can, if either symbol matches another symbol in the rest of the row. Coding, however, requires greater graphomotor skills as participants are required to look at a key of symbols paired with the numbers 1–9 at the top of the page and reproduce the symbol in the correct box in a grid of 90 numbers/symbols. Participants are timed for 120 seconds on both of these tasks. For both subtests, scores (items correct completed in 120 seconds) are converted to age-referenced standard scaled scores ($M = 10$, $SD = 3$) based on normative data.

Grooved Pegboard Test.—The Grooved Pegboard Test (Lafayette Instruments, Lafayette, Indiana), consists of 25 keyholes in a 5 × 5 grid. Participants are asked to fit the pegs in the keyholes as quickly as possible, first with their dominant hand and then again

¹Participants administered the WISC-IV (ages 13–16 years; $n = 73$) or WAIS-IV (age 17 years; $n = 7$) did not significantly differ on Coding or Symbol Search scores, nor did they differ on estimated IQ, Grooved Pegboard times, or SCT scores (all $ps > .05$). Further, the pattern of findings reported in this study were unchanged when analyses were conducted only with participants who were administered the WISC-IV.

with their non-dominant hand. This task is designed to measure motor dexterity [69]. Completion time in seconds for the dominant hand was used in analyses.

Statistical Analyses

All analyses were conducted in SPSS®, version 25 for Windows® (IBM Corporation, Armonk NY, USA). First, zero-order correlation analyses were conducted to examine the correlations among the study variables. A correlation of 0.10 is considered a small effect, 0.30 is considered a medium effect, and 0.50 is considered a large effect. Scatterplots were used to visually depict the association between SCT symptoms and the speeded task variables. Next, hierarchical regression analyses were conducted to examine whether SCT was associated with the speed variables when controlling for age, sex, and ADHD symptom severity. As recommended when examining cognitive functioning in neurodevelopmental disorders [70], we did not include intelligence (IQ) as a covariate. Age, sex, ADHD-IA, and ADHD-HI were entered at Step 1, and then SCT symptoms were entered at Step 2. Separate models were conducted for parent- and adolescent self-reported SCT symptoms².

Finally, supplemental regression analyses were conducted that included both parent- and adolescent-reported SCT symptoms entered simultaneously in order to examine whether one informant's ratings of SCT symptoms were associated with speeded test performance above and beyond the other informant's ratings of SCT. Age, sex, ADHD-IA, and ADHD-HI were again entered at Step 1, and then both parent- and adolescent-reported SCT symptoms were entered at Step 2.

Results

Correlation Analyses

Descriptive statistics and intercorrelations among study variables are provided in Table 1. Male sex was associated with significantly lower self-reported SCT symptoms ($r = -.26$, $p = .02$; male CCI-2 $M \pm SD = 1.08 \pm 0.45$, female CCI-2 $M \pm SD = 1.35 \pm 0.50$) and lower Coding scores ($r = -.24$, $p = .03$; male Coding $M \pm SD = 7.40 \pm 2.48$, female Coding $M \pm SD = 8.96 \pm 3.64$). Age was significantly associated with lower ADHD-HI symptoms ($r = -.31$, $p = .005$) and slower Grooved Pegboard time ($r = -.24$, $p = .04$). Neither ADHD-IN nor ADHD-HI symptoms were associated with any of the processing speed measures (all $ps > .05$). However, as shown in Figure 1, both parent- and adolescent-reported SCT symptoms were associated with slower speeded task performance on tasks with greater graphomotor and fine motor components. More specifically, parent-reported SCT symptoms were not significantly associated with PSI scores ($ps > .05$) but were significantly associated with slower Grooved Pegboard time ($r = .31$, $p = .005$). Adolescent-reported SCT symptoms were not significantly associated with Symbol Search ($r = -.15$, $p > .05$) but were significantly associated with slower Coding scores ($r = -.25$, $p = .025$) and slower Grooved Pegboard time ($r = .31$, $p = .005$).

²The pattern of findings was unchanged when controlling for medication status or when WISC/WAIS raw scores were used instead of standard scores.

Regression Analyses with Parent-Reported SCT Symptoms

Hierarchical regression analyses examining parent-reported SCT symptoms in relation to the speeded performance variables are shown in Table 2. Above and beyond sex, age, ADHD-IN symptoms, and ADHD-HI symptoms, parent-reported SCT symptoms were unassociated with PSI scores or the separate Symbol Search or Coding scores (all $ps > .05$). However, above and beyond these covariates, parent-reported SCT symptoms remained significantly associated with longer completion time on the Grooved Pegboard Test ($\beta = .26, p = .04$). Parent-reported SCT symptoms incrementally explained 5% of the variance in Grooved Pegboard Test times.

Regression Analyses with Adolescent-Reported SCT Symptoms

Hierarchical regression analyses examining adolescent-reported SCT symptoms in relation to the speeded performance variables are shown in Table 3. Above and beyond sex, age, ADHD-IN symptoms, and ADHD-HI symptoms, adolescent-reported SCT symptoms were significantly associated with lower PSI scores ($\beta = -.28, p = .01$), incrementally explaining 7% of the variance in PSI scores. However, analyses with the separate Symbol Search and Coding subtests indicated that adolescent-reported SCT symptoms were not significantly associated with Symbol Search scores ($\beta = -.18, p > .05$) but were significantly associated with lower Coding scores ($\beta = -.33, p = .003$). In addition, above and beyond these covariates, adolescent-reported SCT symptoms remained significantly associated with longer completion time on the Grooved Pegboard Test ($\beta = .36, p = .001$). Adolescent-reported SCT symptoms incrementally explained 10% and 12% of the variance in Coding scores and Grooved Pegboard Test times, respectively. In addition, male sex was associated with lower PSI scores, lower coding scores, and longer completion time on the Grooved Pegboard Test, though these associations were only significant in Step 2 when SCT symptoms were added to the model.

Supplemental Analyses Including both Parent- and Adolescent-Reported SCT Symptoms

Above and beyond sex, age, ADHD-IN symptoms, ADHD-HI symptoms, and parent-reported SCT symptoms, adolescent-reported SCT symptoms remained associated with significantly lower PSI scores ($\beta = -.28, p = .02$), lower Coding scores ($\beta = -.32, p = .004$), and longer Grooved Pegboard times ($\beta = .32, p = .007$). Parent-reported SCT symptoms were not significantly associated with any of the speeded performance variables above and beyond adolescent-reported SCT symptoms.

Discussion

Surprisingly few studies have examined whether behavioral symptoms of SCT are related to task-based processing speed. To our knowledge, the current study is the first to examine both parent- and adolescent-reported SCT in relation to multiple measures of processing speed. Findings from the current study point to two novel directions for examining whether – and under what circumstances – SCT symptoms may be associated with slower processing speed. First, the current study provides preliminary support for the possibility that SCT symptoms are associated with slower speed as motor demands increase and, second, that this association emerges more clearly when youth self-reported SCT symptoms rather than

parent-reported SCT symptoms are used. Each of these findings are discussed in turn, followed by key directions for future research.

Toward a More Nuanced Understanding of SCT and Processing Speed

The hypothesis that SCT would be more clearly associated with slower processing speed as motor task demands increased was largely supported. Neither adolescent- nor parent-reported SCT was significantly associated with Symbol Search scores, adolescent-reported (but not parent-reported) SCT was associated with lower Coding scores, and both adolescent- and parent-reported SCT was associated with longer (slower) Grooved Pegboard Test time. The behavioral characteristics of SCT, which include excessive daydreaming, mental confusion, and foggiess, and slowed behavior/thinking, may be particularly detrimental for task performance as motor demands increase. In contrast, when motor demands are low, these SCT symptoms may be less likely to interfere with speeded task performance. Of course, additional studies will be needed to replicate and extend these findings. It will also be important for research to examine possible mechanisms underlying associations with processing speed. The first neuroimaging studies of SCT identified associations between SCT symptoms and altered default mode network connectivity [36] and hypoactivity in the superior parietal lobe [39]. Default mode network brain areas are heavily implicated in mind wandering [35] and the superior parietal lobe is implicated in visual-spatial input [41], including writing specifically [71]. These findings provide a starting point for studies examining neurobiological mechanisms underlying SCT symptoms and their association with more specific indices of processing speed.

In addition, processing speed is a heterogeneous construct, and measures of ‘processing speed’ also frequently tap executive control processes that require goal maintenance, working memory, and decision making [72]. Our findings should be considered preliminary, as studies are needed that incorporate additional measures of processing speed, including both psychomotor and perceptual speed measures and tasks with verbal and nonverbal components (e.g., rapid automatized naming; Woodcock-Johnson perceptual speed subtests). Working memory appears to have a particularly influential impact on processing speed [22], though perhaps for more complex perceptual speed measures compared to psychomotor speed measures [72]. This is especially important given a recent study that found SCT symptoms to be associated with slower working memory manipulation speed but not with global information processing speed [19]. Future studies should evaluate whether SCT symptoms are linked to speeded test performance under varying conditions of working memory and attentional control demands. It is possible that these cognitive functions contribute to, or exacerbate, the association between SCT and poorer performance on tasks with increased motor demands.

The Importance of Adolescent Self-Report of SCT

A second contribution of the current study is the multi-informant assessment of SCT that includes both parent- and adolescent self-reported SCT. As described earlier, it has been hypothesized that SCT may be best conceptualized under the internalizing umbrella of psychopathology [31,55], for which self-report is generally considered important if not essential [73,74]. Studies have begun to examine self-reported SCT in relation to functional

outcomes such as internalizing symptoms, self-esteem, emotion dysregulation, and academic problems [6,55–57,75], but the current study is the first to our knowledge to examine youth self-reported SCT in relation to neurocognitive test performance. As hypothesized, self-reported SCT was more consistently associated than parent-reported SCT with slower processing speed, as self-reported SCT symptoms were associated with both lower Coding scores and longer Grooved Pegboard Test completion time. In contrast, parent-reported SCT was only associated with longer Grooved Pegboard Test completion times, consistent with previous findings by Hinshaw and colleagues using parent-reported SCT [46]. Yet in supplemental analyses that simultaneously included both parent- and adolescent-reported SCT symptoms, only adolescent-reported SCT symptoms remained significantly associated with longer Grooved Pegboard Test completion time. At a minimum, our findings add to the growing literature supporting the self-report of SCT symptoms in children and adolescents. Given the generally mixed findings among studies examining SCT in relation to neurocognitive functioning [1], our findings also point to the importance of studies examining SCT in relation to executive/neurocognitive functioning to include youth self-report ratings. Including self-report ratings may not only be important for understanding the mixed findings among studies examining SCT in relation to processing speed, but also other neurocognitive domains such as attention and working memory.

Strengths, Limitations, and Future Directions

Strengths of this study include examining SCT in adolescence, which has been far less studied compared to school-aged children. In addition, we included both parent- and adolescent-report of SCT symptoms, and this is the first study to examine adolescent self-reported SCT in relation to neurocognitive performance. We also used separate tests of processing speed with increasing motor demands, a novel approach in an effort to better understand the mixed findings in previous literature and to test more specific hypotheses regarding SCT in relation to processing speed.

Despite these strengths, several limitations are also important to note. This study used validated measures of processing speed but did not capture the full breadth of processing speed measures. The current study included three tasks that are similar in that they are speeded tasks with motor response output. In addition, the order of administration in this study was Symbol Search, Coding, and Grooved Pegboard, which were embedded in a research visit lasting approximately three hours, thus, fatigue/order effects should be ruled out in future studies using counterbalanced testing. It is also unknown if any participants had previous exposure to these tests. Future studies should utilize a wider range of processing speed tasks and incorporate additional measures of processing speed that allow for comparison between speeded tasks with verbal output and tasks with motor output [20]. Possible measures of non-motor processing speed include the Rapid Automatized Naming/Rapid Alternating Stimulus (RAN/RAS [76]) and the Rapid Picture Naming subtest from the Woodcock-Johnson fourth edition (WJ-IV [77]), whereas other subtests on the WJ-IV (Number-Pattern Matching, Letter-Pattern Matching, and Pair Cancellation) capture perceptual speed and orthographic processing with varying attentional control and divided attention demands. Research finding SCT symptoms to be associated with poorer performance on the psychomotor tasks but not the verbal tasks would support the hypothesis

that SCT symptoms are particularly related to slower speed on tasks requiring greater motor demands. It would also be beneficial for future research to more thoroughly assess motor function using measures such as the Bruininks-Oseretsky Test of Motor Proficiency second edition (BOT-2 [78]) as well as visual-motor integration using measures such as the Beery Developmental Test of Visual Motor Integration sixth edition [79].

The current study included a sample of 80 adolescents with ADHD and included eligibility restrictions related to sleep and caffeine intake. The mean scale ADHD scores and relatively low rates of comorbidity suggests that our sample may not be clinically severe. However, the mean self-report and parent-report SCT scores in the present study (1.16 and 1.44 for self- and parent-report, respectively) were higher than the mean scores reported in a large community study of children using the same SCT scales (0.75, 0.60, and 0.55 for self-, mother-, and father-report, respectively) [57]. The higher SCT scores in the present study align with SCT being elevated in ADHD samples [1] as well as the possibility that SCT symptoms increase from childhood to adolescence [80]. Nevertheless, the mean SCT scores in our sample were still not at the elevated end of the distribution. Findings should be replicated in larger samples of youth who exhibit elevated levels of SCT symptoms, who do not have ADHD, and in studies with broader inclusion criteria, to explore generalizability and whether associations hold across samples. Larger samples should also examine whether the association between SCT and processing speed is moderated by sex, as we found male sex to be associated with several processing speed indices but only when SCT symptoms were added to the model (see Table 3). Studies using larger samples will also be well-suited to examine whether specific items or subdimensions of SCT are more consistently or strongly associated with processing speed. For instance, slowed thinking and daydreaming may be relevant across processing speed tasks, whereas slowed behavior may be especially relevant for motor speed tasks and losing train of thought may be especially relevant for naming speed tasks.

Our sample only included adolescents with ADHD and it will be important to examine SCT and processing speed in typically developing adolescents as well as other clinical populations characterized by slowed processing speed (e.g., depression). Finally, the study is cross-sectional and precludes making causal conclusions; it will be important to replicate and extend our findings in studies using experimental and longitudinal designs. Longitudinal studies will be especially well-suited to examining whether SCT symptoms and processing speed similarly relate to important functional outcomes (e.g., academic performance, driving behaviors) in youth with and without ADHD.

Conclusions

Findings from this study of adolescents with ADHD provide preliminary support for the hypothesis that SCT symptoms may be more clearly associated with slower processing speed as motor demands increase. These findings have the potential to shed light on the mixed findings reported in previous studies examining SCT and processing speed. Further, this study adds to a growing body of literature demonstrating the importance of including youth self-report in studies aiming to examine the neurocognitive correlates and functional outcomes of SCT.

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Figure 1. Parent-Reported (top panel) and Adolescent-Reported (bottom panel) Sluggish Cognitive Tempo Symptoms are Associated with Slower Speeded Test Performance as Task Motor Demands Increase.

Note. Symbol Search, Coding, and Grooved Pegboard are z-scores to be on the same scale, with Grooved Pegboard reverse-scored so that for all three tests lower scores represent slower speed.

Table 1

Intercorrelations and Descriptive Statistics of Study Variables

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Sex	--										
2. Age	-.11	--									
3. IQ	.05	-.06	--								
4. ADHD-HI	.06	-.31**	.13	--							
5. ADHD-IN	.11	-.14	.12	.32**	--						
6. PR SCT	.16	-.15	-.05	.02	.50***	--					
7. SR SCT	-.26*	-.03	-.01	-.03	.03	.27*	--				
8. PSI	-.20	.17	.26*	-.09	-.13	-.17	-.22*	--			
9. Symbol Search	-.11	.20	.30**	-.04	-.11	-.12	-.15	.90***	--		
10. Coding	-.24*	.11	.14	-.13	-.14	-.18	-.25*	.88***	.59***	--	
11. Grooved Pegboard	.16	-.24*	-.19	.13	.20	.31**	.31**	-.54***	-.43***	-.55***	--
Mean	--	14.99	103.80	1.00	1.97	1.44	1.16	91.39	9.06	7.85	70.70
Standard Deviation	--	1.09	11.91	0.68	0.62	0.89	0.48	15.47	3.24	2.92	12.65

Note. $N = 80$. The PSI, Symbol Search, and Coding scores are standard scores; the Grooved Pegboard score is time in seconds. The possible score range was from 0 to 3 on the self-report SCT scale, from 0 to 5 on the parent-report SCT scale, and from 0 to 3 on the parent-report ADHD scale. For sex, 0 = female, 1 = male. ADHD-HI = attention-deficit/hyperactivity disorder hyperactivity-impulsivity symptoms. ADHD-IN = attention-deficit/hyperactivity disorder inattention symptoms. PR = parent-report. PSI = Processing Speed Index. SCT = sluggish cognitive tempo. SR = adolescent self-report.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

Table 2

Regression Analyses Examining Parent-Reported Sluggish Cognitive Tempo in Relation to Speeded Test Performance

	Step 1				Step 2			
	<i>b</i>	<i>SE</i>	β	<i>t</i>	<i>b</i>	<i>SE</i>	β	<i>t</i>
PSI	$F(4,75) = 1.40, R^2 = .07$				$F(1,74) = 0.65, R^2 = .008$			
Sex	-5.92	3.82	-.17	-1.55	-5.58	3.86	-.16	-1.45
Age	1.87	1.68	.13	1.12	1.68	1.70	.12	.99
ADHD-HI	-.12	2.80	-.01	-.04	-.59	2.87	-.03	-.21
ADHD-IN	-2.33	2.93	-.09	-.80	-.93	3.41	-.04	-.27
SCT	--	--	--	--	-1.86	2.31	-.11	-.81
SYMBOL SEARCH	$F(4,75) = 1.05, R^2 = .05$				$F(1,74) = 0.13, R^2 = .002$			
Sex	-.57	.81	-.08	-.70	-.54	.82	-.08	-.66
Age	.57	.35	.19	1.60	.55	.36	.18	1.52
ADHD-HI	.25	.59	.05	.42	.21	.61	.04	.34
ADHD-IN	-.46	.62	-.09	-.75	-.33	.72	-.06	-.46
SCT	--	--	--	--	-.18	.49	-.05	-.36
CODING	$F(4,75) = 1.63, R^2 = .08$				$F(1,74) = 1.13, R^2 = .01$			
Sex	-1.44	.72	-.22	-2.00*	-1.35	.72	-.21	-1.87
Age	.13	.32	.05	.41	.08	.32	.03	.25
ADHD-HI	-.33	.53	-.08	-.63	-.45	.54	-.10	-.84
ADHD-IN	-.37	.55	-.08	-.67	-.02	.64	-.01	-.04
SCT	--	--	--	--	-.46	.43	-.14	-1.06
GROOVED PEGBOARD	$F(4,75) = 2.04, R^2 = .10$				$F(1,74) = 4.23^*, R^2 = .05$			
Sex	3.43	3.08	.12	1.11	2.75	3.03	.10	.91
Age	-2.29	1.35	-.20	-1.69	-1.90	1.34	-.16	-1.42
ADHD-HI	.31	2.26	.02	.14	1.26	2.26	.07	.56
ADHD-IN	3.05	2.36	.15	1.29	.23	2.69	.01	.09
SCT	--	--	--	--	3.74	1.82	.26	2.06*

Note. *N* = 80. For sex, 0 = female, 1 = male. ADHD-HI = attention-deficit/hyperactivity disorder hyperactivity-impulsivity. ADHD-IN = attention-deficit/hyperactivity disorder inattention. PSI = Processing Speed Index. SCT = sluggish cognitive tempo.

*
 $p < .05$.

**
 $p < .01$.

 $p < .001$.

Table 3

Regression Analyses Examining Adolescent Self-Reported Sluggish Cognitive Tempo in Relation to Speeded Test Performance

	Step 1				Step 2			
	<i>b</i>	<i>SE</i>	β	<i>t</i>	<i>b</i>	<i>SE</i>	β	<i>t</i>
PSI	$F(4,75) = 1.40, R^2 = .07$				$F(1,74) = 6.32^*, R^2 = .07$			
Sex	-5.92	3.82	-.17	-1.55	-8.48	3.83	-.25	-2.21 [*]
Age	1.87	1.68	.13	1.12	1.62	1.63	.11	1.00
ADHD-HI	-.12	2.80	-.01	-.04	-.46	2.71	-.02	-.17
ADHD-IN	-2.33	2.93	-.09	-.80	-1.83	2.84	-.07	-.65
SCT	--	--	--	--	-9.07	3.61	-.28	-2.51 [*]
SYMBOL SEARCH	$F(4,75) = 1.05, R^2 = .05$				$F(1,74) = 2.39, R^2 = .03$			
Sex	-.57	.81	-.08	-.70	-.91	.83	-.13	-1.10
Age	.57	.35	.19	1.60	.53	.35	.18	1.51
ADHD-HI	.25	.59	.05	.42	.20	.59	.04	.35
ADHD-IN	-.46	.62	-.09	-.75	-.40	.61	-.08	-.64
SCT	--	--	--	--	-1.21	.78	-.18	-1.55
CODING	$F(4,75) = 1.63, R^2 = .08$				$F(1,74) = 9.16^{**}, R^2 = .10$			
Sex	-1.44	.72	-.22	-2.00 [*]	-2.01	.71	-.31	-2.83 ^{**}
Age	.13	.32	.05	.41	.07	.30	.03	.24
ADHD-HI	-.33	.53	-.08	-.63	-.41	.50	-.10	-.82
ADHD-IN	-.37	.55	-.08	-.67	-.26	.52	-.06	-.49
SCT	--	--	--	--	-2.02	.67	-.33	-3.03 ^{**}
GROOVED PEGBOARD	$F(4,75) = 2.04, R^2 = .10$				$F(1,74) = 11.10^{**}, R^2 = .12$			
Sex	3.43	3.08	.12	1.11	6.09	3.00	.22	2.03 [*]
Age	-2.29	1.35	-.20	-1.69	-2.03	1.27	-.17	-1.60
ADHD-HI	.31	2.26	.02	.14	.66	2.12	.04	.31
ADHD-IN	3.05	2.36	.15	1.29	2.53	2.22	.13	1.14
SCT	--	--	--	--	9.41	2.82	.36	3.33 ^{**}

Note. *N* = 80. For sex, 0 = female, 1 = male. ADHD-HI = attention-deficit/hyperactivity disorder hyperactivity-impulsivity. ADHD-IN = attention-deficit/hyperactivity disorder inattention. PSI = Processing Speed Index. SCT = sluggish cognitive tempo.

^{*} $p < .05$.

^{**} $p < .01$.

^{***} $p < .001$.