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Sluggish Cognitive Tempo and Neuropsychological Functioning

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Abstract

Sluggish cognitive tempo (SCT) is marked by impairments across social, emotional, and academic functioning, but few studies have examined the association between SCT and neuropsychological functioning. The present study examined the associations between SCT and measures of processing speed, executive function, attention, and reaction time. From a larger sample of 8,238 children and adolescents, a subsample of 928 children were overselected for symptoms of SCT or attention-deficit/hyperactivity disorder (ADHD) and compared to a matched control sample of 652 individuals without elevations of ADHD or SCT (age range = 5.9–15.4 years). Multiple regression analyses revealed that symptoms of SCT were independently associated with deficits in nearly all domains assessed by a battery of neuropsychological assessments, including slower processing speed, poorer working memory, decreased inhibition, poorer vigilance, and increased reaction time. Further, weaknesses in all five of these domains remained significant even after symptoms of ADHD-inattention, anxiety, and depression were controlled. These findings add to literature that supports the validity of SCT as a symptom profile separate from ADHD-inattention symptoms.

Keywords

sluggish cognitive tempo; neuropsychological; neurocognitive; assessment

Internal and External Validity of Sluggish Cognitive Tempo

Factor analyses of both parent and teacher ratings indicate that inattentive and hyperactive/impulsive symptoms represent two separable factors under the overarching category of attention-deficit/hyperactivity disorder (ADHD) (Willcutt et al., 2012; Tannock, 2013). However, these factors may not be sufficient to explain all attentional difficulties that lead to significant impairment. In addition to the dimensions of inattention and hyperactivity-impulsivity described in the Diagnostic and Statistical Manual of Mental Disorders, 4th and 5th editions (DSM-IV and DSM-5), factor analyses of symptoms of attentional difficulty consistently revealed a third factor of behaviors subsequently labeled “sluggish cognitive tempo” (SCT). First described over 30 years ago by Neeper & Lahey (1986), SCT includes symptoms of slowed cognitive processing, confusion, lethargy, and apathetic behavior (Becker et al., 2016).

While most studies find that symptoms of SCT are moderately correlated with the dimension of inattention symptoms that defines ADHD, the validity of SCT as a distinct construct has been established. In addition to initial factor analyses showing that symptoms of SCT consistently load on a factor separate from either inattention or hyperactivity/impulsivity (Willcutt et al., 2014; Bauermeister et al., 2012), subsequent studies demonstrated that SCT items also load on factors separate from depression, anxiety, and other internalizing symptoms (Willcutt et al., 2014; Lee et al., 2014; Becker et al., 2014; Smith et al., 2019).

Clinical Implications of SCT

Although SCT has never been included as a disorder in DSM-5 or other diagnostic systems, several lines of evidence also support the external validity of SCT as a clinically meaningful construct distinct from other DSM-5 disorders. A comprehensive meta-analysis found that SCT is associated with a range of important aspects of functional impairment, including higher rates of global impairment, social isolation and withdrawal, academic difficulty, and sleep disturbance (Becker et al., 2016). Importantly, several studies have demonstrated that associations between SCT and functional impairment remain significant even after symptoms of ADHD and other psychopathology are controlled, providing additional evidence that SCT is not simply an alternative measure of another established construct (e.g., Barkley, 2014; Carlson & Mann, 2002; Jacobson et al., 2018; Willcutt et al., 2014).

Neuropsychological Functioning

Compared with the extensive literatures on the neuropsychological functioning of children with ADHD and a range of other developmental psychopathologies (e.g., Willcutt et al., 2005; Willcutt et al., 2008; Willcutt et al., 2012), relatively little is known about potential neurocognitive deficits that may accompany elevations of SCT. Neuropsychological studies may provide important support for the validity of SCT as a construct by clarifying the cognitive architecture of SCT and providing additional evidence for the discriminant validity of SCT and other disorders such as ADHD and depression. The remainder of this section provides a brief overview of the small number of previous studies that tested the relationship between SCT and neuropsychological functioning.

Processing Speed

Behavioral ratings suggest that individuals with SCT move more slowly and appear to take longer to process and respond to stimuli, and some initial neuropsychological studies of SCT in children and adults suggest that these difficulties may also be observed on cognitive measures of processing speed (e.g., Willcutt et al., 2014; Jacobson et al., 2018). However, several other studies have found no significant association between SCT and processing speed in samples of children, adolescents, and college students (e.g., Bauermeister et al., 2012; Wood et al., 2017; Cook et al., 2019). Further, processing speed weaknesses are also associated with ADHD and most other childhood disorders (e.g., Willcutt et al., 2008), calling into question whether any observed processing speed weaknesses are uniquely associated with SCT. Therefore, despite the intuitive theoretical link between processing speed and SCT, additional research is needed to clarify the strength and independence of this association.

Attention

At least two aspects of attention have been included in previous neuropsychological studies of SCT. Two initial studies indicated that children with elevations of SCT may have difficulty disengaging from one stimulus to reorient their attention to a novel stimulus (Fassbender et al., 2015; Solanto et al., 2007). Behaviorally, the tendency to get “stuck” on one stimulus before reorienting could lead to the slower responses that characterize SCT.

In contrast, sustained attention and vigilance refer to an individual’s ability to maintain attention over an extended period of time. This construct is often operationalized by the number of correct responses to infrequent target stimuli on a lengthy, monotonous cognitive task. Several studies have found an association between SCT and difficulties with sustained attention (e.g., Wahlstedt & Bohlin, 2010; Baytunca et al., 2018; Willcutt et al., 2014), and the overall effect size for sustained attention was the largest of any of the cognitive constructs included in a recent meta-analysis (Becker et al., 2016). While additional research is needed, these initial studies suggest that poor sustained attention is a promising candidate for a weakness that may underlie symptoms of SCT.

Reaction Time & Response Variability

A small number of studies have examined the association between SCT and specific measures of simple reaction time (RT) and RT variability, the intraindividual variability in RT across trials of a task (e.g., Kofler et al., 2013; Willcutt et al., 2014; see Becker et al., 2016 for a review). One key theoretical issue concerns whether increased RT variability is a unique construct that is separable from other cognitive processes or whether high RT variability occurs as a secondary consequence of dysfunction in another cognitive process. For example, increased response variability might be a simple consequence of slow overall reaction time, although most studies found that the association between ADHD and reaction time variability remains significant when simple reaction time is controlled (see review by Kofler et al., 2013). Alternatively, other models suggest that RT variability may be closely related to the measures of sustained attention described in the previous section, with increased RT variability resulting from extremely long responses that occur on a subset of trials due to difficulties regulating attention over time (e.g., Hervey et al., 2006). A third set of models have proposed that high RT variability could reflect dysfunction in short-duration timing mechanisms that are mediated by cerebellar circuits (e.g., Castellanos & Tannock, 2002).

While additional work is needed to test these competing theoretical models, a slow and variable response style is similar to some of the behavioral features of SCT. Given these plausible theoretical links, measures of overall RT and RT variability have been included in a handful of initial studies of SCT in children, adolescents, and young adults (Capdevila-Brophy et al., 2014; Skirbekk et al., 2011; Jarrett et al., 2017; Baytunca et al., 2018; Camprodon-Rosanas et al., 2017). To date many of these studies have failed to find a consistent association between SCT and either RT variable, but the limited number of studies highlights the need for additional investigation.

Executive Functions

Executive functioning (EF) refers to the higher-order cognitive skills required to plan and carry out complex tasks, as well as those required to organize and monitor goal-directed behavior, including working memory (the ability to hold information in mind and mentally manipulate that information) and inhibition (the ability to control one's behavior, attention, or thoughts and override prepotent or impulsive responses) (e.g., Willcutt et al., 2005; Diamond, 2013). Executive functioning weaknesses are strongly associated with ADHD and a range of other developmental psychopathologies (e.g., Willcutt et al., 2005), but initial studies of SCT have yielded mixed results. The overall effect size in the meta-analysis by Becker and colleagues (2016) was significant for measures of inhibitory control, but other subsequent studies have not found an association between SCT and inhibition (Jimenez et al., 2015), with one recent study even suggesting that individuals with SCT performed better than those without SCT on a widely-used inhibitory task (Kofler et al., 2019).

Similarly, while the meta-analysis yielded a small but significant overall association between SCT and working memory (Becker et al., 2016), several individual studies failed to find an association between SCT and working memory deficits (Wahlstedt & Bohlin, 2010; Bauermeister et al., 2012; Becker et al., 2018), and a large study that reported a significant association found that this association disappeared after controlling for DSM-IV inattention symptoms (Willcutt et al., 2014). Overall, these mixed results underscore the need for additional research to clarify whether EF weaknesses play a role in the neuropsychology of SCT.

The Current Study

Although a number of studies have examined the association between SCT and functional impairment (e.g., Silverstein et al., 2019; Rondon et al., 2020), relatively few have examined the relationship between SCT and neuropsychological functioning. Further, many of the studies that have addressed this relationship have been limited by relatively small sample sizes or measurement using a limited battery of neurocognitive domains. The current study helped to fill a key gap in the literature on SCT by administering an extensive battery of neuropsychological measures to a large community sample of children with and without elevations of SCT or ADHD. The study extends previous research in several ways:

1. Initial analyses tested whether SCT is associated with weaknesses in one or more of six neuropsychological domains. We hypothesized that SCT would be most strongly associated with weaknesses on measures of processing speed and vigilance. In contrast, we did not expect to find an association between SCT and weaknesses in executive functions, providing further support for the distinction between SCT and ADHD.

2. Multiple regression analyses were then conducted to test whether any association between SCT and neuropsychological measures was explained by concurrent symptoms of other psychopathology such as ADHD, depression, or anxiety. We hypothesized that symptoms of these other disorders would also be associated with at least a subset of the neuropsychological measures but

would not completely explain the relationship between SCT and neurocognitive impairment.

3. Finally, we conducted the first test of a multiple deficit neurocognitive model of SCT. In contrast to models that suggest that a single neuropsychological weakness is necessary and sufficient to cause a disorder, multiple deficit models suggest that most disorders arise from a more complex combination of weaknesses in multiple neurocognitive domains (e.g., Pennington, 2006; McGrath et al., 2011; Willcutt et al., 2013). We hypothesized that processing speed, vigilance, and reaction time would be independently associated with SCT when all neuropsychological measures were included in the same model, indicating that weaknesses in these three domains are each important components of an overarching neuropsychological model of SCT.

Materials and Methods

Participants and Initial Screening Measures

Prior to beginning recruitment, approval was obtained from the University of Colorado IRB. A two-step procedure was used to identify the final sample included in the current neuropsychological analyses. In the first step, all students in five school districts were invited to participate in an initial questionnaire screening study. Written consent and assent were obtained from all participants prior to completing the initial screening questionnaires. A subset of participants were then invited to complete a more extensive individual testing session that included measures of intelligence, neuropsychological functioning, and academic achievement. Written consent and assent were again obtained for this further testing.

Initial Screening—Teachers and parents of all students between kindergarten and 8th grade in five public school districts were invited to complete an initial screening questionnaire as the first phase of the study (N = 8,238; Willcutt, 2012). As part of the initial screening, parent and teacher ratings of the 18 symptoms of DSM-IV ADHD were obtained using the *Disruptive Behavior Rating Scale* (DBRS; Barkley & Murphy, 1998). Each symptom is rated on a four-point scale (*never or rarely*, *sometimes*, *often*, and *very often*). Parents and teachers also completed a screening measure of SCT using the same format. Table 1 lists the twelve SCT items that were developed based on theoretical models and studies of SCT that were available at the time that the study was initiated (e.g., Carlson & Mann, 2002; McBurnett et al., 2001; Penny et al., 2009).

To identify the sample that was recruited for the neuropsychological assessment, parent and teacher ratings of each ADHD or SCT symptom were combined using the *or rule* algorithm from the DSM-IV field trials (Lahey et al., 1994). This algorithm codes a symptom as positive if it is endorsed by either the parent or the teacher; this algorithm is therefore the most inclusive of the widely-used algorithms to combine parent and teacher ratings. Approximately 15% of the screening sample met symptom criteria for DSM-IV ADHD, similar to the results of studies that defined cases based on the “or rule” in a meta-analysis of the prevalence of ADHD (Willcutt, 2012). This inclusive definition of cases was used for the initial screening in the larger study so that all individuals who met criteria for DSM-IV ADHD based on any algorithm would be included in the sample. This approach then allowed us to directly compare groups identified by different algorithms to assess the impact on estimates of prevalence and functioning (e.g., Willcutt, 2012).

Based on the finding that approximately 15% of the screening sample met the most inclusive definition of DSM-IV ADHD in the initial cohorts of the screening sample (e.g., Willcutt, 2012), an SCT cutoff score (3 symptoms) was derived that identified the top 15% of the screening sample on the measure of parent and teacher ratings of SCT described in the subsequent section. Results of the initial screening sample illustrate the significant association between SCT and ADHD. Over half of the participants who met screening criteria for ADHD also met screening criteria for SCT (N = 824 of 1,364 individuals; 60%), and 824 of 1,288 individuals who met screening criteria for SCT also scored above the screening cutoff for ADHD (64%).

Identification and Recruitment of the Final Sample—The ADHD and SCT measures from the screening sample were then used to identify the participants who were invited to participate in the neuropsychological study. Due to the primary focus of the overall study on ADHD and SCT, a higher proportion of participants who met the screening cutoff for SCT or ADHD were recruited for the final sample to increase statistical power for analyses of these subgroups.

Study staff conducted a telephone screening interview prior to any testing. We initially attempted to contact a total of 710 participants who met screening criteria for ADHD or SCT and 1,020 participants who did not meet screening criteria. Over 90% of participants that were contacted agreed to participate, yielding a final sample of 652 participants with elevations of SCT or ADHD and a sample of 928 children without elevations of ADHD or SCT. Of the 10% who did not participate, a small number of children were excluded from the study because the parent reported that the child had received a diagnosis of autism spectrum disorder or intellectual disability (6 participants in the ADHD or SCT groups and 6 in the control group; 1% of recruited children) or had significant visual or hearing impairment (2 participants in the ADHD/SCT group and 1 participant in the control group). In addition, 3% of families were successfully contacted but declined to participate (20 families in the groups with SCT or ADHD and 36 control families), and 5% of families did not respond or had moved out of the region (30 families from the ADHD/SCT groups and 35 control families).

Overall, the total sample that completed the neuropsychological measures included 1,580 children (M_{age} = 10.25 years, *SD* = 1.95, range = 5.9 – 15.4 years). Children and adolescents were in kindergarten through ninth grade. The majority of children were male (56.6%) and Caucasian (87.7%); 26.1% were African American, 4.1% were Native American/American Indian, and 3.3% were Asian American (participants were allowed to indicate more than one race). Across all races 13.9% of the sample identified their ethnicity as Hispanic.

Procedures for the Individual Assessment

To maximize participation in the individual assessment, each family chose whether to complete the measures in the home (N = 844; 53%) or in our laboratory (N = 736; 47%). Results were nearly identical when analyses were completed separately in the samples tested in the home and the laboratory. In both settings the cognitive measures were administered in a single session in a quiet room by an examiner who had extensive experience working with children. The testing session lasted approximately two hours, and frequent breaks were provided to minimize fatigue and maximize motivation.

Parents of participants who were taking psychostimulant medication were asked to withhold medication for 24 hours prior to each session of the study. While the child completed the cognitive measures, the parent completed the measures of behavioral and affective functioning in a separate room.

Measures Obtained During the Neuropsychological Assessment Session

Behavioral and Affective Measures—One parent per participant completed the *DSM-IV Diagnostic Interview for Children and Adolescents* (DICA-IV; Reich et al., 1997), a structured diagnostic interview, including modules for measures of anxiety (GAD) and depression (MDD). The primary measure for each module was total symptom count (one-month test-retest reliability in a subset of the current sample was .88 for GAD and .85 for GAD). Parents also completed the second edition of the *Behavior Assessment System for Children* (BASC), a psychopathology screening measure that has excellent reliability and validity in this age range (Reynolds & Kamphaus, 2004). The BASC-II includes measures of externalizing (e.g., Aggressive Behavior) and internalizing (e.g., Anxiety, Depression) symptoms.

A composite score was created for depression by age-correcting and standardizing each child's score on the MDD module of the DICA-IV and the Depression module of the BASC-II and taking the average of these two scores. A similar procedure was used with the GAD module of the DICA-IV and the Anxiety module of the BASC-II to create an anxiety composite score.

Neuropsychological Composites—Five composite measures (processing speed, working memory, inhibition, reaction time, and response variability) were created by age-correcting and standardizing the participant's score on measures of each domain then computing and re-standardizing the mean of those scores. A single task was used to measure vigilance. The six final measures were scaled so that higher scores indicated worse performance.

The *WISC-III Coding* and *Symbol Search* subtests (Wechsler, 1991) are paper-and-pencil measures of processing speed (test-retest reliability in the current age range = .72 – .78). The *Coding* subtest requires the child to rapidly copy symbols associated with specific digits based on a key provided at the top of the page, and the *Symbol Search* subtest requires participants to match a symbol to an identical target symbol that is displayed among distracter stimuli. Part A of the *Trail Making Test*, an additional measure of processing speed, requires the participant to connect numbered dots in numerical order as quickly as possible. The primary dependent measure is completion time in seconds.

In the *Sentence Span* working memory task (Siegel and Ryan, 1989), the participant is instructed to provide the last word for a set of simple sentences read by the examiner. The participant then reproduces the words that they provided after all sentences in that set have been completed. The task starts with a block of three two-sentence sets and increases in difficulty by adding one additional sentence per block up to a total of six sentences. The primary dependent measure is the number of sets completed correctly (test-retest reliability = .65 – .71; Kuntsi et al., 2001).

The *WISC-III Digit Span* subtest (Wechsler, 1991) assesses verbal short-term and working memory. During the first part of the task, Digits Forward, the examiner reads a series of digits that increases in length with each trial, and the child repeats the digits verbatim. The second part of the task, Digits Backward, requires the child to recite the digits in the reverse of the order in which they were initially presented by the examiner. The primary measure is the number of correct trials (test-retest reliability = .80 – .83).

On the *Gordon Diagnostic System* (Gordon, 1983) visual continuous performance test (CPT) assessing inhibition, a single-digit number is presented in the center of the display once per second for nine minutes. The participant is instructed to press the specified button only after they observe the target sequence (*1* followed by *9*) and to inhibit their response to all other sequences. The primary measure of inhibition is the number of commission errors (the total number of responses to a sequence of numbers other than the target sequence). One-year test-retest reliability was adequate in a subset of the current sample that was followed longitudinally (r = .76)

The *Stop-signal task* (e.g., Logan et al., 1997; Schachar et al., 2000) is a computerized measure of inhibitory control. On primary task trials, the letters X or O are presented in the center of the monitor and the participant responds by pressing the corresponding key on the keyboard. On stop-signal trials, the same visual stimulus appears, but an auditory tone is also presented shortly after the X or the O appears on the screen. The participant is instructed to press the X or O keys as rapidly as possible for each trial but to inhibit the key press on trials in which the tone is presented. An iterative tracking procedure is then used to estimate stop-signal reaction time (SSRT), the primary measure of inhibition reflecting the time to respond to the inhibitory cue (test-retest reliability = .80).

The CPT described above (Gordon, 1983) was also used to assess sustained attention. The primary measure was the number of omission errors, operationalized as the total number of times the participant failed to respond to the target sequence (one-year test-retest reliability = .73).

Simple reaction time (RT) and response variability were assessed on the primary trials of the *Stop-signal task* (e.g., trials that did not include a stop-signal). Response variability was operationalized as the intraindividual standard deviation of reaction times on the primary trials. A second measure of reaction time was also obtained for correct responses on the CPT. Estimated test-retest and split-half reliabilities were adequate to high in the current study and other previous samples that were similar in age (*r*s = .72 – .90; e.g., Logan et al., 1997)

Data Analysis

Each variable was examined for outliers (i.e., scores that fell more than three standard deviations (SD) from the variable mean and more than 0.5 SD beyond the next most extreme score), and each outlier was adjusted to a score 0.5 SD units beyond the next most extreme score (one case for SSRT and CPT commission errors). After adjusting for outliers, the distribution of each variable was assessed to identify any significant deviation from normality. If skewness or kurtosis was greater than one, a logarithmic transformation was implemented to approximate a normal distribution for seven variables (SSRT, omission and commission errors on the Gordon Diagnostic Test, completion time for Trail Making Test Part A, and symptoms of GAD and MDD on the DICA-IV).

All behavioral, affective, and neuropsychological measures were age-corrected and standardized based on the overall sample to create composite measures of symptom dimensions (ADHD-PI, ADHD-PH, SCT, depression, and anxiety) and neuropsychological domains. Means of composite measures were restandardized to create the final z-scores. All measures were scaled so that higher scores indicated greater impairment/worse performance.

Zero-order correlations were computed to examine the strength of the associations between SCT and the six measures of neuropsychological functioning, along with the measures of ADHD symptom dimensions and internalizing symptoms. To test whether any measures of neuropsychological functioning were independently associated with SCT beyond covariance with these correlated variables, scores on each neuropsychological measure were then regressed simultaneously onto measures of SCT, inattention, hyperactivity-impulsivity, and internalizing symptoms. Finally, in order to test which neuropsychological measures account for unique variance in SCT in a multiple deficit model, a multiple regression model was constructed by simultaneously entering all six neuropsychological composites as independent variables predicting SCT.

Results

Correlations

Zero-order correlations were significant between SCT and all six domains of neuropsychological functioning (Table 2). Effect sizes for the associations between SCT and the neuropsychological variables were small to medium in magnitude (e.g., Cohen, 1988), with the largest effects on the processing speed composite. SCT symptoms were also significantly associated with both ADHD symptom dimensions, as well as symptoms of anxiety and depression.

Unique Associations with SCT When ADHD and Other Symptoms Are Controlled

Due to the finding that ADHD symptoms, anxiety, and depression were significantly associated with both SCT and lower scores on the neuropsychological measures, a series of multiple regression analyses were conducted to test if SCT was associated with neuropsychological weaknesses after these variables were controlled. All effects of SCT remained significant when depression and anxiety were also included as covariates, so these covariates were dropped from the final models (Table 3). Although depression and anxiety were significantly associated with neuropsychological measures, neither depression nor anxiety were remained significant predictors of any neuropsychological domains in models that contained SCT and ADHD symptoms as covariates. SCT and inattention were both significantly associated with processing speed, working memory, and inhibition when all dimensions of psychopathology were entered simultaneously in multiple regression models predicting each neuropsychological domain. In contrast, only SCT was significantly associated with vigilance and reaction time, and only inattention was significantly associated with response variability.

Multiple Deficits Model

The final analysis tested a multiple deficit model of SCT by regressing the SCT score onto the six neuropsychological composite measures (Table 4). Processing speed and working memory were each independently associated with SCT, whereas effects of inhibition, vigilance, reaction time, and response variability were no longer significant once all neuropsychological measures were included in the model.

Discussion

Neuropsychological Function and SCT

Symptoms of SCT were associated with weaknesses in nearly all domains assessed by an extensive battery of neuropsychological assessments, including slower processing speed, poorer working memory, decreased inhibition, poorer vigilance, and increased reaction time. In a multiple regression model that included all neuropsychological measures simultaneously as predictors, composite measures of processing speed and working memory were each independently associated with SCT.

Given initial concerns regarding the validity of the distinction between SCT and other disorders, it was important to test whether any neuropsychological dysfunction associated with SCT might be better explained by the correlation between SCT and other psychopathology. SCT was significantly associated with nearly all domains of neuropsychological impairment even when ADHD and internalizing symptoms were included in multiple regression models, indicating that the association between SCT and neuropsychological impairment is not explained by these potentially confounding variables. These results provide support for the external validity of SCT and indicate that SCT is not simply a relabeling of another well-defined construct like inattentive ADHD or depression (Becker et al., 2016).

The current results extend the sparse literature on SCT and neuropsychological functioning in several important ways. The association between SCT and sustained attention is consistent with extant research and theoretical models of SCT (Wahlstedt & Bohlin, 2010; Skirbekk et al., 2011). SCT symptoms were also independently related to slower performance on tasks measuring processing speed. Although some studies have demonstrated slower processing speed in individuals with higher levels of SCT (e.g., Willcutt et al., 2014), other studies with smaller samples have failed to find such a relationship (e.g., Bauermeister et al., 2012). Potential reasons for these inconclusive findings may include varying sample sizes, the lack of a standard metric for SCT, and different processing speed tasks. Therefore, the presence in this study of a significant association between SCT and both processing speed and reaction time, even after including ADHD and several other covariates, is promising and suggests that future studies should continue to investigate the relation between SCT and different aspects of response speed by increasing sample sizes, standardizing the way SCT is measured, and drawing on several different tasks for each domain.

Given limited previous research showing no association between SCT and executive function (e.g., Wahlstedt & Bohlin, 2010; Bauermeister et al., 2012; Jimenez et al., 2015), we did not expect to find associations between SCT and working memory or inhibition. Contrary to our initial predictions, however, SCT was significantly associated with poorer performance on tasks measuring inhibition and working memory even after controlling symptoms of ADHD. The finding regarding inhibition was particularly surprising, considering that impulsivity or a failure to inhibit seems counterintuitive to the slowed and sluggish nature of SCT. The finding of impaired inhibition in SCT also contrasts with a recent study that found a negative association between SCT symptoms and inhibitory errors (Kofler et al., 2019). To clarify the interpretation of this unexpected result, secondary analyses were run separately for the two component tests that are included in the composite inhibition score. SCT symptoms were associated with poorer performance on the Stop-signal task but were not associated with the number of commission errors on the Gordon Diagnostic Test. Although the Stop-signal task taps inhibitory processes, the dependent measure is based on response time. Performance on this task may therefore be driven by an overall tendency to respond slowly in addition to disinhibition. In contrast, the measure of commission errors tallies the number of incorrect responses and does not include a measure of speed of response. Therefore, it is possible that the association between SCT and lower scores on the inhibition composite may reflect slow response speed in addition to difficulty inhibiting impulsive responses per se. Future studies that incorporate additional measures of inhibitory control will help to clarify this finding.

Overall, these results provide initial support for a multiple deficit neuropsychological model of SCT in which weaknesses in processing speed and working memory act in combination with other weaknesses to increase risk for SCT symptoms. However, the full multiple deficit model accounted for only 18% of the total variance in SCT. These results indicate that the majority of the variance in SCT remains to be explained by other cognitive weaknesses beyond those included in the current study, and the relatively small effect sizes for each measure suggest that these tasks are unlikely to have adequate sensitivity to be useful for clinical diagnoses. Similarly complex multiple deficit neuropsychological models have been reported for ADHD, learning disabilities, and a number of other developmental disorders (e.g., McGrath et al., 2011; Pennington, 2006; Willcutt et al., 2008).

Limitations and Future Directions

Selection of the Sample—The original screening sample includes children from all families in five local school districts who agreed to participate in the initial screening. Although the "at risk" cases were then selected for symptoms of either ADHD or SCT, slightly more cases with ADHD symptoms were selected due to the initial goals of the overall project. Nearly all associations between SCT and neuropsychological functioning remained significant when ADHD symptoms were controlled, suggesting that the enrichment of the sample for cases with ADHD does not appear to be driving the primary results. Nonetheless, future studies of unselected population-based samples and larger samples of participants selected directly for elevations of SCT would provide a useful extension of the current study.

Measurement of SCT—The items on the current measure of SCT were developed based on the literature at the time the study was initiated, and a subsequent meta-analysis of factor analytic studies indicated that many of the items are excellent measures of the latent construct of SCT (Becker et al., 2016). However, this systematic review also suggested that some items on the current scale may be relatively weak measures of SCT. Specifically, "absentminded," "apathetic or unmotivated," and "easily confused" had relatively low mean loadings on an SCT factor in the meta-analysis and often cross-loaded with DSM-IV inattention symptoms, and items related to indecisiveness and lack of awareness of surroundings were not included in most studies of SCT.

To test whether the inclusion of these items impacted the results, analyses were conducted again using an SCT composite score that excluded these items. Effects were slightly smaller for some analyses, but these changes were minimal (e.g., a difference of .02 – .04 between correlations) and the overall pattern of results was the same. Nonetheless, the meta-analysis underscores the need for continued work to continue to refine the definition and measurement of SCT.

Neuropsychological Measures—The current study includes one of the most extensive batteries of neuropsychological measures that has been included in a study of SCT to date. However, it is still important to acknowledge several important limitations and describe future extensions of this research that will facilitate the continued refinement of neuropsychological models of SCT

One of the most important findings in the current paper is the strong association between SCT and processing speed, as operationalized by fine-motor responses on visual tasks. Future extensions of this research may wish to test whether these findings generalize to other aspects of processing speed such as auditory processing and verbal responses or are specific to nonlinguistic tasks.

A second important direction for future research involves the measurement of executive functions. The multiple deficit model suggests that a weakness in working memory is an important component of the overall neuropsychology of SCT, but larger effects may potentially be obtained in future studies that administer tasks that have a stronger working memory load than the relatively simple Digit Span task used in the current study. Similarly, the optimal approach to measure inhibition remains uncertain, and future studies that incorporate a more extensive set of these measures will provide a useful extension of these results. Finally, the current battery did not include any measures of the ability to switch between different cognitive sets, a third component that emerges in most factor analyses of executive function measures (e.g., Friedman et al., 2007). Ideally future studies of SCT will incorporate multiple measures of each of these primary EF domains.

An important strength of the current study was the administration of multiple measures of many of the neuropsychological constructs. However, the battery included only a single measure of omission errors on a continuous performance task as a measure of sustained attention, and the measure of RT variability was derived exclusively from the stop-signal task. We initially considered combining these measures to create a composite measure of sustained attention. However, given the relatively low correlation between these measures ($r = .28$) and ongoing theoretical debate regarding the interpretation of RT variability, these single measures were analyzed separately. The more limited measurement of these aspects of attentional control may have contributed to the nonsignificant effects for these variables in the multiple deficit model. It would be useful for future studies to include multiple measures that provide more comprehensive coverage of sustained attention and vigilance, particularly given the prominence of this construct in theoretical models of SCT.

Finally, the current neuropsychological battery did not assess several other aspects of neuropsychological functioning that may be important components of a comprehensive multiple deficit model of SCT. These could include measures of other aspects of attentional control such as the ability to reorient attention and selectively attend to relevant stimuli, along with measures of neurophysiological arousal and persistence during difficult and demanding tasks (e.g., Becker et al., 2019; Yung et al., 2020).

Sample Composition—Finally, although this sample is generally representative of the community from which it was drawn (and is in fact more diverse than the population of the Denver/Boulder metropolitan area as a whole), the majority of participants were non-Hispanic Caucasians. This sample composition may limit the generalizability of the current results to children from other racial or ethnic groups, underscoring the need for additional studies of SCT in diverse samples.

Clinical Implications

The present study indicates that SCT is associated with significant neuropsychological weaknesses in several key domains, providing additional support for the validity of SCT as a clinically meaningful construct (e.g., Becker et al., 2016). Although SCT is not included as a disorder in DSM-5 or any other current diagnostic system, it is becoming increasingly clear that elevations of SCT meaningfully describe a subset of the population whose difficulties are impairing and whose symptoms may not be captured by existing DSM-5 disorders. However, in the absence of a comorbid diagnosis such as ADHD or depression, it is unlikely that children with SCT will receive services to address the potential social and academic consequences of SCT. Further, because SCT symptoms are less disruptive for parents and teachers than more overt overactive or oppositional behaviors, children who are experiencing impairment due to these difficulties may never be identified at all.

The repercussions of this gap extend beyond the world of research. Simply because students are not disrupting a classroom does not mean that their cognitive, emotional, and social well-being is not at risk. Previous studies have demonstrated that social impairment is reliably associated with symptoms of SCT, and reduced processing speed, working memory, and vigilance may make it more difficult to complete many school-relevant tasks, including taking notes and participating in classroom discussions.

Conclusion

Although the validity of sluggish cognitive tempo has been established, the extent of its neurocognitive impact on children and adolescents remains understudied. The present study represents an important contribution to understanding the relationships between symptoms of sluggish cognitive tempo and domains of neuropsychological functioning and highlights the need for further research to better define these relationships.

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Table 1

Symptoms of sluggish cognitive tempo

Is apathetic or unmotivated	Is drowsy or sleepy
Is sluggish, slow to respond	Seems not to hear, needs things repeated
Is easily confused	Daydreams, stares into space, or gets lost in thoughts
Seems to be “in a fog”	Is underactive, slow moving, or lacks energy
Is absentminded, forgets things easily	Seems to be unaware of his/her surroundings
Is lethargic	Has trouble making up his/her mind

Table 2

Zero-order correlations between behavioral, internalizing, and neuropsychological covariate measures

	Correlations										
	1. SCT	**2. ADHD-Inattention**	**3. ADHD-Hyperactivity**	**4. Dep**	**5. Anx**	**6. Processing Speed**	**7. Working Memory**	**8. Inhibition**	**9. Vigilance**	**10. RT**	**11. RT Variability**
Behavioral Measures											
1. Sluggish Cognitive Tempo	–										
2. ADHD – Inattention	.77**	–									
3. ADHD – Hyperactivity	.51**	.75**	–								
Internalizing Measures											
4. Depression	.41**	.36**	.31**	–							
5. Anxiety	.25**	.19**	.19**	.66**	–						
Neuropsychological Measures											
6. Processing Speed Composite	.38**	.39**	.27**	.20**	.12**	–					
7. Working Memory Composite	.23**	.25**	.18**	.13**	.10**	−.40**	–				
8. Inhibition Composite	.23**	.25**	.19**	.11**	.07*	−.34**	−.30**	–			
9. Vigilance	.23**	.19**	.12**	.12**	.06*	−.38**	−.27**	.40**	–		
10. Reaction Time Composite	.13**	.08**	.02	.05*	.07**	−.20**	−.15**	.10**	.10**	–	
11. Response Variability Composite	.25**	.28**	.23**	.17**	.12**	−.37**	−.34**	.47**	.28**	.53**	–

Note:

* = $p < .05$,

** = $p < .01$

Table 3

Multiple regression analyses of the relationships between symptoms of ADHD and SCT and measures of neuropsychological functioning

Multiple regression models						
Neuropsych Compositea	**Inattention *B* [95% CI]**	**Hyp-Imp *B* [95% CI]**	**SCT *B* [95% CI]**	R^2	*df*	*F*
Processing Speed	.16 [−.22, −.10]***	−.02 [−.04, .08]	.21 [−.29, −.13]***	.17	3	107.30***
Working Memory	.15 [−.23, −.06]**	0 [−.07, .06]	.08 [−.15, −.01]*	.07	3	37.70***
Inhibition	.14 [.04, .25]**	.01 [−.06, .09]	.10 [.02, .18]*	.07	3	30.49***
Vigilance	.08 [−.04, .18]	−.03 [−.11, .05]	.19 [.11, .27]***	.05	3	28.63***
Reaction Time	.02 [−.08, .10]	−.07 [−.13, −.01]*	.14 [.06, .20]***	.02	3	10.96***
Response Variability	.17 [.07, .27]**	.04 [−.08, .12]	.08 [−.02, .16]	.09	3	33.43***

[a]These measures are scaled so that a positive *B* indicates an association between higher levels of SCT/ADHD and greater neuropsychological weakness.

Note: These results are from a model in which inattention, hyperactivity-impulsivity, and SCT were entered simultaneously as independent variables. Symptoms of MDD and GAD were then entered simultaneously as covariates in a second step. The inclusion of MDD and GAD symptoms did not significantly change results, therefore these variables were dropped from the final model.

Processing speed: N = 1579; Working Memory: N = 1577; Inhibition: N = 1567; Vigilance: N = 1553; Reaction Time: N = 1561; Response Variability: N = 1059

* = p < .05,

** = p < .01,

*** = p < .001

Table 4

Multiple regression analyses testing the relationship between sluggish cognitive tempo and all measures of neuropsychological function

Multiple Deficits Model		
Sluggish Cognitive Tempo		
R^2		.18
F		37.39 ***
Df		6
Processing Speed	−.38	[−.46, −.29] ***
Working Memory	−.11	[−.19, −.03] **
Inhibition	.07	[−.01, .15]
Vigilance	.05	[−.02, .11]
Reaction Time	.05	[−.04, .14]
Response Variability	.07	[−.02, .15]

Note:

* = p < .05,

** = p < .01,

*** = p < .001