What Cognitive Processes Are 'Sluggish' In Sluggish Cognitive Tempo?

Michael J. Kofler, Ph.D.[1], **Lauren N. Irwin, M.A.**[1], **Dustin E. Sarver, Ph.D.**[2,3], **Whitney D. Fosco, Ph.D.**[4], **Caroline E. Miller, B.A.**[1], **Jamie A. Spiegel, M.S.**[1], **Stephen P. Becker, Ph.D.**[5,6]

[1]Florida State University, Department of Psychology

[2]Department of Pediatrics, Center for Advancement of Youth, University of Mississippi Medical Center, 2500 North State Street, Jackson MS 39216, USA

[3]Department of Psychiatry and Human Behavior, University of Mississippi Medical Center, 2500 North State Street, Jackson MS 39216, USA

[4]Center for Children and Families, Florida International University, Miami, FL 33199, USA

[5]Division of Behavioral Medicine and Clinical Psychology, Cincinnati Children's Hospital Medical Center, 3333 Burnet Avenue, MLC 10006, Cincinnati, OH 45229, USA

[6]Department of Pediatrics, University of Cincinnati College of Medicine, 3230 Eden Avenue, Cincinnati, OH 45267, USA

Abstract

Objective: Sluggish cognitive tempo refers to a constellation of symptoms that include slowed behavior/thinking, reduced alertness, and getting lost in one's thoughts. Despite the moniker 'sluggish cognitive tempo,' the evidence is mixed regarding the extent to which it is associated globally with slowed (sluggish) mental (cognitive) information processing speed (tempo).

Method: A well-characterized clinical sample of 132 children ages 8–13 years (*M*=10.34, *SD*=1.51; 47 girls; 67% White/non-Hispanic) were administered multiple, counterbalanced neurocognitive tests and assessed for sluggish cognitive tempo symptoms via multiple-informant reports.

Results: Bayesian linear regressions revealed significant evidence *against* associations between sluggish cognitive tempo and computationally-modeled processing speed (BF_{01}>3.70), and significant evidence *for* associations with slower working memory manipulation speed. These

Corresponding Author: Michael J. Kofler, Ph.D., Florida State University | Department of Psychology, 1107 W. Call Street | Tallahassee, FL 32306-4301, Phone: (850) 645-0656, Fax: (850) 644-7739, kofler@psy.fsu.edu.

Conflict of Interest:
The authors have no conflicts of interest to report.

Ethical Approval:
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent:
Informed consent was obtained from all individual participants included in the study.

findings were consistent across parent and teacher models, with and without control for ADHD-inattention and IQ. There was also significant evidence linking faster inhibition speed with higher parent-reported sluggish cognitive tempo symptoms.

Conclusions: These findings provide strong evidence *against* characterizing children with 'sluggish cognitive tempo' symptoms as possessing a globally sluggish cognitive tempo. Instead, these symptoms appear to be related, to a significant extent, to executive dysfunction characterized by working memory systems that are too slow and inhibition systems that are too fast. Behaviorally, these findings suggest that requiring extra time to re-arrange the active contents of working memory delays responding, whereas an overactive inhibition system likely terminates thoughts too quickly and therefore prevents intended behaviors from starting or completing, thereby giving the appearance that children are absent-minded or failing to act when expected.

Sluggish cognitive tempo refers to a constellation of symptoms that include slowed behavior/thinking, reduced alertness, excessive daydreaming, and getting lost in one's thoughts (Becker et al., 2016; McBurnett et al., 2014). Currently, sluggish cognitive tempo symptoms are assessed solely by rating scales, and despite its name it remains unclear whether 'sluggish' cognitive processes actually underlie the sluggish cognitive tempo construct. Identifying the specific cognitive mechanisms and processes that underlie sluggish cognitive tempo symptoms is imperative given evidence that these symptoms begin in early childhood, increase in severity as children progress in school, and predict impairments in important areas of functioning (for review see Becker et al., 2016). For example, higher sluggish cognitive tempo symptoms are associated with lower reading and math achievement (Langberg et al., 2014; Wåhlstedt & Bohlin, 2010), impaired social functioning (Becker et al., 2019; Willcutt et al., 2014) and increased internalizing symptoms (Penny et al., 2009; Servera et al., 2018), over and above the risk conveyed by ADHD-inattentive symptoms (Becker et al., 2016). Thus, it is not surprising that research on sluggish cognitive tempo has begun to extend beyond the domain of ADHD in an effort to better understand the construct and how it may be conceptualized within broader models of psychopathology (Becker et al., 2016; Becker & Willcutt, 2019).

Despite converging evidence supporting the validity of sluggish cognitive tempo (Becker et al., 2016), little is known about the underlying mechanisms and processes responsible for these symptoms. Identifying these mechanisms reflects a critical step for advancing theory as well as prevention and intervention approaches. Although the moniker sluggish (slow) cognitive (mental) tempo (speed) presumes that the symptoms are attributable to slow processing speed, the evidence to support this conceptualization is surprisingly mixed (for review see Mueller et al., 2014). Studies specifically evaluating sluggish cognitive tempo symptoms have assessed processing speed using speeded tests with graphomotor, skeletomotor, and oral response demands. Results based on all three response formats have been mixed, with a similar number of studies finding (Hinshaw et al., 2002; Lundervold et al., 2011; Solanto et al., 2007; Tamm et al., 2018; Willcutt et al., 2014) and not finding (Bauermeister et al., 2012; Hinshaw et al., 2002; Skirbekk et al., 2011; Willard et al., 2013) associations with sluggish cognitive tempo.

The reason for the discrepancy between the construct's namesake and the mixed evidence for a 'sluggish' (slow) cognitive tempo is unclear, but may be related to the use of relatively non-specific tests of processing speed (Canivez et al., 2016). In addition, to our knowledge all previous studies have used test metrics such as mean reaction time that are confounded by a host of processes beyond cognitive information processing speed, including stimulus encoding, motor output, and response tendencies such as an emphasis on accuracy over speed (Huang-Pollock et al., 2016). As detailed below, the current study addresses these limitations and is the first to use a battery of tests informed by contemporary cognitive science and computational modeling to decompose speeded test performance into theoretically and empirically distinct components of information processing speed.

In addition to global information processing speed, studies investigating the neurocognitive correlates of sluggish cognitive tempo have emphasized examination of specific executive functions. The early interest in executive functioning appears to be related to sluggish cognitive tempo's origins in the ADHD literature, where executive function deficits are well established (e.g., Kofler et al., 2019). Indeed, early accounts suggested that sluggish cognitive tempo may differ from ADHD-inattention in that ADHD-inattention is characterized by executive dysfunction whereas sluggish cognitive tempo does not affect specific cognitive functions *per se* but rather compromises task performance broadly by slowing down task-related processes (Mueller et al., 2014). However, this dual-dissociation hypothesis does not appear to be well supported in the literature. Similar to the mixed evidence for processing speed deficits reviewed above, recent findings offer conflicting evidence as to whether executive functions such as inhibitory control and working memory abilities are significantly (Skirbekk et al., 2011; Willard et al., 2013) or not significantly (Bauermeister et al., 2012; Willcutt et al., 2014) associated with sluggish cognitive tempo symptoms. These conflicting findings may be related to psychometric and construct validity concerns similar to those described above. In particular, most studies assessed working memory using simple span tasks that show poor construct validity (Wells et al., 2018) and to our knowledge all available studies relied at least in part on power-based metrics (e.g., number of errors) rather than speed-based metrics that may be more relevant for understanding executive functioning in the context of symptoms presumed to be characterized by 'sluggish' cognitive speed.

Current Study

Despite the moniker 'sluggish cognitive tempo,' the evidence is mixed regarding the extent to which sluggish cognitive tempo is associated globally with slowed (sluggish) cognitive information processing speed or specifically with impairments in the efficiency of particular executive functions. In addition, the evidence base relies primarily on relatively non-specific tests of processing speed and gross neuropsychological functioning (Snyder et al., 2015) and metrics that may be confounded by physical and strategic processes (e.g., encoding, motor speed, speed-accuracy trade-offs; Huang-Pollock et al., 2016). The current study addressed these limitations via the use of (a) a battery of multiple, cognitively-informed tests per construct; (b) computational modeling to decompose task performance data into more refined estimates of information processing efficiency and related processes (Voss et al., 2013); (c) speed-based rather than power-based estimates of inhibitory control (Verbruggen et al., 2013), working memory manipulation (Trapp et al., 2017), and cognitive set shifting abilities (Miyake et al., 2012); (d) a hierarchical approach to differentiate global information processing speed deficits from specific executive function speed deficits; and (e) Bayesian statistics that assess support both for and against effects of each neurocognitive process. Our primary research questions are as follows:

1. Is sluggish cognitive tempo associated with a sluggish cognitive tempo? That is, do children with higher sluggish cognitive tempo symptoms demonstrate slower information processing efficiency (drift rate)? If sluggish cognitive tempo is a syndrome characterized globally by slowed cognitive processing, then we would expect children with higher sluggish cognitive tempo symptoms to evince slower information processing speed (i.e., drift rate should negatively predict sluggish cognitive tempo symptoms).

2. Are specific cognitive processes beyond global information processing speed associated with sluggish cognitive tempo? In particular, to what extent do children with higher sluggish cognitive tempo symptoms demonstrate impairments in the speed of the inhibitory stop process (inhibition speed), cognitive set shifting speed, and working memory manipulation speed? No firm predictions are offered given mixed findings and/or lack of prior research as reviewed above. Preregistered hypotheses are detailed below, and include speculation that sluggish cognitive tempo may in part reflect:

    a. An over-inhibited condition, such that the speed of the inhibitory stop process might be *faster* in these children. In the race-horse model of inhibition (Logan, 1994), a behavior is initiated when a ‘go’ process finishes before a ‘stop’ process can catch the ‘go’ process, whereas a behavior is inhibited (restrained or cancelled) when the ‘stop’ process successfully catches the ‘go’ process. Perhaps counterintuitively, slower inhibition (stopping) speed is associated with quick and impulsive behaviors (Nigg, 2016) due to the failure of the ‘stop’ process to catch the ‘go’ process (i.e., the child is unable to stop themselves before it is too late). Conversely, *faster* inhibition speed may be characterized by *slower or less frequent* behavioral responses to the extent that the ‘stop’ process too frequently stops the ‘go’ process before a behavior can begin. Conceptually, we hypothesized an association between sluggish cognitive tempo and faster inhibition speed (over-inhibition) given the preponderance of sluggish cognitive tempo items that reflect informant perceptions of the *absence* of expected behavior (e.g., stares into space, off in own world, lost in thoughts). This hypothesis would be supported by findings that faster inhibition speed predicts greater sluggish cognitive tempo symptoms.

    b. Slower cognitive set shifting that delays these children’s attempts to flexibly shift back and forth between mental sets. In this case, children who cannot quickly shift between mental sets might appear ‘sluggish’ in that it takes them longer to shift their focus of attention to an alternate rule set in response to changing environmental demands. In this case, we expect that children who take longer to shift between mental sets would be viewed as exhibiting higher sluggish cognitive tempo symptoms.

c. Slowed manipulation of information within working memory. That is, children with higher sluggish cognitive tempo may be able to accumulate and use information to make decisions as quickly as their peers (i.e., no relation with global information processing speed) but may take longer to actively manipulate that information within the internal focus of attention (Oberauer & Kliegl, 2006). In this case, we would expect a positive relation between sluggish cognitive tempo and how long it takes children to correctly reorder stimuli within working memory.

d. A deliberate, cautious response strategy and/or an outcome of slow-downs in non-cognitive processes associated with initial encoding and motor output. In this case, we would expect response caution (speed/accuracy trade-off) and/or non-decision time (encoding/motor speed) to positively predict sluggish cognitive tempo.

3. Are any associations detected above unique to sluggish cognitive tempo or better attributed to sluggish cognitive tempo's association with ADHD-inattention? We expected that any associations detected above would be robust to control for ADHD-inattention symptoms.

Method

Preregistration and Open Data

Detailed data analytic plans were preregistered at https://osf.io/nvfer/. There were no departures from the preregistration with one clearly marked exception. The de-identified dataset (.jasp) and annotated results output (including test statistics) are available for peer review: https://osf.io/2hmqp/.

Participants

The sample included 132 children aged 8–13 years (*M*=10.34, *SD*=1.51; 47 girls) from the Southeastern U.S. recruited through community resources from 2015–2018 for participation in a clinical research study of the neurocognitive mechanisms underlying pediatric attention and behavioral problems. Psychoeducational evaluations were provided to all caregivers. All parents and children gave informed consent/assent, and IRB approval was obtained/maintained. Sample ethnicity was mixed with 88 White/Non-Hispanic (66.7%), 17 Hispanic/English-speaking (12.9%), 16 African-American (12.1%), 3 Asian (2.3%), and 8 multiracial children (6.1%; Table 1).

All children and caregivers completed an identical, comprehensive evaluation that included detailed, semi-structured clinical interviewing for DSM-5 (K-SADS; Kaufman et al., 1997) and multiple norm-referenced parent and teacher questionnaires. Please see the study's preregistration for a detailed account of the comprehensive psychoeducational evaluation: https://osf.io/nvfer/. The final sample included 82 children with ADHD (76% combined, 22% inattentive, 2% hyperactive/impulsive presentation; clinical consensus best estimate comorbidities: 23% anxiety, 10% oppositional-defiant, 6% depressive, 7% high-functioning autism spectrum disorders) and 50 children without ADHD (48% neurotypical, 32% anxiety, 16% high-functioning autism spectrum, 6% depressive, 4% oppositional-defiant disorders; Table 1)[1]. Positive screens for reading (15% ADHD, 0% Non-ADHD) and math disability (11% ADHD, 0% Non-ADHD) were defined based on score(s) >1.5 *SD* below age-norms on one or more KTEA-3 reading and math core subtests, as specified in DSM-5 (APA, 2013). Psychostimulants ($N_{prescribed}$=25) were withheld ≥24 hours for neurocognitive testing. Children were excluded for gross neurological, sensory, or motor impairment; history of seizure disorder, psychosis, or intellectual disability; or non-stimulant medications that could not be withheld for testing.

Procedures

Testing occurred during a larger battery of two, 3-hour sessions. Tasks were counterbalanced within/across sessions to minimize order/fatigue effects. Children received brief breaks after each task and preset longer breaks to minimize fatigue.

Computerized Task Battery

Stop-signal.—Task and administration instructions were identical to Alderson and colleagues (2008). Psychometric evidence includes high internal consistency (α=.83–.89), 3-week test-retest reliability (.72), and convergent validity with other inhibition tests (Soreni et al., 2009). Go-stimuli were displayed for 1000-ms as uppercase letters X and O positioned in the center of a computer screen (500-ms ISI; total trial duration=1500-ms). Xs and Os appeared with equal frequency. A 1000-Hz auditory tone (stop-stimulus) was presented randomly on 25% of trials. Stop-signal delay (SSD) – the latency between go- and stop-stimuli presentation – was initially set at 250-ms, and dynamically adjusted +50-ms contingent on performance. The algorithm was designed to approximate successful inhibition on 50% of stop-trials. In the current study, inhibition success was 58.5%, 56.6%, 56.0%, and 56.2% across the four experimental blocks. The percent of successful inhibitions was within the acceptable range (>20% and <80%) for all but *n*=6 cases; the pattern and interpretation of results was unchanged in exploratory analyses that excluded these 6 cases. Children used a modified response pad to complete two practice and four consecutive experimental blocks of 32 trials/block (8 stop-trials per block).

Global-local.—The Miyake et al. (2012) local-global task was adapted for use with children. This computerized task uses Navon figures, which feature a ‘global’ shape (e.g., square) constructed using smaller, ‘local’ figures (e.g., triangles). Figures were presented sequentially in one of four quadrants in a clockwise rotation on a computer monitor (jittered ISI 800–2000-ms). Children were required to shift their response between global and local

[1]As recommended in the K-SADS, oppositional defiant disorder was diagnosed clinically only with evidence of multi-informant/multi-setting symptoms. Neurotypical children had normal parent-reported developmental histories and did not meet criteria for any psychiatric disorder. The ADHD and non-ADHD groups were statistically equivalent in the proportion of non-ADHD clinical disorders (47.6% and 52.0% of ADHD and non-ADHD groups, respectively; overall: BF01 = 17.54).

features depending on which quadrant the figures appeared (top quadrants: global; bottom quadrants: local). Trials with stimuli in the top left or bottom right quadrants involved set shifting (shift trials) because responses required a different rule than the previous trial; trials with stimuli in remaining quadrants did not require shifting because they featured the same rule as the previous trial (no-shift trials). To minimize memory demands, on-screen cues (“big shape,” “small shapes”) remained visible next to each quadrant. Sixty trials were administered following three blocks of 6–8 practice trials (100% correct required). Children responded via mouse click.

Local-local.—This task is identical to the global-local task except that children always responded to the smaller, ‘local’ stimuli (i.e., no explicit set shifting demands).

Number-color.—The Miyake et al. (2012) number-letter task was adapted for use with children. A pair of single-digit numbers appeared on the screen, and children were instructed to click either the larger or smaller value depending on the font color. Both digits were the same color on any given trial. To minimize memory demands, on-screen instructions (“blue bigger,” “yellow smaller”) remained visible throughout the task. Trials were presented in a semi-random sequence to require shifting every other trial, with an equal number of bigger-smaller and smaller-bigger shifts. RT and response data were recorded separately for ‘shift’ and ‘no-shift’ trials. Following an 8-trial practice block (100% correct required), children completed 60 trials (jittered ISI 80–200-ms).

Rapport phonological and visuospatial working memory tests.—The Rapport et al. (2009) computerized working memory tasks involve serial reordering of characters presented (numbers, black dot locations), and reordering of a target stimulus (letter, red dot location) into the final serial position recalled. Six trials were administered at each set size for each task (3–6 stimuli/trial; 1 stimuli/second). The 24 total trials per task were randomized, then grouped into 2 blocks of 12 trials each, with short breaks between each block (approximately 1-minute) (Kofler et al., 2016). Five practice trials were administered before each task (80% correct required). The phonological task involved mentally reordering and verbally recalling a jumbled series of sequentially presented numbers and letters (e.g., 4H62 is correctly recalled as 246H). The visuospatial task involved mentally reordering a sequentially presented series of spatial locations based on what color dot appeared in each location (black dots in serial order, red dot last) and responding on a modified keyboard. Partial-credit unit scoring (stimuli correct per trial) at each set size was used (Conway et al., 2005); response times (milliseconds) for each response (visuospatial) or trial (phonological) were recorded.

Evidence Accumulator Modeling of Information Processing Speed

Most cognitive tasks extract reaction time and/or accuracy parameters to evaluate performance. Yet, these metrics are comprised of numerous psychologically-distinct processes, making interpretation difficult (see Huang-Pollock et al., 2016 for an elegant discussion of this problem). Well-validated computational stochastic accumulator models were therefore used to decompose performance data into theoretically-linked components of information processing speed. Models include the drift diffusion model for 2-choice response tasks (stop-signal, number-color) and the linear ballistic accumulator (LBA) model for tasks with >2 response options (global-local, local-local) as recommended (Donkin et al., 2009).

Both models assume that, when faced with a simple decision, individuals accumulate information continuously until they reach a threshold, at which point they have sufficient information to make a decision. The length of time required to make a response can be described by three computationally and psychometrically distinct processes: drift rate, response caution, and non-decision time.

Drift rate.—Drift rate (v) is the primary indicator of information processing speed (Voss et al., 2013), and refers to the speed of information uptake; smaller drift rates indicate less rapid information uptake/greater processing demands. Drift rate estimates were obtained from no-shift trials during four tasks: stop-signal, local-local, global-local, and number-color.

Response caution.—Response caution (a) refers to the quantity of information considered before a decision is executed; higher boundary separation (diffusion models) or upper boundary (LBA models) indicates a slower, more accurate decision style (i.e., more reflective response style) and is often interpreted as evidence of a speed-accuracy trade-off (Voss et al., 2013). Speed-accuracy trade-off (response caution) estimates were obtained from the same four tasks used to estimate drift rate.

Non-decision time.—Non-decision time (t_0) captures aspects of reaction time performance unrelated to decision-making, including stimulus encoding and response execution speed. Higher non-decision time reflects slower encoding and/or motor speed, which are not separable in these models. Non-decision time estimates were obtained from the same 4 tasks used to estimate drift rate.

Diffusion modeling was conducted using the Kolmogorov-Smirnov (K-S) algorithm as implemented in the *fast-dm* software v.30.2 (Voss & Voss, 2007) given its robustness to outliers, use of individual trial data to derive diffusion parameters, and evidence that it provides excellent parameter recovery with as few as 20 trials per participant (Voss & Voss, 2007). Separate drift rates were modeled for shift and no-shift trials (number-color). Boundaries for the number-color set-shifting task were set as the response options “larger” and “smaller,” and boundaries for the stop-signal task were the response options “X” and “O.”

The LBA is a well-validated evidence accumulator model of multiple-response tasks (Donkin et al., 2011). The LBA is conceptually similar to the diffusion model but was explicitly developed to model multiple-response task data (Donkin et al., 2009). Diffusion and LBA models tend to agree closely when fit to real datasets as done in the current study (Donkin et al., 2011). Whereas the diffusion model assumes a single evidence accumulator moving toward opposing boundaries (choice A vs. choice B), the LBA model assumes that evidence accumulates separately for each response option until one has sufficient data to make a decision (Donkin et al., 2009). Thus, under the LBA, there is a separate drift rate for each response option (e.g., 12 total drift rates for the global-local task: one for each of the 6 response options during no-shift trials: circle, triangle, square, etc.; and one for each of these same 6 response options during shift trials). Presentation of a stimulus causes evidence to accumulate linearly over time for each response option separately. The participant's response represents the accumulator whose evidence total reaches the response threshold first. Drift rates from no-shift trials for each stimulus were averaged to create a single indicator of overall information processing speed for each task.

LBA parameters were estimated using the R package hBayesDM (hierarchical Bayesian modeling of Decision-Making tasks; Ahn et al., 2017; Annis et al., 2017) separately for shift and no-shift trials using 3 Markov Chain Monte Carlo (MCMC) chains, each with 2000 samples and a 1000 sample burn-in. Convergence was verified by visual inspection of the sampling chains and $\widehat{R} < 1.1$ for the drift rate hyperparameters (*mu*) and for participant-level data for all parameters for all tasks for all participants[2]. Visual inspection of the posterior distributions of the hyperparameters indicated the expected unimodal distributions.

Executive Functioning Speed

Executive functions are a set of interrelated, higher-order cognitive processes that enable goal-directed behavior and novel problem-solving (Miyake et al., 2012). Among the diverse models of executive functioning, factor analytic and theoretical work provides the most empirical support for models that include three primary executive function domains: working memory, inhibitory control, and set shifting (Karr et al., 2018).

Set shifting speed.—*Set shifting* refers to the ability to flexibly switch back-and-forth between mental sets via activation of prefrontal and posterior parietal cortices (Pa et al., 2010). Cognitive set shifting speed was defined as the difference between drift rate during shift and no-shift trials (shift_cost=shift–no_shift), computed for the global-local and number-color set shifting tasks. We decided *a priori* to use drift rate rather than mean RT because drift rate explicitly controls for non-cognitive processes that may otherwise confound estimates based on summary statistics such as mean RT as described above (Voss et al., 2013).

Inhibition speed.—*Inhibitory control* refers to a set of interrelated cognitive processes that underlie the ability to withhold or stop an on-going response (Alderson et al., 2007) and are supported by networks involving bilateral frontal and interconnected networks (Cortese et al., 2012). Inhibition speed refers to the speed of the inhibitory stop process (iSSRT) and was estimated separately for each of the 4 stop-signal task blocks using the Verbruggen et al. (2013) integrated method.

Working memory manipulation speed.—*Working memory* refers to the active, top-down manipulation of information held in short-term memory, and includes interrelated

[2]For the LBA models, there were 8 total $\widehat{R}$ values > 1.1, indicating potential convergence issues for one of the 6 response options for 1 of the 2 conditions in 1 of the 2 tasks for 8 participants (0.38% of estimated parameters). Each of these 8 data points were removed and replaced with the mean of that participant's drift rate for the other 5 response options for that task/condition. For the diffusion models, there were 4 total p-values < .05 indicating potential poor fit; these estimates were discarded and replaced using group mean substitution.

functions of the mid-lateral prefrontal cortex and interconnected networks (Wager & Smith, 2003). Working memory manipulation speed was operationalized as response time per correct response on the PHWM and VSWM tasks, separately for each task for each set size (3–6; 8 total variables).[3]

Neurocognitive Dimension Reduction

Statistically, we controlled for task impurity by computing Bartlett weighted averages based on the intercorrelations among task performance scores (DiStefano et al., 2009). Conceptually, this process isolates reliable variance associated with each neurocognitive construct by removing task-specific demands associated with non-executive processes, time-on-task effects via inclusion of multiple blocks per task, and non-construct variance attributable to other measured executive and non-executive processes (e.g., short-term memory load). Thus, the multiple estimates of each neurocognitive metric were separately reduced to single principal components: Drift rate (38.0% variance accounted; loadings=.63–.76), response caution (48.1% variance accounted; loadings=.56–.69), non-decision time (39.6% variance accounted; loadings=.64–.78), set shifting speed (53.2% variance accounted; loadings=.73–.73), inhibitory speed (51.8% variance accounted; loadings=.63–.76), and working memory manipulation speed (49.8% variance accounted; loadings=.58–.80)[4]. Higher scores reflect faster information processing speed (drift rate), greater emphasis on accuracy over speed (response caution), slower stimulus encoding and/or motor speed (non-decision time), slower cognitive set shifting, slower inhibitory speed, and slower working memory manipulation speed. These neurocognitive component scores were used in all analyses below.

Sluggish Cognitive Tempo (SCT)

The Kiddie-Sluggish Cognitive Tempo (K-SCT; McBurnett et al., 2014) parent and teacher forms each include 15 items that assess sluggish cognitive tempo symptoms on a 4-point scale (*never/rarely, sometimes, often, very often*). Higher scores reflect greater sluggish cognitive tempo symptom severity. K-SCT development emphasized convergent and discriminant validity, such that item retention required both high sluggish cognitive tempo

---

[3]There is not a clear distinction in the literature between cognitive information processing speed (e.g., as assessed by drift rate) and working memory manipulation speed (e.g., how quickly children can mentally re-order information). Further, to our knowledge current time-based resource-sharing models of working memory focus on the decay of items from passive storage (e.g., when they are outside the internal focus of attention and cannot be refreshed due to distractor tasks), but are unable to model the processes involved in actively manipulating the information currently held within working memory's internal focus of attention. Our working view is to distinguish between the rate of information accumulation toward a decision as described in evidence accumulator models (i.e., drift rate) and the speed with which the accumulated information can be mentally manipulated. Both can be considered to involve "processing" in the general sense, but it seems useful to distinguish what type of processing is occurring: in this case, building internal evidence to discriminate among competing response options (with relevance for maintaining items in working memory when the focus of attention is moved away from the memory set by a concurrent distractor task), and actively manipulating information within the focus of attention. We refer to the former as information processing speed (drift rate) and the latter as working memory manipulation speed. In the current study we entered drift rate into the hierarchical regression models in a separate step prior to entering working memory manipulation speed (and the other executive function speed variables) to ensure that any overlap between these two constructs does not mask effects of drift rate given the primacy of this question, In the current study, drift rate and working memory speed were modestly correlated $r= -.35$ (BF^{10}=391.37), supporting their distinctiveness as constructs. Drift rate was also correlated with inhibition speed ($r= -.44$, $BF^{10}=7.64 \times 10^4$) and shifting speed ($r= -.27$, BF^{10}=14.23) in the expected directions (faster processing speed associated with faster executive functioning speed).

[4]Significant loadings (<.3) are reported. The stop-signal task failed to contribute to the response caution and non-decision time components, and the number-color task failed to contribute to the drift rate component. All neurocognitive components were defined by at least 3 task variables with significant loadings with one exception (only 2 shifting tasks were included in the battery).

and low ADHD-inattention factor loadings (McBurnett et al., 2014). Internal consistency in the current sample was α=.93 (teacher) and α=.90 (parent). K-SCT parent and teacher total raw scores served as the primary DVs. Additional analyses examined K-SCT subscales (alertness, working memory slips, sleepy/tired).

ADHD-Inattention (ADHD-I)

The ADHD Rating Scale for DSM-5 (ADHD-RS-5; DuPaul et al., 2016) parent and teacher forms each include the 9 DSM-5 ADHD-inattentive symptoms assessed on a 4-point scale (*never/rarely*, *sometimes*, *often*, *very often*). Higher scores reflect greater quantity/frequency of inattentive symptoms. Internal consistency in the current sample was α=.94 (teacher and parent). Cross-informant zero-order correlations between ADHD-inattention and K-SCT were .25–.35 (BF_{10}>6.24).

Intellectual Functioning (IQ) and Socioeconomic Status (SES)

IQ was estimated using the WISC-V short-form IQ (Sattler, 2018); SES was estimated using the Hollingshead (1975) scoring based on caregiver(s)' education and occupation.

Bayesian Analyses

The benefits of Bayesian methods over null hypothesis significance testing (NHST) are well documented (Rouder & Morey, 2012). For our purposes, Bayesian analyses were selected because they allow stronger conclusions by estimating the magnitude of support for both the alternative and null hypotheses (Wagenmakers et al., 2016). Bayesian linear regressions with default Jeffrey-Zellner-Siow priors were conducted using JASP 0.9.1 (JASP Team, 2018). Instead of a *p*-value, these analyses provide BF_{10}, which is the Bayes Factor of the alternative hypothesis (H_1) against the null hypothesis (H_0). BF_{10} is an odds ratio, where values above 3.0 are considered moderate evidence supporting the alternative hypothesis (i.e., statistically significant evidence for the alternative hypothesis). BF_{10} values above 10.0 are considered strong (≥30=very strong, ≥100=decisive/extreme support; Wagenmakers et al., 2016).

Conversely, BF_{01} is the Bayes Factor of the null hypothesis (H_0) against the alternative hypothesis (H_1). BF_{01} is the inverse of BF_{10} (i.e., BF_{01}=1/BF_{10}), and is reported when the evidence indicates a lack of an effect (favors the null hypothesis, i.e., when BF_{10}<1). BF_{01} values are interpreted identically to BF_{10} (≥3.0=moderate, ≥10.0=strong, ≥100=decisive/extreme support for the null hypothesis that a predictor does *not* have an effect on an outcome).

Thus, finding BF_{10}=10.0 would indicate that the observed data are 10 times more likely under the alternative hypothesis (i.e., strong evidence for an effect), whereas BF_{01}=10.0 would indicate that the observed data are 10 times more likely under the null hypothesis (i.e., strong evidence *against* an effect). In the current study, we refer to findings of $BF_{10} \geq 3$ as significant evidence for an effect (i.e., support for the alternative hypothesis of an effect at/above pre-specified evidentiary thresholds), and findings of $BF_{01} \geq 3$ as significant evidence *against* an effect (i.e., support for the null hypothesis of no effect at/above pre-specified evidentiary thresholds).

Data Analysis Overview

Our primary and exploratory analyses are organized into three tiers. The primary Tier 1 analyses examine neurocognitive, behavioral, and demographic predictors of parent- and teacher-reported sluggish cognitive tempo symptoms. We selected a hierarchical approach *a priori* in which we evaluated potential covariates for inclusion/exclusion at each step, including demographics (step 1), information processing speed (step 2), and executive function speed (step 3). In each step, the best fitting model was selected (criteria: combination of predictors with highest $BF_{10} \geq 3$), and each additional predictor was tested relative to this best-fitting model (Rouder & Morey, 2012).

Demographic and behavioral variables were entered in the first step of each Bayesian linear regression (age, gender, SES). Step 1 variables that did not provide at least anecdotal support for the alternative hypothesis of a significant effect (i.e., $BF_{10} \geq 2$) were removed prior to step 2. The three information processing speed predictors (drift rate, response caution, non-decision time) were added in the second step given the primary research question's focus on information processing speed and retained based on the same threshold ($BF_{10} \geq 2$). The three executive function variables (inhibitory speed, cognitive set shifting speed, working memory manipulation speed) were then added in a third step. Cross-informant ADHD-inattention symptoms were added last (step 4) to check the robustness of the final model and specificity of the findings to sluggish cognitive tempo given the expected moderate overlap between sluggish cognitive tempo and ADHD-inattention symptoms. Cross-informant ratings were used to prevent spurious associations attributable to mono-informant bias (i.e., parent ADHD ratings were used to predict teacher sluggish cognitive tempo ratings, and vice versa). The decision to exclude ADHD hyperactivity/impulsivity symptoms was made *a priori* given replicated evidence that they are less clearly related to sluggish cognitive tempo symptoms (Becker et al., 2016).

Separate models were estimated for parent- and teacher-reported sluggish cognitive tempo symptoms. These parent and teacher omnibus models were repeated in the Tier 2 and 3 models, which used the K-SCT subscales (Tier 2) and IQ (Tier 3) to probe the extent to which the Tier 1 findings were driven by particular sluggish cognitive tempo parameters and robust to control for IQ, respectively.

Results

Preliminary Analyses

Outliers ≥3.0 *SD* were winsorized relative to the within-group distribution (0.49–0.79% of Non-ADHD/ADHD data points, respectively). Task data from subsets of the current battery have been reported previously for subsets of the current sample to examine conceptually unrelated hypotheses.[5] Data for the study's primary outcome (sluggish cognitive tempo symptoms) has not been previously reported.

[5]Performance data on differing subsets of the current study's tasks for subsets of the current sample were included in the datasets used for recent studies to investigate conceptually distinct hypotheses as control tasks when investigating the episodic buffer component of working memory (Kofler, Spiegel et al., 2018), as part of the battery used to investigate executive functioning heterogeneity in ADHD (Kofler, Irwin et al., 2019), as predictors of social problems (Kofler, Harmon et al., 2018), as control and experimental tasks when

Tier 1 Primary Analyses: Mechanisms Associated with Sluggish Cognitive Tempo (SCT)

The Tier 1 results are presented below and summarized in Table 2.

Parent-reported sluggish cognitive tempo symptoms

Potential covariates.—The evidence trended toward support for an effect of SES (BF_{10}=2.00) but this effect failed to exhibit an adequate level of support. There was significant evidence *against* effects of age (BF_{01}=4.35) but insufficient evidence against effects of gender (BF_{01}=1.37). Therefore, only SES was retained for step two based on the preregistered plan.

Information processing predictors.—Bayesian linear regression provided significant evidence *against* effects of drift rate (BF_{01}=4.94), response caution (BF_{01}=5.31), and non-decision time (BF_{01}=5.09) predicting SCT symptoms. Therefore, only SES was retained (BF_{10}=2.02).

Executive function predictors.—The final best fitting model included SES, inhibitory speed, and working memory manipulation speed (BF_{10}=20.32; R^2=.12). With reference to this model, the evidence trended toward a null relation but was insufficient evidence to conclusively rule out an effect of set shifting on SCT (BF_{01}=2.06); set shifting was therefore removed based on the preregistered plan. Inspection of the posterior summaries of coefficients for the best fitting model (mean B-weights) indicated that lower SES (B=−0.10, 95% credible interval = −0.20 to −0.001), slower working memory manipulation (B=1.86, 95% credible interval = 0.61–3.11), and faster inhibition speed (B=−1.27, 95% credible interval = −2.50 to −0.04) were associated with greater parent-reported SCT symptoms.

Robustness check.—Teacher-reported ADHD-I symptoms were added to the final model to probe the specificity of the results to sluggish cognitive tempo. The results suggest that the findings are robust, with the best fitting model (BF_{10}=48.04; R^2=.15) retaining the final model variables above (SES, inhibition speed, working memory speed) and adding ADHD-I. Greater teacher-reported ADHD-I was associated with greater parent-reported SCT (B=0.14, 95% credible interval = 0.004–0.32; ΔR^2=.03).

Teacher-reported sluggish cognitive tempo symptoms

Potential covariates.—Results failed to provide significant support for any of the covariate models; SES (BF_{01}=3.23), age (BF_{01}=1.68), and gender (BF_{01}=5.06) were all removed prior to step 2.

Information processing predictors.—Bayesian linear regression provided the strongest support for an effect of response caution (BF_{10}=2.86), although this effect failed to reach prespecified evidence levels for a significant effect despite reaching prespecified levels for retaining variables to the next step. There was significant evidence *against* an

investigating set shifting abilities (Irwin et al., 2019), and as predictors of organizational skills in children with ADHD (Kofler, Sarver et al., 2018).

effect of drift rate (BF_{01}=3.70) but insufficient evidence to conclusively rule out an effect of non-decision time (BF_{01}=2.59). Therefore, only response caution was retained.

Executive function predictors.—The final best fitting model included only working memory manipulation speed (BF_{10}=20.95; R^2=.08). With reference to this model, there was significant evidence *against* effects of inhibition (BF_{01}=3.65) and set shifting speed (BF_{01}=4.25). There was insufficient evidence to conclusively rule out an effect of response caution (BF_{01}=2.29). Inspection of the posterior coefficients (mean B-weights) indicated that slower working memory manipulation speed was associated with greater teacher-reported SCT symptoms (B=2.70, 95% credible interval = 1.00–4.39).

Robustness check.—Adding parent-reported ADHD-I to the final model suggests that the findings are robust, with the best fitting model (BF_{10}=2133.10, R^2=.17) retaining the final model variable above (working memory speed) and adding ADHD-I. Greater parent-reported ADHD-I was associated with greater parent-reported SCT symptoms (B=0.38, 95% credible interval = 0.16–0.59; ΔR^2=.09).

Tier 2 Confirmatory Analyses: Mechanisms Associated with Sluggish Cognitive Tempo Alertness Deficits, Working Memory Slips, and Sleepy/Tired Symptoms

We repeated the Tier 1 analyses, separately for the K-SCT alertness, working memory slips, and sleepy/tired subscales. Results are reported in the Supplementary Online materials and summarized in Table S1. Overall, results were consistent with the omnibus analyses reported above, such that there was no evidence for, and in almost all models significant evidence *against*, effects of information processing speed (drift rate), response caution, encoding/motor output speed (non-decision time), and set shifting on parent- and teacher-reported SCT subscale scores. Slower working memory manipulation speed predicted parent- and teacher-reported alertness deficits and working memory slips, and faster inhibition speed predicted parent-reported alertness deficits. There were no significant neurocognitive predictors of parent or teacher perceptions of children's sleepy/tired symptoms.

Tier 3 Exploratory Analyses: Effects of IQ

The final exploratory analyses involved repeating the Tier 1 analyses again, this time including IQ as an additional demographic predictor in step 1. This exploratory step was added after accessing the data, secondary to author discussions regarding our updated literature review. Meta-analytic evidence supports a modest but significant association between SCT and lower IQ (*r*=0.24), with an approximately equal number of studies finding vs. not finding significant effects (Becker et al., 2016).

For the parent model, there was significant evidence *against* an association between IQ and SCT symptoms (BF_{01}=3.29). For the teacher model, IQ was a significant predictor in step 1 and retained in the final model that included slower working memory manipulation (B=1.81, 95% credible interval = 0.18–3.44), lower IQ (B=−0.12, 95% credible interval = −0.23 to −0.004), and higher ADHD-I symptoms (B=0.38, 95% credible interval = 0.16–0.60) as predictors of higher SCT symptoms (BF =4029.86; R^2 10 =.19). Thus, the final model was robust to inclusion of IQ in that it was identical to the best fitting model reported above, with the addition of IQ that explained an additional 2% of the variance (ΔR^2 from .17 to .19).

Discussion

The current study was the first to use computational modeling to examine the extent to which sluggish cognitive tempo is associated with a general or specific pattern of sluggish cognitive processes. That is, do children perceived by parents and teachers as cognitively ‘sluggish’ actually process information more slowly (sluggishly) than their peers? Overall, the data indicate strongly that the answer is ‘no.’ There was no evidence for, and significant evidence *against*, associations between cognitively-modeled information processing speed (drift rate) and sluggish cognitive tempo symptoms. This finding was consistent across both parent and teacher report, overall and when examining subcomponents of sluggish cognitive tempo, and with and without control for global intelligence (IQ). The use of Bayesian statistics allowed stronger conclusions by providing significant support for the null hypothesis rather than just failing to reject it, which in this case provides convincing evidence that the term ‘sluggish cognitive tempo’ is not only pejorative and offensive (Barkley, 2014, 2016; Becker & Barkley, 2018) but also inaccurate.[6] That is, findings from the current study provide significant evidence *against* characterizing these symptoms as reflective of a globally sluggish (slow) cognitive tempo. These findings help clarify the mixed findings in the literature, and suggest that the relatively equal number of studies finding significant (Hinshaw et al., 2002; Lundervold et al., 2011; Solanto et al., 2007; Tamm et al., 2018; Willcutt et al., 2014) and non-significant (Bauermeister et al., 2012; Hinshaw et al., 2002; Skirbekk et al., 2011; Willard et al., 2013) associations between sluggish cognitive tempo and processing speed may be a function of study-level sampling error.

The symptoms currently labeled as ‘sluggish cognitive tempo’ also do not appear to reflect differences in deliberate strategies such as an emphasis on accuracy over speed, or difficulties with basic perceptual or motor processes (i.e., stimulus encoding and motor output). Indeed, there was significant evidence *against* effects of response caution and non-decision time on sluggish cognitive tempo symptoms in the final parent and teacher models. Of note, however, there was anecdotal support ($BF_{10} < 3$) for effects of response caution in the teacher model (which may reflect low power despite the large sample size) before adding the executive function predictors; replications are needed to conclusively rule out strategy-related factors that may influence observer perceptions of phenotypic sluggish cognitive tempo behaviors. In addition, perceptual and/or psychomotor processes cannot be conclusively ruled out because the computational models used in the current study cannot separate these processes (see for example Raiker et al., 2019, who showed a suppressor

[6]The current findings thus add support to recent calls to change the name of ‘sluggish cognitive tempo.’ While proposing a new name based on the current results would be presumptive, we echo these calls and propose that a new term be adopted that (1) reflects the current data (e.g., does not suggest an as-of-yet-unknown etiology), (2) is reasonably understandable to professionals and laypersons alike, (3) does not overlap with ADD/ADHD, (4) is not misleading (e.g., does not characterize the condition as involving globally slowed cognitive tempo/processing speed), and (5) recognizes the dimensional nature of the construct.

effect such that children with ADHD demonstrated a strength in fine motor speed but a moderate impairment in encoding speed).

In the context of significant evidence against a global processing speed deficit explanation for sluggish cognitive tempo symptoms, the most consistent finding in the current study was that sluggish cognitive tempo is related specifically to reduced working memory efficiency such that it takes these children longer to mentally rearrange information. This association was found based on both parent and teacher report, overall and across the alertness deficits and working memory slips subscales, and was robust to covariation of both IQ and ADHD-inattentive symptoms. These findings are consistent with some previous studies showing associations between sluggish cognitive tempo symptoms and working memory maintenance capacity (Willard et al., 2013) and well as memory for conversations (Mikami et al., 2007), but inconsistent with several studies that failed to find effects of working memory maintenance (Bauermeister et al., 2012; Skirbekk et al., 2011; Wåhlstedt & Bohlin 2010; Willcutt et al., 2014). Given construct validity concerns with the simple span tasks used in most previous studies (Wells et al., 2018), the robust associations detected in the current study are most likely attributable to the active mental manipulation component of the tasks used herein and/or our use of speed-based rather than power-based indicators consistent with the hypothesis that there is something cognitively ‘sluggish’ in sluggish cognitive tempo.

There was also support for conceptualizing sluggish cognitive tempo as a disorder of over-inhibition, such that faster inhibition speed predicted higher levels of parent-reported sluggish cognitive tempo symptoms. This finding was robust to control for ADHD-I symptoms and IQ and was also observed when predicting parent-reported alertness deficits specifically. Faster inhibition speed, in the context of intact information processing speed, is likely to result in a high probability that intended behaviors fail to initiate. In the race-horse model of inhibition (Logan, 1994), a behavior is initiated when a ‘go’ process finishes before a ‘stop’ process, whereas the behavior is inhibited (restrained or cancelled) when the ‘stop’ process catches the ‘go’ process. Whereas *slower* inhibition speed has been associated with acting quickly and impulsively (i.e., these children have difficulty stopping themselves before it is too late; Nigg, 2016), in the current study *faster* inhibition speed was associated with reduced alertness and an overall behavioral profile characterized as ‘sluggish.’ Thus, results of the parent model suggest that the appearance of these children as being less alert or sluggish may in part be because they are behaviorally over-inhibited. Although a link between faster inhibition and slower behavior may initially appear counterintuitive, these findings are consistent with other studies linking sluggish cognitive tempo with increased behavioral inhibition system (BIS) sensitivity (Becker, Fite et al., 2013; Becker, Schmitt et al., 2018), conflicted shyness (Servera et al., 2018), and internalizing symptoms (Becker et al., 2016). Thus, it appears that the inhibition system of these children may be ‘too good’ at stopping behaviors, which in turn appears to adult observers as sluggish-cognitive-tempo-related symptoms (e.g., ‘stares into space,’ ‘appears lost in thought’) in that they are not initiating or completing a behavior as – or when – expected. It is unclear whether this delayed/sluggish appearance occurs because the children are actively trying to re-engage the go process several times to outrun the overdeveloped inhibition process (which results in delayed onset of action), or whether the go process is only re-started by external cues from others. It is also unknown whether the inhibition process is being initiated intentionally or is 'misfiring' to stop behaviors that the child did not intend to stop. Importantly, these effects were only found in the parent models, and as such replication and extension is needed. Nonetheless, this appears to be an intriguing area for future research that may help explain the association between sluggish cognitive tempo and internalizing disorders such as social anxiety that have been characterized by excessive behavioral inhibition (Henderson et al., 2015). Such research would inform the hypothesis that sluggish cognitive tempo, despite emerging in the field of ADHD, is best conceptualized within the internalizing spectrum of psychopathology, a possibility with important theoretical and clinical implications (Becker & Willcutt, 2019).

Finally, it is worth noting that there were no significant predictors of sleepy/tired symptoms in either the parent or teacher models, suggesting the need to examine factors beyond the demographic and neurocognitive abilities examined herein. Not surprisingly, SCT sleepy/tired symptoms are strongly related to daytime sleepiness, and there is ongoing interest in the extent to which these behaviors may be at least in part due to poor or insufficient sleep (Becker et al., 2016; Langberg et al., 2014). In addition, there was significant evidence *against* effects of set shifting in most models, despite our use of computational modeling that allowed us to isolate the cognitive component of shifting. Set shifting has garnered much less attention than inhibitory control and working memory in the clinical child literature, potentially due in part to measurement difficulties and inconsistent evidence that set shifting is a unique executive function in early-to-middle-childhood (Karr et al., 2018). Combined with recent evidence that included a subset of the current sample (Irwin et al., 2019), there appears to be strong evidence that set shifting abilities are intact in both ADHD and sluggish cognitive tempo – at least at the group level (Kofler et al., 2019).

Limitations

The current study was the first to examine the neurocognitive correlates of sluggish cognitive tempo symptoms using computational modeling, a battery of multiple, cognitively-informed tests per construct, and multiple informant reports of sluggish cognitive tempo symptoms. Additional strengths of the study include the detailed preregistration, hierarchical approach for differentiating effects of global information processing speed deficits from specific executive function speed deficits, and our use of Bayesian statistics that evaluated the strength of evidence both for and against each candidate predictor. At the same time, several caveats merit consideration. Although our models replicated across informants and explained a sizeable proportion of variance in sluggish cognitive tempo symptoms (R^2 = .17–.19), significant unexplained variance remained. This was presumably due in part to deliberate design choices to minimize inflated effect sizes (e.g., elimination of mono-informant and mono-method bias via the use of other-informant ratings and objective tests when predicting each informant's sluggish cognitive tempo ratings). Nonetheless, the non-multicollinearity between predictors and outcomes highlights the need to identify additional neurocognitive, psychophysiological, temperamental, behavioral health (e.g., anxiety), and environmental factors to fully explicate the mechanisms and processes underlying children's sluggish cognitive tempo symptoms. Relatedly, our reliance on subjective sluggish cognitive tempo ratings introduced error (e.g., negative halo, rater expectation), and our *a priori* decision to focus on speeded estimates of neurocognition (consistent with the hypothesis that there is something ‘sluggish’ in sluggish cognitive tempo) disallowed conclusions regarding power/capacity components of executive function that merit scrutiny in future studies. Our processing speed metrics were derived in part from the executive function test battery, which may have influenced results despite our broad estimation of processing speed based on a composite of four counterbalanced tasks and dimension reduction approach that removed task-specific variance. Cross-sectional, subjective ratings disallow causal attributions, and effect sizes may be blunted by measuring cognitive abilities and overt behaviors in different settings. Longitudinal and experimental studies are clearly warranted (Burns et al., 2019; Vu et al., 2019). Approximately 30% of our ADHD sample was prescribed stimulant medication, which was somewhat lower than epidemiological estimates and may have dampened association magnitudes when juxtaposing neurocognitive performance obtained off medication with parent/teacher perceptions that may be influenced by medication. Finally, although we obtained nearly the full range of sluggish cognitive tempo scores (range obtained=0–41; maximum possible range=0–45), we did not recruit our clinical sample specifically for sluggish cognitive tempo symptoms but rather broadly for ‘suspected attention, behavior, or learning problems for our research on children’s attention, memory, and learning.’ When designing the study, we considered recruitment of a sample enriched for ADHD ideal for studying sluggish cognitive tempo given the construct’s origins in the ADHD literature and initial conceptualizations that sluggish cognitive tempo reflected a ‘restricted inattentive presentation’ of ADHD caused by slow processing speed. Future work is needed to clarify the neurocognitive and behavioral ‘construct space’ of sluggish cognitive tempo and determine its role in behavioral health more broadly given that it no longer appears to reflect a subtype of ADHD (Becker et al., 2016).

Clinical and Research Implications

Taken together, the results of the current study provide strong evidence *against* characterizing children with ‘sluggish cognitive tempo’ symptoms as possessing a globally sluggish (slow) cognitive tempo. Instead, these ‘sluggish cognitive’ symptoms appear to be related, to a significant extent, to executive dysfunction characterized by a working memory system that is too slow and an inhibition system that is too fast. Behaviorally, requiring extra time to re-arrange the active contents of working memory is likely to delay responding, at least in situations where information must be mentally reordered before it can be used (e.g., sorting locations by distance before deciding where to go first). Similarly, an inhibition system that is too fast is likely to result in a high probability of behaviors that are intended but never started, which may give the appearance that children are absent-minded or failing to act when expected. However, it remains unclear whether parent perceptions of ‘sluggishness’ are due to children actively attempting to re-start the ‘go’ process, whether the ‘go’ process is restarted by external cues (e.g., parents repeating a command), and/or whether the too-speedy inhibition process is being intentionally engaged or is ‘misfiring’ to stop behaviors that these children do not intend to inhibit. It is also unclear why this finding was observed across parent models but not teacher models. Nonetheless, the current results provide a promising direction for future studies aimed at identifying the neurocognitive mechanisms and processes implicated in sluggish cognitive tempo, while also providing evidence against reification of the syndrome as 'sluggish cognitive tempo' (Barkley, 2014, 2016).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements:

This work was supported in part by NIH grants (R34 MH102499–01, R01 MH115048; PI: Kofler). Stephen Becker is supported by award number K23MH108603 from the NIMH. The sponsor had no role in design and conduct of the study; collection, management, analysis, and interpretation of the data; or preparation, review, or approval of the manuscript.

References

Ahn WY, Haines N, & Zhang L(2017). Revealing neurocomputational mechanisms of reinforcement learning and decision-making with the hBayesDM package. Computational Psychiatry,1,24–57. [PubMed: 29601060]

Alderson RM, Rapport MD, & Kofler MJ(2007). ADHD and behavioral inhibition: a meta-analytic review of the stop-signal paradigm. J abnormal child psychology,35,745–758.

Alderson RM, Rapport MD, Sarver DE, & Kofler MJ(2008). ADHD and behavioral inhibition: a re-examination of the stop-signal task. J abnormal child psychology,36,989–998.

Annis J, Miller BJ, & Palmeri TJ(2017). Bayesian inference with Stan: A tutorial on adding custom distributions. Behavior research methods,49,863–886. [PubMed: 27287444]

Barkley RA(2014). Sluggish cognitive tempo (concentration deficit disorder?): current status, future directions, and a plea to change the name. J abnormal child psychology,42,117–125.

Barkley RA(2016). Sluggish cognitive tempo: A (misnamed) second attention disorder?. J American Academy of Child & Adolescent Psychiatry, 55, 157–158.

Bauermeister JJ, Barkley RA, Bauermeister JA, Martínez JV, & McBurnett K(2012). Validity of the sluggish cognitive tempo, inattention, and hyperactivity symptom dimensions: neuropsychological and psychosocial correlates. J abnormal child psychology,40,683–697.

Becker SP, & Barkley RA(2018). Sluggish cognitive tempo. Banaschewski T, Coghill D, Zuddas A, (Eds.), Oxford textbook of ADHD,147–153.

Becker SP, Burns GL, Leopold DR, Olson RK, & Willcutt EG(2018). Differential impact of trait sluggish cognitive tempo and ADHD inattention in early childhood on adolescent functioning. J child psychology and psychiatry,59,1094–1104.

Becker SP, Garner AA, & Byars KC(2016). Sluggish cognitive tempo in children referred to a pediatric Sleep Disorders Center: Examining possible overlap with sleep problems and associations with impairment. J psychiatric research,77,116–124.

Becker SP, Fite PJ, Garner AA, Greening L, Stoppelbein L, & Luebbe AM(2013). Reward and punishment sensitivity are differentially associated with ADHD and sluggish cognitive tempo symptoms in children. J Research in Personality,47,719–727.

Becker SP, Garner AA, Tamm L, Antonini TN, & Epstein JN(2019). Honing in on the social difficulties associated with sluggish cognitive tempo in children: Withdrawal, peer ignoring, and low engagement. J Clinical Child & Adolescent Psychology,48,228–237.

Becker SP, & Langberg JM(2013). Sluggish cognitive tempo among young adolescents with ADHD: Relations to mental health, academic, and social functioning. J Attention Disorders,17,681–689.

Becker SP, Leopold DR, Burns GL, Jarrett MA, Langberg JM,…Willcutt EG(2016). The internal, external, and diagnostic validity of sluggish cognitive tempo: A meta-analysis and critical review. J American Academy of Child & Adolescent Psychiatry,55,163–178.

Becker SP, Schmitt AP, Jarrett MA, Luebbe AM,…Burns GL(2018). Sluggish Cognitive Tempo and Personality: Links to BIS/BAS Sensitivity and the Five Factor Model. Journal of Research in Personality,75,103–112. [PubMed: 31289415]

Becker SP,& Willcutt EG (2019). Advancing the study of sluggish cognitive tempo via DSM, RDoC, and hierarchical models of psychopathology. European Child and Adolescent Psychiatry,28,603–613. [PubMed: 29524018]

Burns GL, Becker SP, Geiser C, Leopold DR,& Willcutt EG (2019). Are sluggish cognitive tempo, ADHD, and oppositional defiant disorder trait- or state-like constructs from prekindergarten to fourth grade? J Clinical Child and Adolescent Psychology. Advance online publication. doi: 10.1080/15374416.2019.1567348

Canivez GL, Watkins MW, & Dombrowski SC(2016). Factor structure of the WISC-V: Exploratory factor analyses with the 16 primary and secondary subtests. Psychological Assessment,28,975. [PubMed: 26569464]

Conway AR, Kane MJ, Bunting MF,…Engle RW(2005). Working memory span tasks: A methodological review and user's guide. Psychonomic Bulletin & Review,12,769–786

Cortese S, Kelly C, Chabernaud C, Proal E,…Castellanos FX(2012). Toward systems neuroscience of ADHD: a meta-analysis of 55 fMRI studies. American J Psychiatry,169,1038–1055.

DiStefano C, Zhu M, & Mindrila D(2009). Understanding and using factor scores: Considerations for the applied researcher. Practical Assessment, Research & Evaluation,14,1–11.

Donkin C, Averell L, Brown S, & Heathcote A(2009). Getting more from accuracy and response time data: Methods for fitting the linear ballistic accumulator. Behavior Research Methods,41,1095. [PubMed: 19897817]

Donkin C, Brown S, Heathcote A, & Wagenmakers EJ(2011). Diffusion versus linear ballistic accumulation: different models but same conclusions about psychological processes? Psychonomic bulletin & review,18,61–69.

Henderson HA, Pine DS, & Fox NA(2015). Behavioral inhibition and developmental risk: a dual-processing perspective. Neuropsychopharmacology,40,207. [PubMed: 25065499]

Hinshaw SP(2002). Preadolescent girls with ADHD: I.Background characteristics, comorbidity, cognitive and social functioning, and parenting practices. J consulting and clinical psychology, 70,1086.

Hollingshead AB(1975). Four factor index of social status. New Haven:Yale.

Huang-Pollock C, Ratcliff R, McKoon G, Shapiro Z, Weigard A,& Galloway-Long H(2017). Using the diffusion model to explain cognitive deficits in ADHD. J abnormal child psychol,45,57–68.

Irwin LN, Kofler MJ, Soto EF, & Groves NB(2019). Do children with attention-deficit/hyperactivity disorder (ADHD) have set shifting deficits? Neuropsychology. Advance online publication. doi: 10.1037/neu0000546

JASP Team (2017). JASP. Version 0.9.1.[Computer Software]

Karr JE, Hofer SM, Iverson GL,& Garcia-Barrera MA(2018). Examining the Latent Structure of the Delis–Kaplan Executive Function System. Archives of Clinical Neuropsychology,34,381–394.

Kofler MJ, Irwin LN, Soto EF, Groves NB, Harmon SL,& Sarver DE(2019). Executive Functioning Heterogeneity in Pediatric ADHD. J abnormal child psychology,47,273–286.

Kofler MJ, Raiker JS, Sarver DE, Wells EL,& Soto EF(2016). Is hyperactivity ubiquitous in ADHD or dependent on environmental demands? Evidence from meta-analysis. Clinical Psychology Review,46,12–24. [PubMed: 27131918]

Kofler MJ, Sarver DE, Harmon SL, Moltisanti A,…Ferretti N(2018). Working memory and organizational skills problems in ADHD. J Child Psychology and Psychiatry,59,57–67.

Kofler MJ, Spiegel JA, Austin KE, Irwin LN, Soto EF,& Sarver DE(2018). Are Episodic Buffer Processes Intact in ADHD? Experimental Evidence and Linkage with Hyperactive Behavior. J abnormal child psychology,46,1171–1185.

Langberg JM, Becker S,& Dvorsky M(2014). The association between sluggish cognitive tempo and academic functioning in youth with ADHD. J Abnormal Child Psychology,42,91–103.

Langberg JM, Becker SP, Dvorsky MR,& Luebbe AM(2014). Are sluggish cognitive tempo and daytime sleepiness distinct constructs?. Psychological assessment,26,586–597. [PubMed: 24611789]

Logan G(1994). On the ability to inhibit thought and action: Users' guide to the stop signal paradigm.

Lundervold AJ, Posserud MB, Ullebø AK, Sørensen L,& Gillberg C(2011). Teacher reports of hypoactivity symptoms reflect slow cognitive processing speed in primary school children. European child & adolescent psychiatry,20,121–126.

McBurnett K, Villodas M, Burns GL, Hinshaw SP, Beaulieu A,& Pfiffner LJ(2014). Structure and validity of sluggish cognitive tempo using an expanded item pool in children with attention-deficit/hyperactivity disorder. J abnormal child psychology,42,37–48.

Miyake A,& Friedman NP(2012). The Nature and Organization of Individual Differences in Executive Functions. Current Directions in Psychological Science,21,8–14. [PubMed: 22773897]

Mikami AY, Huang-Pollock CL, Pfiffner LJ, McBurnett K,& Hangai D(2007). Social skills differences among attention-deficit/hyperactivity disorder types in a chat room assessment task. J abnormal child psychology,35,509–521.

Moruzzi S, Rijsdijk F,& Battaglia M(2014). A twin study of the relationships among inattention, hyperactivity, and sluggish cognitive tempo problems. J Abnormal Child Psychology,42,63–75.

Mueller AK, Tucha L, Koerts J, Groen Y, Lange KW,& Tucha O(2014). Sluggish cognitive tempo and its neurocognitive, social and emotive correlates: a systematic review of the current literature. J molecular psychiatry,2,5.

Oberauer K,& Kliegl R(2006). A formal model of capacity limits in working memory. J Memory and Language,55,601–626.

Pa J, Possin KL, Wilson SM, Quitania LC, Kramer JH,& Boxer AL(2010). Gray matter correlates of set-shifting among neurodegenerative disease, mild cognitive impairment, and healthy older adults. J International Neuropsychological Society,16,640–650.

Penny AM, Waschbusch DA, Klein RM, Corkum P,& Eskes G(2009). Developing a measure of sluggish cognitive tempo for children: Content validity, factor structure, and reliability. Psychological Assessment,21,380–389. [PubMed: 19719349]

Raiker JS, Friedman LM, Orban SA, Kofler MJ, Sarver DE,& Rapport MD(2019). Phonological working memory deficits in ADHD revisited: The role of lower level information-processing deficits in impaired working memory performance. Journal of Attention Disorders,23,570–583. [PubMed: 28077012]

Rapport MD, Bolden J, Kofler MJ, Sarver DE, Raiker JS,& Alderson RM(2009). Hyperactivity in boys ADHD: a ubiquitous core symptom or manifestation of working memory deficits? J Abnormal Child Psychology,37,521–534.

Rouder JN,& Morey RD(2012). Default Bayes factors for model selection in regression. Multivariate Behavioral Research,47,877–903. [PubMed: 26735007]

Rouder JN, Morey RD, Speckman PL,& Province JM(2012). Default Bayes factors for ANOVA designs. J Mathematical Psychology,56,356–374.

Sattler JM(2018). Assessment of children:Cognitive Foundations. San Diego: Sattler.

Servera M, Sáez B, Burns GL,& Becker SP(2018). Clinical differentiation of sluggish cognitive tempo and ADHD in children. Journal of abnormal psychology,127,818–829. [PubMed: 30265014]

Skirbekk B, Hansen BH, Oerbeck B,& Kristensen H(2011). The relationship between sluggish cognitive tempo, subtypes of ADHD, and anxiety disorders. J abnormal child psychol,39,513–525.

Snyder HR, Miyake A & Hankin BL(2015). Advancing understanding of executive function impairments and psychopathology: bridging the gap between clinical and cognitive approaches. Front. Psychol,6,328. [PubMed: 25859234]

Solanto MV, Gilbert SN, Raj A, Zhu J, Pope-Boyd S,…Newcorn JH(2007). Neurocognitive functioning in AD/HD, predominantly inattentive and combined subtypes. J abnormal child psychology,35,729–744.

Soreni N, Crosbie J, Ickowicz A,& Schachar R(2009). Stop signal and conners' continuous performance tasks: Test-retest reliability of two inhibition measures in ADHD children. J Attention Disorders,13,137–143.

Tamm L, Brenner S, Bamberger M,& Becker S(2018). Are sluggish cognitive tempo symptoms associated with executive functioning in preschoolers?. Child Neuropsychology,24,82–105. [PubMed: 27622982]

Trapp W, Dotterweich S, Hintner L, Wollny H, Lautenbacher S,& Hajak G(2017). Speed and capacity of working memory and executive function in schizophrenia compared to unipolar depression. Schizophrenia Research:Cognition,10,1–6. [PubMed: 28824849]

Verbruggen F, Chambers C,& Logan GD(2013). Fictitious inhibitory differences: how skewness and slowing distort the estimation of stopping latencies. Psychological science,24,352–362. [PubMed: 23399493]

Voss A, Nagler M,& Lerche V(2013). Diffusion models in experimental psychology. Experimental psychology,60,385–402. [PubMed: 23895923]

Voss A, & Voss J(2007). Fast-dm: A free program for efficient diffusion model analysis. Behavior Research Methods,39,767–775. [PubMed: 18183889]

Vu A, Thompson L, Willcutt E, & Petrill S (2019). Sluggish cognitive tempo: longitudinal stability and validity. ADHD Attention Deficit and Hyperactivity Disorders, online early, 1–9.

Wagenmakers EJ, Morey RD,& Lee MD(2016). Bayesian benefits for the pragmatic researcher. Current Directions in Psychological Science,25,169–176.

Wager TD, & Smith EE(2003). Neuroimaging studies of working memory. Cognitive, Affective, & Behavioral Neuroscience,3,255–274.

Wåhlstedt C, & Bohlin G(2010). DSM-IV-defined inattention and sluggish cognitive tempo: independent and interactive relations to neuropsychological factors and comorbidity. Child Neuropsychology,16,350–365. [PubMed: 20574866]

Wells EL, Kofler MJ, Soto EF, Schaefer H,& Sarver DE(2018). Assessing working memory in children with ADHD: Minor administration and scoring changes may improve digit span backward's construct validity. Research in Developmental Disabilities,72,166–178. [PubMed: 29156389]

Weigard A, & Huang-Pollock C(2017). The role of speed in ADHD-related working memory deficits: a time-based resource-sharing and diffusion model account. Clinical Psychological Science,5,195–211. [PubMed: 28533945]

Willard V, Hardy K, Allen T, Hwang E.,…Bonner M(2013). Sluggish cognitive tempo in survivors of pediatric brain tumors. Journal of Neuro-oncology,114,71–78. [PubMed: 23661102]

Willcutt EG, Chhabildas N,…& Pennington BF(2014). The internal & external validity of sluggish cognitive tempo and its relation with DSM–IV ADHD. J abnormal child psychol,42,21–35.

Public Health Significance Statement

This study indicates that the syndrome called 'sluggish cognitive tempo' is not associated with the globally sluggish (slow) processing speed implied by its name. Instead, the syndrome appears to be characterized by disruptions in the speed of specific cognitive abilities that involve mentally re-ordering information and inhibiting behavior.

Table 1.

Sample and Demographic Variables

Variable	ADHD (N=82)		Non-ADHD (N=50)		Cohen's *d*	BF_{10}	BF_{01}
	M	***SD***	***M***	***SD***			
Gender (Boys/Girls)	55/27		30/20		—		3.36
Ethnicity (AA/A/C/FT/M)	11/0/60/7/4		5/3/28/10/3		—		9.71
Age	10.06	1.44	10.79	1.54	−0.46	5.59	
SES	47.49	11.57	49.59	1224	−0.16		3.35
FSIQ	103.01	15.43	108.02	1035	−0.33	1.22	
ADHD-5 Inattention (Raw Scores)							
Parent	19.32	6.09	14.26	8.14	0.69	257.62	
Teacher	16.73	6.61	10.38	7.73	0.86	8808.25	
K-SCT Parent Report (Raw Scores)							
Total Score	13.01	7.51	9.52	7.18	0.44	4.25	
Alertness	6.31	4.42	4.42	3.87	0.41	3.09	
Working Memory Slips	5.01	3.30	3.14	2.91	0.55	23.29	
Sleepy/Tired	1.70	1.94	1.96	2.22	−0.12		4.14
K-SCT Teacher Report (Raw Scores)							
Total Score	18.28	9.83	12.48	1037	0.54	18.86	
Alertness	9.61	5.12	6.66	6.44	0.48	8.23	
Working Memory Slips	5.88	3.93	3.60	3.58	0.56	26.37	
Sleepy/Tired	2.79	3.18	2.22	2.34	0.18		3.01
Ncurocognitivc Component Scores (Z-scores)							
Drift Rate (v)	−0.31	0.90	0.50	0.95	0.83	5728.36	
Response Caution (a)	0.26	1.02	−0.42	0.81	0.66	185.23	
Non-decision lime (t0)	−0.16	0.98	0.26	0.99	0.39	2.33	
Working Memory Manipulation Speed	0.35	0.96	−0.59	0.72	1.02	4.00×10^5	
Inhibitory Control	0.23	1.08	−0.38	0.73	0.59	48.28	
Set Shifting	0.0005	0.86	−0.0007	1.21	0.004		5.23

Note. BF_{01} = Bayes Factor for the null hypothesis of no ADHD/Non-ADHD group differences the alternative hypothesis that the ADHD and Non-ADHD groups differ (values> 3.0 indicate significant between-group equivalence; $BF_{01} = 1/BF_{10}$). SCT Sluggish Cognitive Tempo. Ethnicity; AA = Afiican American, A = Asian, C = Caucasian Non-Hispanic, H = Hispanic, M = Multiracial

Author Manuscript

Author Manuscript

Author Manuscript

Table 2.

Summary of findings regarding demographic, cognitively-modeled information processing speed, and executive functioning speed predictors of higher parent- and teacher-reported sluggish cognitive tempo (SCT) symptoms.

	Higher parent-reported sluggish cognitive tempo (SCT) symptoms associated with:	Higher teacher-reported sluggish cognitive tempo (SCT) symptoms associated with:
Demographies		
Age	*No effect*	*Unlikely effect*
Gender	**No effect**	**No effect**
SES	Lower SES	No effect
Processing Speed		
Drift rate (v)	**No effect**	**No effect**
Response caution (a)	*No effect*	*Unlikely effect*
Nondecision time (t0)	*No effect*	*Unlikely effect*
Executive Functioning Speed		
Inhibitory control	Faster inhibition speed	No effect
WM manipulation	**Slower working memory speed**	**Slower working memory speed**
Set shifting	*Unlikely effect*	*No effect*
Robustness Checks		
Cross-informant ADHD-Inattentive symptoms	**Higher ADHD-I symptoms**	**Higher ADHD-I symptoms**
Intellectual functioning (IQ)	No effect	Lower IQ

Note: Descriptors (higher, lower, faster, slower) for significant predictors ($BF_{10} \geq 3$) are underlined and based on interpretation of B-weight direction to indicate correspondence with *higher* levels of sluggish cognitive tempo (SCT) symptoms. "No effect" is reported for predictors showing significant support for the null hypothesis of no effect (B-weights are conceptually 0.00). "Unlikely effect" is reported when the data provided support for the null hypothesis that failed to reach prespecified evidence thresholds (i.e., $1 < BF^{01} < 3$). **Bolded** cells indicate findings that are consistent across parent and teacher models. *Italicized* cells indicate findings that may also be consistent across models, with both models showing evidence in the same direction but at least one failing to reach preset significance thresholds. WM = working memory.