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ADHD and sluggish cognitive tempo throughout childhood: Temporal invariance and stability from preschool through ninth grade

Daniel R. Leopold,
University of Colorado Boulder

Micaela E. Christopher,
University of Colorado Boulder

G. Leonard Burns,
Washington State University

Stephen P. Becker,
Cincinnati Children's Hospital Medical Center

Richard K. Olson, and
University of Colorado Boulder

Erik G. Willcutt
University of Colorado Boulder

Abstract

Background—Although multiple cross-sectional studies have shown symptoms of sluggish cognitive tempo (SCT) and attention-deficit/hyperactivity disorder (ADHD) to be statistically distinct, studies have yet to examine the temporal stability *and* measurement invariance of SCT in a longitudinal sample. To date, only six studies have assessed SCT longitudinally, with the longest study examining SCT over a two-year period. The overall goals of this study were to assess the ten-year longitudinal stability and inter-factor relationships of ADHD and SCT symptoms among a community sample of children.

Methods—Confirmatory factor analysis was used to assess the temporal invariance of ADHD and SCT symptoms in a large population-based longitudinal sample (International Longitudinal Twin Study of Early Reading Development) that included children assessed at preschool and after kindergarten, first, second, fourth, and ninth grades (n=489). Latent autoregressive models were then estimated to assess the stability of these constructs.

Results—Results demonstrated invariance of item loadings and intercepts from preschool through ninth grades, as well as invariance of inter-factor correlations. Results further indicated that both ADHD and SCT are highly stable across these years of development, that these symptom

Corresponding author: Daniel Leopold, M.A., Department of Psychology and Neuroscience, UCB 345, University of Colorado, Boulder, CO 80309-0345. Phone: 720.432.1757; Fax: 303.492.2967; Daniel.Leopold@colorado.edu.

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dimensions are related but also separable, and that hyperactivity/impulsivity and SCT are both more strongly correlated with inattention than with each other and show differential developmental trajectories. Specifically, even in the presence of latent simplex analyses providing support for the developmental stability of these dimensions, linear comparisons indicated that that mean levels of hyperactivity-impulsivity decreased with time, inattentive ratings were generally stable, and SCT tended to increase slightly across development.

Conclusions—This study adds to the current literature by being the first to systematically assess and demonstrate the temporal invariance and stability of ADHD and SCT across a span of ten years.

Keywords

ADHD; attention-deficit/hyperactivity disorder; SCT; sluggish tempo; inattention; hyperactivity; stability; temporal invariance; measurement invariance

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The notion that a cluster of symptoms related to, but distinct from, inattention (IN) might reliably distinguish between individuals with and without hyperactivity/impulsivity (HI) symptomatology has been around for almost three decades (Neeper & Lahey, 1986). This symptom cluster, composed of items such as sluggishness, being "lost in a fog", and daydreaming, has been termed sluggish cognitive tempo (SCT). SCT was initially identified as a set of symptoms separable from the IN symptoms of Attention Deficit Disorder from the third edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-III*; American Psychiatric Association [APA], 1980). Although SCT-related items were included in the DSM-IV (APA, 1994) Attention-Deficit/Hyperactivity Disorder (ADHD) field trials (Frick et al., 1994), research on SCT largely remained dormant until the turn of the century, when more investigations turned to examining SCT in its own right (Becker, Marshall, & McBurnett, 2014). Thus, studies of SCT are increasingly moving away from examining its prevalence and correlates among ADHD-selected samples and instead exploring these two constructs side-by-side (Barkley, 2012; 2013; Bernad et al., 2014).

Despite strong support for the validity of the ADHD diagnosis (Willcutt et al., 2012), SCT is in a comparatively nascent state. As the body of SCT literature continues to grow, it is imperative that we test whether SCT meets the criteria for validation of a mental disorder (e.g., Cantwell, 1980). Although SCT has been described as a disorder and alternative names have been proposed (Barkley, 2014), these proposals run the risk of pathologizing non-pathological behaviors and jeopardizing public perception of psychology and psychiatry. It is therefore important to put the extant literature into perspective and systematically assess these criteria before recommending its diagnostic status and inclusion in clinical practice. As such, the current study aims to evaluate fundamental nosological requirements, namely the temporal stability, measurement invariance, and developmental trajectory of SCT and its relationship with ADHD.

Validity of SCT in children and adolescents

Factor analyses and external correlates

Initial and ongoing factor analyses have repeatedly supported the separability of SCT and ADHD, as well as SCT's comparatively stronger relationship with symptoms of IN than with symptoms of HI (Barkley, 2013; Leopold, Bryan, Pennington, & Willcutt, 2014; Penny, Waschbusch, Klein, Corkum, & Eskes, 2009; Willcutt et al., 2012). Numerous studies have subsequently found that symptoms of SCT are associated with aspects of functional impairment and elevated internalizing symptoms, even after controlling for symptoms of ADHD, related psychopathologies, and demographic characteristics (Becker, Langberg, Luebbe, Dvorsky, & Flannery, 2013; Lee, Burns, Snell, & McBurnett, 2014; Willcutt et al., 2014). Of note, a smaller body of literature has also begun to explore the SCT construct among adults (Barkley, 2012; Becker et al., 2013; Leopold et al., 2014), as well as the presence of rater effects and the importance of collecting ratings from multiple sources (Burns, Servera, Bernad, Carrillo, & Cardo, 2013; Lee et al., 2014; Leopold et al., 2014).

Temporal stability

Although the categorical ADHD subtype classifications described in DSM-IV are developmentally unstable (Willcutt et al., 2012), the DSM-IV symptom dimensions and overall ADHD diagnosis demonstrate high stability throughout the lifespan, with diagnostic symptomatology and impairment extending into adulthood for 50-80% of cases (Barkley, 2013; Wilens, Faraone, & Biederman, 2004). Test-retest reliability of the IN and HI dimensions range from r=.78-.82 for less than one year, and r=.64 for these dimensions for intervals of one to five years (Willcutt et al., 2012). The ADHD dimensions also show differential longitudinal courses, with IN remaining relatively stable while HI shows significant age-related decline, particularly during the early school years (e.g., Lahey & Willcutt, 2010).

In comparison to the large body of literature on ADHD across the lifespan, only six studies to date have investigated the developmental stability of SCT. Over a period of four to six weeks, test-retest reliability estimates of parents' ratings range from r=.73 to .80 using both latent factors (Burns et al., 2013) and composites (Lee et al., 2014). Using teacher ratings of 176 first to sixth graders, Becker found that Penny's et al. (2009) SCT scale ($\alpha_{initial}$=.92; $\alpha_{follow\text{-}up}$=.95) had a 6-month test-retest correlation of r=.76 (unpublished data from Becker, 2014). These results support Penny and colleagues' initial three-month test-retest reliability of r=.87 for parents' ratings. Bernad et al. (2014) found that three commonly used SCT items – *seems drowsy, thinking is slow*, and *slow moving* – demonstrated both convergent and discriminant validity as well as temporal stability. Specifically, in a sample of primary and secondary teachers' reports of Spanish children's behavior, Bernad et al. found that the one-year test-retest correlations were r=.74 and .61, respectively. A recent study followed this same sample for an additional year and, using different teachers across time points, reported two-year latent test-retest correlations of r=.46 and .42 for primary and secondary teachers, respectively; among mothers and fathers the two-year latent test-retest correlations (using the three aforementioned SCT items in addition to *loses train of thought* and *easily confused*) were r=.60 and .65, respectively (Bernad et al., 2015). Thus, across parents, caregivers, and primary and secondary teachers, SCT appears to be a highly stable trait over these six-week to two-year timespans.

Measurement invariance

In order to ensure that a construct can be reliably measured at different time points, it is necessary to demonstrate that the construct's items and variances are stable (i.e., invariant) across time. Confirmatory factor analyses of ADHD have previously demonstrated this important quality of temporal and measurement invariance across settings and raters (e.g., Burns, Servera, Bernad, Carrillo, & Geiser, 2014), but the temporal measurement invariance of SCT has yet to be investigated.

The current study

The current study sought to address this lack of longitudinal research on SCT by using parent ratings of IN, HI, and SCT collected six times between preschool and ninth grade among a representative, community sample of 489 children. Furthermore, the current study uses structural equation modeling (SEM) to explore the temporal invariance and longitudinal stability of these dimensions by using latent variables that minimize occasion-specific measurement error. The study had three main objectives:

1. To clarify the relations between IN, HI, and SCT, initial CFAs were fit to parent ratings at each of the six time points prior to testing the temporal invariance of these dimensions from preschool through the end of ninth grade. Based on previous findings, we hypothesized that correlated dimensions of IN, HI, and SCT symptoms would fit the data well at all ages, providing support for the measurement invariance of SCT across a ten-year span.
2. Cross-sectional inter-factor and longitudinal intra-factor correlations were computed to explore the relations between SCT, IN, and HI, as well as their stability across development. If parent ratings show stability both between and within these dimensions over time, the findings will provide key support for the internal and discriminant validity of ADHD and SCT during childhood and adolescence.
3. Finally, latent simplex (i.e., autoregressive) models of the IN, HI, and SCT dimensions were tested in order to explore the stability of these traits across all time points by only modeling the shared, reliable variance among symptoms. High path coefficients between time points would indicate that the overall rank order of individuals in this community sample remained consistent.

Methods

Participants

The participants in the present study were 489 individuals from 224 monozygotic (MZ; i.e., identical) and 265 dizygotic (DZ; i.e., fraternal) twin pairs first assessed in the year prior to starting kindergarten (N=482, M_{age}=4.89 years, SD_{age}=0.41 years; 49.7% male). For all analyses presented, one randomly selected member from each pair was used to eliminate issues related to non-independence. All participants were part of the Colorado component of the International Longitudinal Twin Study of Early Reading Development (ILTSERD; e.g., Christopher et al., 2013). All twin pairs were recruited from the Colorado Twin Registry based on birth records and had English as their first language.

After the initial preschool wave, the participants were assessed in the summers following kindergarten (N=453, M_{age}=6.3 years, SD_{age}=.31 years), first grade (N=442, M_{age}=7.4 years, SD_{age}=.32 years), second grade (N=451, M_{age}=8.5 years, SD_{age}=.31 years), fourth grade (N=445, M_{age}=10.5 years, SD_{age}=.32 years), and ninth grade (N=389, M_{age}=15.4 years, SD_{age}=.30 years). Attrition from preschool through the end of fourth grade was minimal (92-94% retention). The current rate of retention is similar for the ninth grade assessment (92%), but the sample size for this wave is smaller because one of the five cohorts had not yet completed the ninth grade assessment. Importantly, this last cohort did not differ from the other cohorts included in this study in age or gender, or on any of the parent- or teacher-rated ADHD, SCT, parental education, or reading measures administered at any of the previous time points (all ps>.10). Furthermore, all differences were of negligible magnitude, with the largest effect sizes still of small magnitude (ds<.16).

Procedures

All study procedures were fully approved by the Institutional Review Boards of the University of Colorado Boulder. All participants and parents provided informed consent or assent prior to enrollment and at each follow-up assessment. Overall testing procedures for the ILTSERD are described in detail in previous papers (e.g., Christopher et al., 2013). Briefly, the twins completed a battery of measures related to reading development in individual testing sessions while one parent or caregiver completed a battery of questionnaires that included the measures described in this report.

Measures

DSM-IVADHD symptoms—The Disruptive Behavior Rating Scale (DBRS; Barkley & Murphy, 1998) was used to obtain parent ratings of ADHD symptoms. Nearly all ratings were completed by the mother at all time points (91-95%). The child's parent is asked to indicate how often in the last 6 months each of the 18 DSM-IV ADHD symptoms is true on a 4-point Likert scale (0=*never or rarely*, 1=*sometimes*, 2=*often*, and 3=*very often*).

Sluggish cognitive tempo—Seven potential SCT items (sluggish, slow to respond, lethargic; seems not to hear, needs things repeated; seems to be “in a fog”; is drowsy or sleepy; easily confused; daydreams, stares into space; absentminded, forgets things easily) were used based on previous studies and theoretical models of SCT (e.g., Penny et al., 2009). Each item was added to the ADHD rating scale and administered in the same four-point scale format.

Analytic Strategy

Structural and measurement model analyses were conducted using Mplus (Version 7.0; Muthén & Muthén, 2012). Items were treated as ordered categorical manifest variables using the robust weighted least squares estimator (WLSMV). Overall model fit was determined with the robust comparative fit index (CFI; study criteria ≥.90, with approximately .95 being ideal), the Tucker-Lewis Index (TLI; study criteria ≥.90), and the robust root-mean-square error of appoximation (RMSEA; study criteria ≤.08).

Criteria and procedure for invariance tests—Due to the ability of the chi-square difference test to detect small discrepancies of no theoretical or practical consequence in large samples (Chen, Sousa, & West, 2005), changes in CFI, TLI, and RMSEA were used to assess the invariance of model constraints. Specifically, if the decrease in CFI was less than 0.01 and the TLI and RMSEA showed little change (Chen, 2007; Little, 2013), the imposed constraints were assumed to be invariant by this procedure. In order to reduce model complexity while maintaining the full ten-year timespan, only the preschool, post-first, post-fourth, and post-ninth grade time points were used for the invariance analyses.

CFA of temporal invariance

The baseline model contains 12 factors and 100 items (i.e., 25 items on 3 factors at each time point – 9 IN, 9 HI, and 7 SCT). We now outline the sequence of steps used to test the temporal invariance of IN, HI, and SCT at these four time points (see Chapter 5 of Little, 2013 for a similar model). To evaluate configural invariance with correlated errors for identical items, none of the model parameters are constrained to be equal across time points in the baseline model. Furthermore, because the residual variance of each item was expected to covary with that same item's residual variance at the other time points (Little, 2013), correlated errors were estimated between identical items at the four time points (see Figure 1). To evaluate invariance of loadings and intercepts (i.e., comparing raw and latent means across time points), it is first necessary to demonstrate the invariance of loadings and intercepts (i.e., thresholds for categorical items) for the same items rated at different time points (Chen et al., 2005). If statistical equivalence of items' loadings and thresholds is supported, it can be inferred that observed score differences between time points reflect true differences on the dimensions' means and not the effect of the measurement occasion itself. Finally, to assess the stability and strength of relationships between the IN, HI, and SCT dimensions, the tenability of factor correlation invariance was assessed. In order to impose these constraints, phantom constructs were used to estimate the variance-covariance information as standard deviations and correlations. When the variances of constructs differ between measurement occasions or groups, phantom constructs conveniently model the strength of these associations on a common metric rather than the non-comparable metric of the covariance relationships (Little, 2013).

Bivariate and longitudinal simplex analyses—After establishing the measurement invariance of these three constructs across the ten-year timespan, longitudinal intra-construct and cross-sectional inter-construct bivariate correlations were calculated (See Table S1 in Appendix S1). Finally, because the measured bivariate correlations indicated that correlations among adjoining time points were stronger than correlations between distant time points (Table S1), latent simplex (i.e., autoregressive) models were estimated in order to explore the temporal stability of IN, HI, and SCT, free from measurement error.

Missing data—As noted earlier, attrition from preschool through post-fourth grade was minimal; roughly 9% of the sample was lost to follow-up. The post-ninth grade sample, however, had not been fully collected, so 80% of the original sample was available at this time. Factor correlations among this reduced post-ninth grade sample are similar to the other time points. Covariance coverage for preschool to post-ninth grade ranged from .73 to .99 (*M*=.85, *SD*=.09). Analyses with the WLSMV estimator use a pairwise approach to missing data.

Results

Factor structure and internal consistency

Preliminary CFAs in which each hypothesized latent construct predicted its respective indicators were estimated using the factor variance method of identification. The three factor models provided a reasonable fit at each time point, providing support for estimation of the full configural invariance model (results available from first author upon request).

Individual IN, HI, and SCT items loaded strongly on their corresponding latent trait at each of the time points (mean standardized loadings = .79 for IN, .75 for HI, and .77 for SCT), and estimates of internal consistency were high for composite measures of IN, HI, and SCT (mean αs=.90, .87, and .81, respectively; Table 1).

Invariance of the three factor model from preschool through post-ninth grade

Table 2 shows that the baseline configural invariance model with correlated errors between like items displayed an excellent fit to the present data (*CFI*=.95; *TLI*=.95; *RMSEA*=.025 [*90% CI*=.023, .026]). The model remained invariant with the loading, threshold, and latent factor correlation constraints imposed (see Table 2); all changes in fit indices were below the critical values suggested by Chen (2007) and Little (2013). Furthermore, none of these changes from the baseline to final model approached the critical values of .01 (CFI), .01 (TLI), and .015 (RMSEA).

Developmental stability of ADHD and SCT ratings

Mean levels of HI symptoms declined significantly across development (Table 1), with medium to large effect sizes for the difference between parents ratings obtained in preschool and after kindergarten and ratings obtained after fourth and ninth grades (*d*=.34 - .94). Mean levels of IN during this timespan generally remained stable (all *d*<.17), whereas mean levels of SCT demonstrated small but significant increases, particularly from second to fourth and fourth to ninth grades (*d*s=.18-.31).

Table 3 shows the latent variance-covariance and correlation matrixes from the strong invariant model. With the addition of constraints on the latent inter-factor correlations across all time points, the standardized correlations between IN and HI, IN and SCT, and HI and SCT were .68, .83, and .53, respectively.

As noted by Brown (2015, p.116) and Little (2013), it is reasonable to question whether factors represent separate constructs as the inter-factor correlation approaches 1.0. In particular, they cite $r = .85$ as an upper bound for the demonstration of discriminant validity. In order to test whether our latent correlation of .83 is significantly less than 1.0, we directly compared our model against one in which the correlation was set to 1.0. A highly significant difference test, χ^2 (1, N=489)=174.6, p<.001 indicates that our original model with separable IN and SCT factors demonstrates superior fit. This latent correlation of .83 means that 31% of the true score variance of the IN and SCT factors is non-overlapping. Thus, although IN and SCT are highly correlated, they still satisfy the minimum conditions for discriminant validity.

Figure 2 shows the latent simplex models of IN, HI, and SCT with their standardized path coefficients and disturbance (i.e., unexplained latent factor variance) terms. Both the IN (χ^2(df)=2186.1(1402); CFI=.97; TLI=.97; RMSEA[90% CI]=.034[.031,.037]) and SCT simplex models (χ^2(df)=984.7(819); CFI=.99; TLI=.98; RMSEA[90% CI]=.020[.015,.025]) provided excellent fit to the data. In comparison, the HI simplex demonstrated good fit (χ^2(df)=2520.4(1402); CFI=.94; TLI=.94; RMSEA[90% CI]=.040[.038,.043]). The simplex models showed high levels of stability between the time points, with standardized transmission paths all .69 or higher. Overall, latent factors of parents' ratings of their children's preschool behavior were moderately correlated with the children's behavior up to ten years later (rs=.35 for IN, .38 for HI, and .43 for SCT).

Discussion

We examined the developmental stability and temporal invariance of ADHD and SCT among a representative, community sample of 489 children across a ten-year span. The overall goals of the study were to test the developmental stability of the SCT construct and its relation with symptoms of ADHD over a ten-year period. Strong support was found for the temporal measurement invariance of these constructs – at least as assessed with parent ratings – across childhood and adolescence. While linear comparisons showed that mean levels of HI decrease with time, mean levels of SCT tend to increase slightly with age, and IN ratings are generally stable, latent simplex analyses provided support for the developmental stability of these dimensions.

Implications for the validity of SCT

The current study is the first investigation of children and adolescents to explicitly examine the measurement invariance of SCT, as well as the developmental stability and relations between ADHD and SCT dimensions for more than two years. The finding that like-item loadings and thresholds were found to be statistically equivalent across measurement occasions provides support for the underlying construct validity of the SCT dimension as assessed by our seven-item measure. This demonstration of measurement invariance, as well as the latent stability of parent-rated SCT throughout childhood and into adolescence, is a significant advance in evaluating the diagnostic validity of this construct (Cantwell, 1980).

Our findings of high developmental stability provide important new information regarding the "natural history" of SCT, one of the key criteria that Cantwell proposed to evaluate the validity of a disorder. Further, a recent meta-analysis of extant SCT literature (Becker et al., under review) suggests that SCT is associated with multiple aspects of social and academic impairment and other psychosocial correlates, supporting the external validity of SCT as a potential diagnostic construct. However, data are sparse regarding several of the other levels of analysis described by Cantwell. Only a handful of studies has examined the external correlates of groups selected directly due to elevations of SCT (e.g., Barkley, 2013), included measures of SCT symptoms in studies of clinical intervention (e.g., Ludwig et al., 2009; Pfiffner et al., 2007), examined the etiological influences on SCT (Moruzzi, Rijsdijk, & Battaglia, 2014), or explored SCT-related neurophysiology (Fessbender, Krafft, & Schweitzer, 2015). While the current result represent an important step forward in the initial evaluation of the validity of the construct of SCT, much more work is needed before it will be possible to take a definite stance on SCT's clinical and/or diagnostic status.

Longitudinal stability of ADHD and SCT

In agreement with previous studies of children with ADHD (e.g., Lahey & Willcutt, 2010), mean levels of HI symptoms in the population declined significantly across development while IN remained stable. In contrast, mean levels of SCT significantly increased over this ten-year timespan. While the current study is the first to demonstrate small but significant age-related increases in SCT in a longitudinal study of the same individuals over time, it is important to note that these small increases may reflect the development and progression of SCT psychopathology or the increasing manifestation of SCT as performance demands in the school setting increase over time.

This mean level increase in SCT is consistent with Barkley' (2012 Barkley' (2013) nationally representative cross-sectional studies that found that individuals with elevated SCT symptoms were older than individuals with elevated ADHD or co-occurring ADHD and SCT symptoms. However, other studies have not found age differences between youth with high or low levels of SCT (e.g., Becker, 2014; Lee et al., 2014). Taken together, these results suggest that additional research is needed to clarify the relation between age and SCT.

Finally, the latent correlations between the IN, HI, and SCT dimensions were relatively stable across development. The correlations, while high, were significantly less than 1.0, consistent with previous findings that SCT is separable from the ADHD dimensions (e.g., Barkley, 2013; Penny et al., 2009; Willcutt et al., 2012). This finding is also in line with a recent meta-analysis of SCT that found correlations of SCT and IN ratings of .63 for children and adolescents and .72 for adults (Becker et al., under review).

Limitations and future directions

Strengths of the current study include the use of a large community sample assessed six times over a ten-year period. The same measures of ADHD and SCT were obtained at all assessments, and the high rate of retention (approximately 92% retention through ninth grade) helped to simplify interpretation and maximize statistical power. Despite these strengths, the current study also has several important limitations that should be taken into account when interpreting the results.

Use of twins—All participants in the current study were members of twin pairs recruited through a community twin registry. While this sampling procedure facilitated the recruitment of a sample that is generally representative of the overall population of twins in Colorado, any effects of being a twin may limit generalizability to the larger population of singletons. The stability coefficients in the current analyses are similar to the effects reported in earlier follow-up studies of non-twin samples over shorter intervals, supporting the validity of the current findings. Nonetheless, the current conclusions would be strengthened by replication in a longitudinal sample of non-twins.

Measurement of ADHD and SCT—Due to time and budgetary constraints of the overall study, SCT and DSM-IV ADHD were measured by parent ratings rather than a full structured diagnostic interview, and teacher ratings were only obtained for a subsample of participants in two assessment waves. Secondary analyses indicated that parent-teacher inter-rater reliabilities at the end of second grade (r_{IN}=.55, r_{HI}=.42, r_{SCT}=.49; all p<.001) were comparable to those reported in a recent meta-analysis of ADHD (Willcutt et al., 2012). In addition, recent one- and two-year longitudinal studies of SCT using mother, father, primary teacher, and secondary teacher ratings report stability estimates that closely match those founds in the present sample, supporting the generalizability of our findings (Bernad et al., 2014; 2015). Nonetheless, future studies that include teacher ratings, as well as child self-report ratings (e.g., Becker, Luebbe, & Joyce, 2015) and a full parent interview to assess ADHD or SCT (e.g., McBurnett, 2010) would constitute a useful extension of the current results by better isolating how much of the observed developmental stability is due to the construct itself versus rater effects.

In light of a recent multi-informant scale demonstrating convergent and discriminant validity using an initial pool of 44 candidate SCT items (McBurnett et al., 2014), our particular SCT scale may also be lacking important factors of the SCT construct, such as working memory problems. In order to advance the search for risk factors and neuropsychological, behavioral, and neurophysiological indicators of SCT, subsequent studies of ADHD and related pathologies could easily include a brief measure of the SCT construct. More generally, the wide variability in number, type, and wording of SCT items is a pervasive limitation of the literature on SCT. The development and validation of a standard set of SCT items would significantly advance the SCT field and make findings across studies more easily comparable (see Becker et al (under review) for a review of the most promising SCT items).

Limitations of SEM—An important limitation of any SEM approach is the existence of alternative, equally well-fitting models. The current model only provides an acceptable, parsimonious description of the data. Although the current literature strongly supports a two-factor (i.e., correlated) model of ADHD with separate IN and HI dimensions (Willcutt et al., 2012), bi-factor (i.e., hierarchical) models of ADHD (e.g., Toplak et al., 2014) have also been shown to demonstrate comparable or superior fit to two-factor models (for a review, see Willoughby et al., 2014). Early evidence suggests that SCT still falls outside the umbrella of ADHD even when using bi-factor models of these constructs (Garner et al., 2014; Lee et al., in press), but these and other alternative models warrant further exploration in future studies.

Conclusions

Results of longitudinal analyses provide the first empirical evidence that the SCT construct can be reliably measured over a ten-year period from early childhood through adolescence. These results provide important support for the construct validity of SCT and the discriminant validity of ADHD and SCT.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

ADHD

IN

HI

SCT

CFA

SEM

Key Points

- Sluggish cognitive tempo (SCT) represents a behaviorally defined construct characterized by inconsistent alertness and slow thinking and behavior.
- Measurement invariance and longitudinal stability are essential criteria for diagnostic validity that have been previously supported for the attention-deficit/hyperactivity disorder (ADHD) diagnosis and dimensions, but not for SCT.
- Using a longitudinal, community sample of children, the current study demonstrated temporal invariance and high stability of the ADHD and SCT dimensions between preschool and after ninth grade.
- Results provide further evidence for both the stability and separability of the ADHD and SCT dimensions, as well as the notion that SCT can be reliably measured with parent ratings at different time points during childhood and adolescence.

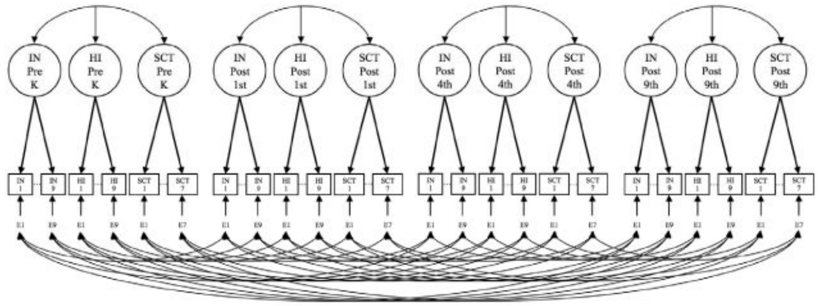

Figure 1.

Baseline model used for the confirmatory factor analytic invariance analysis of inattention (IN), hyperactivity/impulsivity (HI), and sluggish cognitive tempo (SCT) at preschool, post-1st, post-4th, and post-9th grade. E=residual.

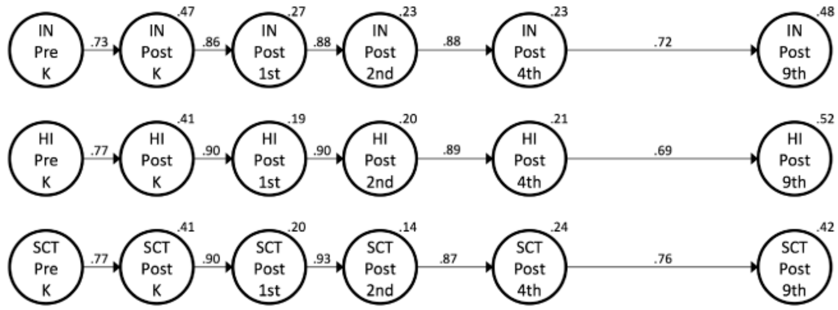

Figure 2.

Latent simplex models of inattention (IN), hyperactivity/impulsivity (HI), and sluggish cognitive tempo (SCT) at preschool, post-K, post-1st, post-2nd, post-4th, and post-9th grade. For visual clarity, each dimensions' indicators are not depicted. Numbers above the endogenous latent variables indicate the percent of variance unaccounted for in each latent variable. All path coefficients are standardized estimates, p<.001

Table 1

Descriptive Statistics and Internal Reliability of Parent Ratings of IN, HI, and SCT

Measure/Wave	M(SD)	α
Inattention		
Preschool	.67(.50)	.89
Post K	.56(.48)	.89
Post 1st	.57(.50)	.90
Post 2nd	.59(.51)	.90
Post 4th	.65(.56)	.92
Post 9th	.63(.61)	.93
Hyperactivity/Impulsivity		
Preschool	.78(.55)	.87
Post K	.55(.51)	.88
Post 1st	.49(.49)	.88
Post 2nd	.45(.46)	.88
Post 4th	.40(.44)	.87
Post 9th	.33(.43)	.86
Sluggish Cognitive Tempo		
Preschool	.22(.29)	.75
Post K	.21(.32)	.80
Post 1st	.20(.29)	.76
Post 2nd	.24(.35)	.82
Post 4th	.29(.42)	.88
Post 9th	.35(.45)	.86

Note. IN=inattention; HI=hyperactivity/impulsivity; SCT=sluggish cognitive tempo.

Table 2

Invariance of Parent-rated IN, HI, and SCT at Preschool, Post-1st, Post-4th, and Post-9th Grades

Model tested	*df*	χ^2	*p*	Δdf	$\Delta\chi^2$	*p*	CFI	TLI	RMSEA [90% CI]	MC	ΔCFI	ΔTLI	Pass?
Null model	4950	36649.9	<.001	–	–	–	–	–	–	–	–	–	–
Measurement model estimates													
1: Configural invariance; correlated errors across like items	4634	6191.7	<.001	–	–	–	.95	.95	.026 [.024, .028]	–	–	–	Yes
2: Loading and threshold invariance (strong invariance)	4829	6440.7	<.001	–	–	–	.95	.95	.026 [.024, .028]	2 vs. 1	.002	.000	Yes
Latent model estimates													
3: Latent factor correlation invariance	4838	6435.4	<.001	9	16.1	.064	.95	.95	.026 [.024, .028]	3 vs. 2	.001	.000	Yes

Note. IN=inattention; HI=hyperactivity/impulsivity; SCT=sluggish cognitive tempo; CFI=comparative fit index; TLI=Tucker-Lewis Index; RMSEA=root-mean-square error of approximation; CI=confidence interval; MC=model comparison; Pass=comparison meets invariance study criteria.

Table 3

Latent Variance-Covariance Matrix and Latent Means from Strong Factorial Invariance Model

Construct	IN T1	HI T1	SCT T1	IN T2	HI T2	SCT T2	IN T3	HI T3	SCT T3	IN T4	HI T4	SCT T4
IN T1	**.81**	.78	.82	.64	.56	.63	.60	.55	.55	.59	.49	.57
HI T1	.62	**.79**	.62	.51	.73	.47	.48	.67	.40	.47	.63	.42
SCT T1	.61	.45	**.68**	.66	.53	.78	.54	.44	.62	.44	.33	.60
IN T2	.55	.43	.51	**.90**	.75	.92	.80	.61	.75	.63	.49	.65
HI T2	.52	.67	.45	.73	**1.06**	.68	.62	.84	.53	.44	.66	.43
SCT T2	.53	.39	.60	.81	.65	**.87**	.78	.56	.84	.61	.42	.74
IN T3	.56	.44	.46	.78	.66	.75	**1.08**	.76	.92	.75	.55	.72
HI T3	.53	.64	.38	.62	.92	.56	.84	**1.15**	.67	.51	.72	.43
SCT T3	.55	.40	.57	.80	.62	.88	1.07	.80	**1.27**	.70	.46	.79
IN T4	.60	.48	.41	.67	.51	.64	.88	.62	.89	**1.28**	.68	.90
HI T4	.52	.65	.32	.54	.79	.45	.67	.90	.60	.90	**1.35**	.56
SCT T4	.60	.44	.58	.72	.51	.81	.88	.54	1.04	1.18	.76	**1.37**
Means:	.05	.05	.08	-.17	-.66	-.07	-.05	-.95	.18	-.26	-1.51	.09

Note. Results based on standardized variance method of identification. **Bold** numbers on the diagonal are estimated variances. Covariances are below the diagonal and correlations are above. Latent means set to zero at T1 in order to establish metric; subsequent means therefore reflect change from T1. IN=inattention; HI=hyperactivity/impulsivity; SCT=sluggish cognitive tempo; T1=preschool; T2=post-1st grade; T3=post-4th grade; T4=post-9th grade.