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Longitudinal associations between cognitive control consistency and academic skills across kindergarten and first grade

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ABSTRACT

Cognitive control fluctuates from moment to moment, even when the sensory and contextual demands of the task remain constant. However, traditional approaches used to measure cognitive control have largely treated such variability as noise and predominantly relied on overall performance metrics, such as accuracy and average response time. Using response time variability as an index of fluctuations in cognitive control, we examined how cognitive control consistency relates to the development of academic skills in children ($N = 112$) who were followed across kindergarten and first grade, an important period encompassing the transition and acclimation to formal schooling. Cognitive control consistency was assessed via response time variability in a Go/No-Go task, and math and literacy skills were assessed by the Applied Problems and Letter-Word Identification subtests of the Woodcock-Johnson III Tests of Achievement. More consistent cognitive control (indexed by lower response time variability) was associated with stronger math skills both concurrently in kindergarten and prospectively in first grade, above and beyond an accuracy-based metric (d'). In contrast, cognitive control consistency did not relate to literacy skills in kindergarten or first grade, suggesting potential domain-specificity in these relations during the early school years. Together, these findings demonstrate that consistency is an important aspect of cognitive control that uniquely contributes to math performance in early childhood.

Introduction

Cognitive control refers to a class of mechanisms that support goal-directed behaviors, especially in the face of distractions or irrelevant behavior choices (Badre, 2025; Cohen, 2017). Although cognitive control and executive functions are often used interchangeably and can be assessed using similar tasks, the term “executive functions” is more commonly used to refer to a set of skills and abilities such as inhibition and set shifting, whereas cognitive control emphasizes the underlying mechanisms that enable context-dependent selection and execution of goal-directed behaviors (Badre, 2025). Here, we adopt this mechanistic framing and use the term cognitive control throughout.

In early childhood, cognitive control has been robustly linked to school readiness and academic success (Isbell et al., 2019; Rueda et al., 2010; Welsh et al., 2010). Most developmental research on these links focuses on how cognitive control is deployed *on average* in

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a given task. However, given that cognitive control fluctuates from moment to moment (Decker et al., 2023a; Esterman et al., 2013; Mansouri et al., 2024; Unsworth, 2015), children may also differ in how consistently cognitive control is engaged across trials within a task. Such (in)consistent engagement of cognitive control may be particularly important for the development of academic skills during the early school years, as the transition to formal schooling is characterized by increased demands on cognitive control and academic learning (Bassok et al., 2016; Posner & Rothbart, 2014). Although there is some evidence that cognitive control consistency relates to academic performance in young children (Isbell et al., 2018; Michel et al., 2025), there remains a scarcity of work examining these associations specifically across kindergarten and first grade – a foundational period for the acquisition of skills critical for later academic achievement (Duncan et al., 2007; Ellis et al., 2021; Morgan et al., 2018). Thus, the goal of the present study was to assess longitudinal associations between cognitive control consistency and academic skills across the transition from kindergarten to first grade.

Consistency of cognitive control

Even in the absence of changes to the sensory and contextual demands of a task, cognitive control fluctuates from moment to moment (Decker et al., 2023a; Fortenbaugh et al., 2015; Isbell et al., 2018; Unsworth, 2015). It has been argued that such fluctuations in cognitive control can be assessed via response time variability, a person-level metric of response time fluctuations across trials (Fortenbaugh et al., 2015; Mansouri et al., 2024; Unsworth, 2015). Multiple interrelated factors contribute to cognitive control consistency and, in turn, response time variability.

Building on the executive attention framework (Engle & Kane, 2004; Unsworth et al., 2024), many have argued that fluctuations in attention primarily account for greater response time variability (Kane et al., 2016; Unsworth, 2015; Welhaf & Kane, 2024). According to this framework, attention control refers to the ability to maintain focus on task-relevant goals while resisting interference from distractors and irrelevant information (Burgoyne & Engle, 2020; Engle & Kane, 2004). Lapses in attention control can lead to both very fast responses – reflecting reliance on automatic tendencies rather than controlled processes – and very slow responses, given that such lapses can slow down information processing and the execution of goal-directed behaviors (Cheyne et al., 2009; deBettencourt et al., 2019; Kane & McVay, 2012; Löffler et al., 2021; Unsworth et al., 2010). Such attentional lapses likely reflect inefficient modulation of the fronto-parietal control network (FPN) and inadequate suppression of the default mode network (DMN), networks largely modulated by the locus coeruleus-norepinephrine (LC-NE) system, which plays a crucial role in attention control (Mittner et al., 2016; Unsworth & Robison, 2017). Such imbalances between the FPN and DMN are associated with heightened response time variability (Esterman et al., 2013, 2014; Yamashita et al., 2021) and are argued to be a mechanism through which fluctuations in cognitive control contribute to increased response time variability (Mansouri et al., 2024). Fluctuations in attention may also alter the signal-to-noise ratio in sensory information processing and motor control, contributing to the quality and consistency of perceptual encoding and response execution on a trial-by-trial basis (Mansouri et al., 2024). In other words, attentional lapses can modulate sensorimotor processes and contribute to greater variability in response times. Thus, fluctuations in attention are likely a key factor contributing to inconsistent engagement of cognitive control and greater response time variability.

Arousal and conative factors, and their associations with attention control, may also contribute to the consistency with which cognitive control is engaged. In particular, states of hypo- or hyper-arousal, as well as greater variability in tonic arousal, are associated with more frequent attentional lapses and greater response time variability (Robison & Brewer, 2022; Unsworth & Miller, 2021; Unsworth & Robison, 2017). In terms of conative factors, greater interest and motivation have been found to be associated with fewer attentional fluctuations and lower response time variability (Welhaf & Kane, 2024; Unsworth & Miller, 2021). Altogether, attention, arousal, and conative factors can collectively contribute to how consistently cognitive control is engaged.

Although response time variability can index cognitive control consistency, it is important to acknowledge that processing speed may also contribute to response time and its variability. Slower overall processing speed is associated with both slower average response times and greater response time variability, given that very slow response times increase the spread of the response time distribution (Wagenmakers & Brown, 2007). However, fluctuations in cognitive control may also impact both metrics; for example, attentional lapses that result in very slow responses will increase both average response time and variability. Adults with slower processing speed tend to exhibit less consistent cognitive control (Unsworth et al., 2021), suggesting that processing speed and cognitive control consistency are interrelated. These intercorrelations underscore the importance of accounting for individual differences in overall processing speed, such as via the coefficient of variation (Unsworth, 2015; Wagenmakers & Brown, 2007), when using response time variability as an index of cognitive control consistency.

In summary, response time variability reflects the extent to which goal-directed behavior remains stable amid fluctuations in various factors, such as attention, arousal, motivation, perceptual processing, and motor execution. When sensory-motor demands and contextual factors remain relatively stable during a task requiring sustained goal maintenance, trial-to-trial variability in response time is most plausibly attributable to fluctuations in cognitive control engagement across trials. As a behavioral measure, response time variability does not permit precise decomposition of the relative contributions of these underlying factors. Rather, it serves as an aggregate index of the consistency with which cognitive control supports goal-directed behavior under conditions requiring sustained attention and goal maintenance, especially in the presence of distractions or irrelevant behavior choices.

It is important to note that although cognitive control fluctuations may affect accuracy (i.e., lead to errors of omission and commission; Cheyne et al., 2009; deBettencourt et al., 2019; Decker et al., 2023a), response time variability metrics can provide a more sensitive measure of how consistently cognitive control is engaged during a task. Critically, fluctuations in cognitive control may not necessarily result in errors. For example, faster-than-normal responses on trials requiring a response may reflect lapses in active goal maintenance but still be accurate. Accuracy-based metrics reflect whether performance crosses an error threshold that results in an

incorrect response, whereas response time variability captures graded fluctuations in multiple underlying factors that may not culminate in errors. As such, individuals may display comparable accuracy but differ markedly in the consistency with which cognitive processes are engaged, as reflected in their response time variability (Kievit, 2025). Importantly, previous work has shown that compared to accuracy metrics, response time variability measures capture distinct aspects of performance (Judd et al., 2024; Michel et al., 2025), display different time-on-task effects (Lewis et al., 2017), and differentially relate to attention problems (Ali et al., 2024; Gómez-Guerrero et al., 2011). Altogether, these findings suggest response time variability offers a source of unique insights into the consistency of cognitive control.

Cognitive control consistency in childhood

Developmental research has demonstrated that childhood may be a period of heightened susceptibility to fluctuations in cognitive control. In particular, compared to adults, children have been found to display less consistent engagement of cognitive control across various tasks, as indexed by greater response time variability (Decker et al., 2023a; Fortenbaugh et al., 2015; Hoyer et al., 2021). Further, findings from cross-sectional and longitudinal studies suggest robust improvements in cognitive control consistency across childhood, reflected by rapid declines in response time variability during this period (Fortenbaugh et al., 2015; Hoyer et al., 2021; Lewis et al., 2017; Williams et al., 2005). These age-related changes in response time variability coincide with major developmental changes in neural networks critical for cognitive control (Fiske & Holmboe, 2019; Posner et al., 2014; Song et al., 2021). Together, these findings suggest that consistent engagement of cognitive control improves across childhood, and that response time variability can capture these developmental changes.

Although response time-based measures, particularly difference scores, have been debated as being less stable in young children (Draheim et al., 2019), a growing body of evidence demonstrates that response time variability metrics can capture meaningful individual differences in cognitive control in children. For example, in preschoolers, Isbell et al. (2018) demonstrated that children who displayed more consistent cognitive control, indexed by lower response time variability during a Go/No-Go task, also performed better on a cognitive flexibility task. Decker et al., 2023a found that 7–10-year-old children who displayed more frequent lapses in cognitive control, indexed by the number of trials with highly deviant response times, showed lower overall categorization accuracy in a visual oddball task and worse memory performance on a surprise old/new recognition task. Together, these findings suggest that cognitive control consistency, indexed via response time variability, captures meaningful variation in children's cognitive control that relates to other cognitive abilities.

Further supporting the utility of response time variability as a measure during childhood, heightened response time variability has been consistently implicated in a wide spectrum of clinical disorders in childhood, including attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorder (ASD; Ali et al., 2024; Gómez-Guerrero et al., 2011; Karalunas et al., 2014; van Belle et al., 2015). Developmental trajectories of response time variability have also been found to differ between typically developing children and children with ADHD or ASD (van Belle et al., 2015). Beyond clinical populations, response time variability has also been linked to subclinical attention difficulties in a population-based sample of 5–14-year-olds, such that children with higher teacher-reported attention problems also displayed greater response time variability (Aristodemou et al., 2024). Taken together, converging evidence from developmental and clinical research demonstrates that response time variability captures meaningful individual differences in cognitive control consistency during childhood.

Cognitive control consistency and early academic skills

Developmental changes in cognitive control consistency may be particularly important during the early school years. This developmental period encompasses the transition to formal schooling, which poses new challenges and expectations for children as they must consistently control their attention and actions in the classroom. As such, increases in cognitive control consistency during this period may be particularly consequential for meeting the demands of formal schooling. Frequent fluctuations in cognitive control may impair learning processes, especially via lapses in attention control, and lead children to miss information in their environment that is relevant to the acquisition of academic skills (Markant & Amso, 2022). Additionally, the application of academic skills requires cognitive control processes (Cragg & Gilmore, 2014; Rueda et al., 2010; Stevens & Bavelier, 2012). As such, fluctuations in cognitive control may disrupt consistent goal maintenance and the execution of goal-directed behaviors during academic tasks, thereby hindering performance. Thus, cognitive control consistency may be important for both the acquisition and execution of various academic skills.

Nevertheless, developmental research examining the links between cognitive control and academic performance has primarily examined how cognitive control is deployed on average in a given task via accuracy or average response time metrics (Allan et al., 2014; Checa & Rueda, 2011; Kubota et al., 2020; Welsh et al., 2010). As such, there remains limited work examining the links between cognitive control consistency, indexed via response time variability, and academic performance in early childhood. There is some evidence that greater fluctuations in cognitive control, indexed by higher response time variability, predict worse concurrent performance on math and literacy assessments during kindergarten (Michel et al., 2025). In a longitudinal study, more consistent cognitive control, indexed by lower response time variability, in preschool predicted greater concurrent math and literacy skills, which in turn predicted better teacher-reported academic performance in first grade (Isbell et al., 2018). These findings demonstrate the importance of cognitive control consistency for concurrent and later academic skills during early childhood.

However, an important gap in the literature remains to be addressed. These studies did not examine whether cognitive control consistency, indexed via response time variability, independently predicted academic performance above and beyond accuracy-based

metrics that capture how cognitive control is deployed on average during a task. Two children can show similar accuracy, especially on tasks that are not highly challenging, yet differ considerably in how consistently they engage cognitive control across the task (Kievit, 2025). As mentioned earlier, unlike accuracy-based metrics, response time variability measures can capture graded fluctuations in cognitive control that may not culminate in errors. Further, response time variability and accuracy-based metrics display different time-on-task effects, developmental trajectories, and relations with other outcomes (Ali et al., 2024; Gómez-Guerrero et al., 2011; Judd et al., 2024; Lewis et al., 2017; Michel et al., 2025). These findings suggest that response time variability and accuracy reflect separable dimensions of performance, underscoring the importance of examining whether each metric shows unique associations with children's academic development. When only accuracy is considered, fluctuations in controlled behavior risk being treated as noise rather than as potentially informative variation in how cognitive control is sustained over time. Conversely, when response time variability is examined in isolation, it remains unclear whether cognitive control consistency reflects a unique dimension of goal-directed behavior rather than shared variance with overall task performance. Addressing this issue is important for understanding whether consistency of cognitive control is a distinct aspect of goal-directed behavior that matters for children's academic achievement. Thus, the current study examined whether cognitive control consistency uniquely contributes to academic achievement above and beyond overall task performance across kindergarten and first grade.

Current study

Here, we assessed cognitive control consistency by measuring response time variability in a sustained attention to response task (i.e., Go/No-Go), which is frequently used to measure response time variability in children (Fortenbaugh et al., 2015; Isbell et al., 2018; Simmonds et al., 2007). Specifically, we used a person-level metric of response time variability over the course of the task to examine individual differences in cognitive control consistency.

Our first aim was to examine how cognitive control consistency relates to academic performance concurrently in kindergarten and prospectively in first grade. Broadly, we hypothesized that cognitive control consistency would display concurrent and prospective links with academic performance. However, we refrained from predicting whether these links would be domain-general or domain-specific. Given that prior work has demonstrated associations between cognitive control consistency and academic skills across multiple domains (Isbell et al., 2018; Michel et al., 2025), it is plausible that these associations may be domain-general. As such, less consistent cognitive control, indexed by greater response time variability, in kindergarten may relate to worse performance on both math and literacy assessments in kindergarten and first grade.

Alternatively, it is possible that these links may be domain-specific. Cubillo and colleagues employed a cognitive training program and found that lower post-intervention response time variability was associated with better math but not reading skills in 7–9-year-olds (Cubillo et al., 2023). Further, research on controlled, goal-directed behavior that has examined abilities such as inhibition, working memory, and shifting may provide insight into potential domain-specific links between cognitive capacities and academic skills. These abilities are often studied under the umbrella term of executive functions, a construct closely related to cognitive control but typically used to characterize the abilities through which control is expressed (Badre, 2025). Such work has demonstrated robust positive links between executive functions and various early math skills. In contrast, results regarding the associations between executive functions and early literacy skills have been inconsistent, with some studies reporting a positive association and others finding no link (Ernst et al., 2022; Fuhs et al., 2014; Ribner et al., 2023; Valcan et al., 2020). One reason may be that typical early literacy tasks (e.g., letter and word recognition) rely heavily on knowledge and place fewer demands on cognitive control processes compared to early math tasks. Thus, cognitive control consistency may relate to math but not literacy skills in kindergarten and first grade.

Our second aim was to assess whether consistency of cognitive control independently relates to children's academic achievement, above and beyond an accuracy-based measure of overall performance (i.e., d'). In line with previous studies (Decker et al., 2023a; Isbell et al., 2018; Michel et al., 2025), we hypothesized that children who display less consistent cognitive control, indexed by greater response time variability, on the Go/No-Go task would exhibit worse overall performance, indexed by lower d' scores. Given that response time variability and accuracy-based measures are argued to be distinct and have been found to display unique developmental trajectories and relations to other outcomes (Cubillo et al., 2023; Gómez-Guerrero et al., 2011; Judd et al., 2024; Lewis et al., 2017; Michel et al., 2025), we also predicted that when taking into account overall task performance, cognitive control consistency would uniquely contribute to academic performance.

Our third aim was to investigate the indirect associations between cognitive control consistency and first-grade academic performance through kindergarten academic skills. Given that kindergarten academic skills are crucial for later academic achievement (Duncan et al., 2007; Rabiner et al., 2016), greater cognitive control fluctuations may relate to worse kindergarten academic performance, which in turn, contributes to worse academic performance in first grade. Thus, we also assessed indirect pathways in which cognitive control consistency would relate to academic skills in kindergarten, which in turn would predict first-grade academic performance.

Method

Participants

Participants were part of a longitudinal study on the effects of schooling on children's cognitive and academic development. The initial sample consisted of 217 kindergartners who were recruited from 4 public schools in the Midwestern United States. Of these 217 kindergartners, 48 did not participate during any first-grade assessment one year later due to moving ($n = 28$), repeating kindergarten

($n = 3$), not wanting to participate ($n = 2$), or unknown reasons ($n = 15$). Thus, 169 children participated in both kindergarten and first-grade assessments (22% longitudinal attrition rate).

Children were excluded from the final sample of the present study if they did not participate in the Go/No-Go task (e.g., child did not want to play the game, equipment error, $n = 38$), completed less than half of the task (i.e., less than 4 blocks, $n = 12$), had 50% or less accuracy on Go trials (i.e., did not press a button on most trials, $n = 4$), or did not complete the Woodcock-Johnson assessments in kindergarten ($n = 2$) or first grade ($n = 1$).

The final sample consisted of 112 children (46% female). On average, children were 5.74 years old at the kindergarten assessment ($SD = 0.41$, range = 4.96–6.94 years). Children who were included in the final sample ($n = 112$) did not differ from children who were not included ($n = 105$) in terms of age at initial testing, $t(130.62) = -0.446$, $p = .656$, or sex, $\chi^2(1, 217) = 0.029$, $p = .864$. Of the 4 schools from which students were recruited, 1 was characterized as low-poverty, meaning 0 to 25% of students are eligible for free or reduced-price lunch (FRPL), and 3 were characterized as mid-high poverty, which are schools where 50.01 to 75% of students are eligible for FRPL (National Center for Education Statistics, 2023). In our sample, 67% of children attended a mid-high poverty school.

Procedure

We obtained written permission to conduct the study from school principals, informed consent from classroom teachers and parents, and verbal assent from the child before data collection. All assessments were conducted in children's elementary schools during the school day at times agreed upon with each child's teacher. Children were tested in quiet spaces within the school, including conference rooms, empty classrooms, and libraries, as designated by the school staff. Each school visit lasted approximately 1–1.5 hours. Children completed the academic assessments first and then completed the Go/No-Go task during a separate visit, approximately two weeks later. The first-grade data collection took place approximately 1 year after the kindergarten visit. Children received a small toy for participating.

Measures

Cognitive control. To assess children's cognitive control, we used a computerized Go/No-Go task called the Zoo Game, which consists of real-life photographs of animals (Grammer et al., 2014; He et al., 2010). The task was presented using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA, USA). In this task, children were told that they were playing a game in which their goal was to help a zookeeper catch all of the animals loose in the zoo and return them to their cages. They were informed that 3 of the animals, friendly orangutans, were helping the zookeeper, so they should not be put back in their cages. As such, children were instructed to press a button as quickly as they could each time they saw an animal (Go trials), except for when they saw an orangutan (No-Go trials).

During the Go/No-Go task, children were seated directly in front of the computer monitor and given a game controller to make responses. The task began with a brief practice block consisting of 12 trials, 9 with zoo animals (Go) and 3 with orangutans (No-Go). If children performed at or below chance for either trial type during the practice block, instructions were repeated, and they were given another opportunity to practice. Following this, children completed 8 blocks of the task, each with 40 trials (30 Go, 10 No-Go), for a total of 320 trials (75% Go). The Go stimuli consisted of 240 novel animal photos (no repeats). The No-Go stimuli consisted of 3 orangutan photos presented in random order. Each block consisted of novel sets of animal photographs, with each set balanced in terms of animal type, color, and size. As shown in Fig. 1, each trial began with a fixation cross displayed for a randomized interval ranging between 200 and 300 ms. Following this, the stimulus was presented for 750 ms and then proceeded by a blank screen for 500 ms. Responses could be made while the stimulus was on the screen or at any point during the following 500 ms of blank screen. Subsequent trials began after the blank screen period. Children made responses on a standard game controller (Logitech Dual Action

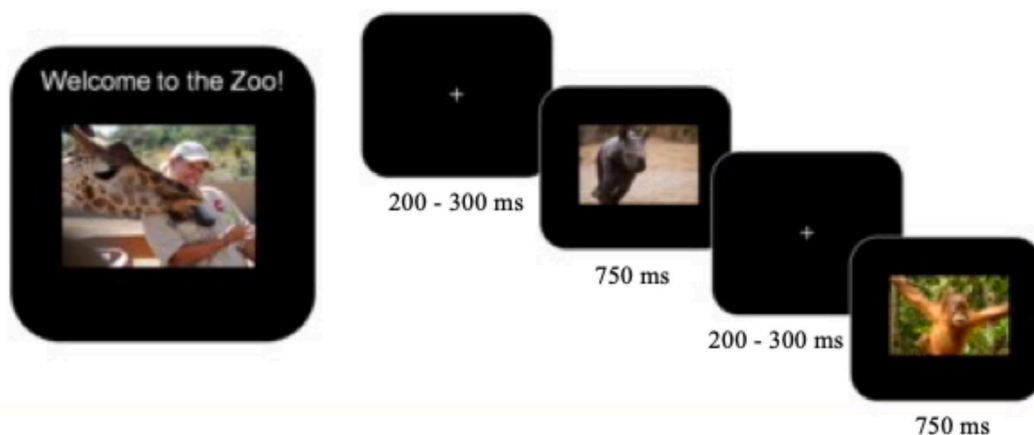


Fig. 1. Schematic of Go/No-Go (i.e., Zoo Game) task structure. A blank screen was presented for 500 ms following the stimulus. Reprinted from Grammer et al. (2014), retrieved from <https://doi.org/10.1016/j.dcn.2014.02.001>, © Grammer, Carrasco, Gehring, and Morrison.

Gamepad USB). Both speed and accuracy were emphasized; children received performance feedback of either “Try to catch them even faster next time!” or “Watch out for the orangutan friends!” after each block based on their accuracy in the preceding block. To sustain enthusiasm and task engagement, children were provided with short breaks as necessary and shown a “Zoo map” before the beginning of the task and after blocks 2, 4, 6, 7, and 8 to allow them to monitor their task progress.

Response time variability was used to assess cognitive control consistency. Although response time variability is derived from trial-to-trial fluctuations within individuals, our analytic focus was on stable individual differences in the degree of such variability across participants (i.e., inter-individual variability). Thus, the present analyses treat response time variability across trials as a person-level metric of consistency, rather than modeling moment-to-moment within-person dynamics. Response time variability was captured using the coefficient of variation (CoV) – a metric of variability that accounts for average response times and has been used across a wide range of ages (e.g., Fortenbaugh et al., 2015; Hobbiss & Lavie, 2024; Isbell et al., 2018). CoV was computed for each child by dividing the standard deviation of response time by the mean response time ($SD/$ Mean RT). Because CoV expresses variability relative to an individual’s average speed of responding, individual differences in overall processing speed were partially accounted for. Consistent with other studies that used Go/No-Go paradigms, CoV was derived from only the correct Go trials (Fortenbaugh et al., 2015; Gallen et al., 2023; Isbell et al., 2018; Kane et al., 2016). Greater CoV scores correspond to less consistent cognitive control. Split-half reliability (odd–even trials) with Spearman-Brown correction indicated high internal consistency for CoV in the current sample ($r = .97$).

A discriminability index (d') was used to obtain an accuracy-based metric of cognitive control. Specifically, d' was calculated as follows: $d' = Z(\text{Correct}/\text{Hit}) - Z(\text{Incorrect}/\text{False Alarm})$. This measure considers both the hit rate and false alarm rate, distinguishing signal from noise, independent of response bias. Larger values of d' indicate better overall task performance, taking into account Go and No-Go trial accuracy. Split-half reliability (odd–even trials) with Spearman-Brown correction indicated high internal consistency for d' in the current sample ($r = .95$).

Academic achievement. Math and literacy skills were assessed using the Applied Problems and Letter-Word Identification subtests from the Woodcock-Johnson III Tests of Achievement (Woodcock, McGrew & Mather, 2001). Neither subtest was speeded and each grew increasingly difficult as children progressed. The Applied Problems subtest (WJ-AP) was used to assess early math skills. This subtest assesses children’s early math skills, including counting and arithmetic using word problems, pictures, and numbers.

The Letter-Word Identification subtest (WJ-LWID) was used to assess children’s early literacy skills. The WJ-LWID requires children to identify letters and words in expressive and receptive language. Due to a lack of item-level data, we were unable to calculate the internal consistency of the WJ-AP and WJ-LWID measures. However, external validation efforts have demonstrated excellent internal consistency (Cronbach’s $\alpha = 0.93$) for the academic achievement battery among young children and very high test–retest reliability (McGrew et al., 2007; Woodcock et al., 2001).

For all analyses, grade-equivalent scores derived from W scores were used. Specifically, raw scores from each subtest were converted into W scores, which are derived from the Rasch model and provide an equal-interval measurement scale, allowing direct comparison of academic achievement across students regardless of age (Jaffe, 2009). The W scale for each subtest is centered at 500, which approximates the average performance of beginning fifth-grade students.

Covariates. Two child-level characteristics were included as covariates to control for their potentially confounding influence. First, given that child age has been found to relate positively to performance on math and literacy assessments, both concurrently and prospectively during the early school years (e.g., Ellis et al., 2021), we included child age at initial testing in kindergarten as a covariate. Second, while some studies have reported no sex-related differences in academic achievement in early childhood (e.g., Matthews et al., 2009), others have found that females perform better than males on math and literacy assessments during elementary school (for a review, see Voyer & Voyer, 2014). Thus, we also included child sex as a covariate.

Analytic strategy

We conducted path analyses to evaluate the hypothesized direct and indirect associations among cognitive control consistency, overall task performance, and academic performance assessed in kindergarten and first grade.¹ A separate path analysis was conducted for math skills (Applied Problems W scores) and literacy skills (Letter-Word Identification W scores). In each path model, the index of cognitive control consistency (i.e., CoV) and the accuracy-based performance metric (i.e., d') in kindergarten were specified as exogenous variables that predicted academic skills in kindergarten and first grade. Academic skills in kindergarten were specified as predicting academic performance in first grade. The exogenous variables (CoV and d') were allowed to covary. We controlled for child age at initial testing and child sex on the main outcomes (math and literacy skills in kindergarten and first grade) to examine whether the predictors of interest (CoV and d') relate to academic skills above and beyond these child-level characteristics. To test indirect effects, we used a bias-corrected bootstrapping procedure (10,000 draws), a nonparametric method that corrects for potential bias in non-normal distributions, reduces Type I error rates, and yields more robust confidence intervals for the indirect effects (Mackinnon et al., 2004). Data were assumed to be missing at random (MAR). To examine the MAR assumption for these data, missing data indicator variables were created and used as dependent variables in logistic regressions. Independent variables used to predict

¹ We ran exploratory analyses with median response time as the only predictor of academic skills, controlling for age and sex, to examine whether basic processing speed relates to academic performance. Median response time was used as it provides a measure of central tendency that is independent of the CoV calculation ($SD/$ Mean RT). Median response time did not relate to math or literacy skills in kindergarten or first grade (all $ps > .173$), suggesting that processing speed alone does not account for the associations observed in the primary analyses.

missingness included child age and sex, as these were the only potential auxiliary variables available. Neither variable was found to predict missingness (all $ps > .662$), indicating that the MAR assumption was reasonable. Given the limited auxiliary information (only child age and sex were available in this school-based study), we did not use a model-based approach to handle missing data; instead, analyses were conducted using children for whom we had data for all variables of interest ($N = 112$). Analyses were conducted in R (Version 4.4.1; R Core Team, 2025) and RStudio (Version 5.1; RStudio Team, 2025) using the *lavaan* package (Version 0.6; Rosseel, 2012).

Results

Preliminary analyses

Descriptive statistics and bivariate correlations are reported in Tables 1 and 2, respectively. Skewness and kurtosis were within the limits of moderate normality (i.e., skewness < 2 and kurtosis < 7 ; Kline, 2023). Scores above or below 3.29 SD were considered univariate outliers (Tabachnick et al., 2007). One outlier was identified for CoV.² All analyses were conducted using children's original scores as well as with the outlier set to missing. Given the direction and strength of the results remained consistent across the analyses, the subsequent results reported here include all children to reflect the true range of scores.

Because CoV and d' were highly correlated ($r = -0.80$), we evaluated whether this multicollinearity was problematic by computing the variance inflation factor (VIF) and tolerance for each predictor within each regression equation of the path model. VIF values ranged from 1.07 to 2.92, and tolerance values ranged from 0.34 to 0.93. These values fall within acceptable limits (VIF < 5 , tolerance > 0.20 ; O'Brien, 2007), suggesting that the collinearity between CoV and d' was not problematic for parameter estimation.

Math skills

The path model predicting math skills in kindergarten and first grade had good fit, $\chi^2(4) = 2.20$, $p = 0.70$; CFI = 1.00; RMSEA = 0.00 [90% CI = 0.000 – 0.107]. The model explained 6.8% of the variance in kindergarten math skills ($R^2 = 0.068$) and 39.5% of the variance in first-grade math skills ($R^2 = 0.395$). Standardized path coefficients are presented in Fig. 2, and standardized and unstandardized path coefficients for all paths are reported in Table 3.

Cognitive control consistency (indexed via CoV) and the accuracy-based metric (d') were significantly correlated, such that children with greater CoV values (i.e., more variable response times) demonstrated lower d' values (i.e., poorer overall task performance). Age, sex, and d' did not relate to math skills in kindergarten or first grade (all $ps > .055$). Independent of age, sex, and d' , cognitive control consistency in kindergarten was significantly associated with math skills in kindergarten and first grade. Specifically, children with higher CoV values in kindergarten (i.e., less consistent cognitive control) displayed poorer performance on the Applied Problems subtest in kindergarten and first grade.

Kindergarten math skills were significantly positively associated with first-grade math skills. However, the indirect effect of cognitive control consistency on first-grade math skills via kindergarten math skills was not significant ($p = .056$). The indirect effect of d' on first-grade math skills via kindergarten math skills was also not significant ($p = .185$).

Literacy skills

The path model predicting literacy skills in kindergarten and first grade had good fit, $\chi^2(4) = 2.20$, $p = 0.70$; CFI = 1.00; RMSEA = 0.00 [90% CI = 0.000 – 0.107].³ The model explained 20.8% of the variance in kindergarten literacy skills ($R^2 = 0.208$) and 48% of the variance in first-grade literacy skills ($R^2 = 0.480$). Standardized path coefficients are presented in Fig. 3, and standardized and unstandardized path coefficients for all paths are reported in Table 3.

Cognitive control consistency (indexed via CoV) and d' were significantly correlated, such that children with greater CoV values (i.e., more variable response times) demonstrated lower d' values (i.e., poorer overall task performance). Child age at initial testing was positively related to literacy skills in kindergarten, such that older children performed better on the Letter-Word Identification subtest. Controlling for kindergarten literacy skills, children who were older in kindergarten performed worse on the Letter-Word Identification subtest in first grade. Child sex did not relate to literacy skills in kindergarten ($p = .103$). However, compared to females, males displayed better literacy skills in first grade. In addition, d' did not relate to literacy skills at either time point (all $ps > .118$). Controlling for age, sex, and d' , cognitive control consistency in kindergarten did not relate to literacy skills in kindergarten or first grade (all $ps > .073$).

Kindergarten literacy skills were significantly positively associated with first-grade literacy skills. However, the indirect effect of

² One outlier was also identified for kindergarten Applied Problems and one outlier was identified for kindergarten Letter-Word Identification. However, the standardized academic assessments used in this study are norm-referenced and designed to capture performance across the full range, including very high and very low scores. There was no evidence of task administration error or child compliance issues for these participants; therefore, their scores were treated as valid observations and retained in all analyses.

³ The path models predicting math and literacy skills had identical structural specifications and were based on similar data. Because global fit indices are determined by the discrepancy between the observed and model-implied covariance matrices (Kline, 2023), the similarity in model structure and covariance patterns likely resulted in equivalent model fit.

Table 1
Descriptive Statistics.

Variable	Mean	SD	Min	Max	Median	Skewness	Kurtosis
Kindergarten age (years)	5.74	0.41	4.96	6.94	5.70	0.20	2.47
d'	1.64	0.76	-0.25	3.11	1.65	-0.33	2.59
CoV	0.33	0.10	0.18	0.68	0.30	1.05	3.78
Math skills (K)	433.86	14.90	372.00	476.00	435.00	-0.47	4.90
Math skills (1st)	461.12	15.97	423.00	502.00	458.00	0.32	2.96
Literacy skills (K)	392.53	34.61	283.00	507.00	384.00	0.70	4.70
Literacy skills (1st)	452.82	31.07	384.00	525.00	451.00	0.03	2.28

Note. d' : discriminability index, an accuracy-based metric of task performance. CoV: coefficient of variation derived from correct Go trials, an index of cognitive control consistency. K: kindergarten; 1st: first grade.

Table 2
Bivariate Correlations.

Variable	1	2	3	4	5	6	7	8
1. Age (K)	–							
2. Female	-0.27	–						
3. d'	-0.10	0.11	–					
4. CoV	0.06	-0.05	-0.80	–				
5. Math skills (K)	0.16	-0.02	0.03	-0.15	–			
6. Math skills (1st)	0.04	-0.13	0.17	-0.31	0.56	–		
7. Literacy skills (K)	0.38	-0.23	0.07	-0.16	0.55	0.45	–	
7. Literacy skills (1st)	0.04	-0.26	0.01	-0.15	0.47	0.52	0.63	–

Note. d' : discriminability index, an accuracy-based metric of task performance. CoV: coefficient of variation derived from correct Go trials, an index of cognitive control consistency. K: kindergarten; 1st: first grade. Boldface type indicates $p < .050$.

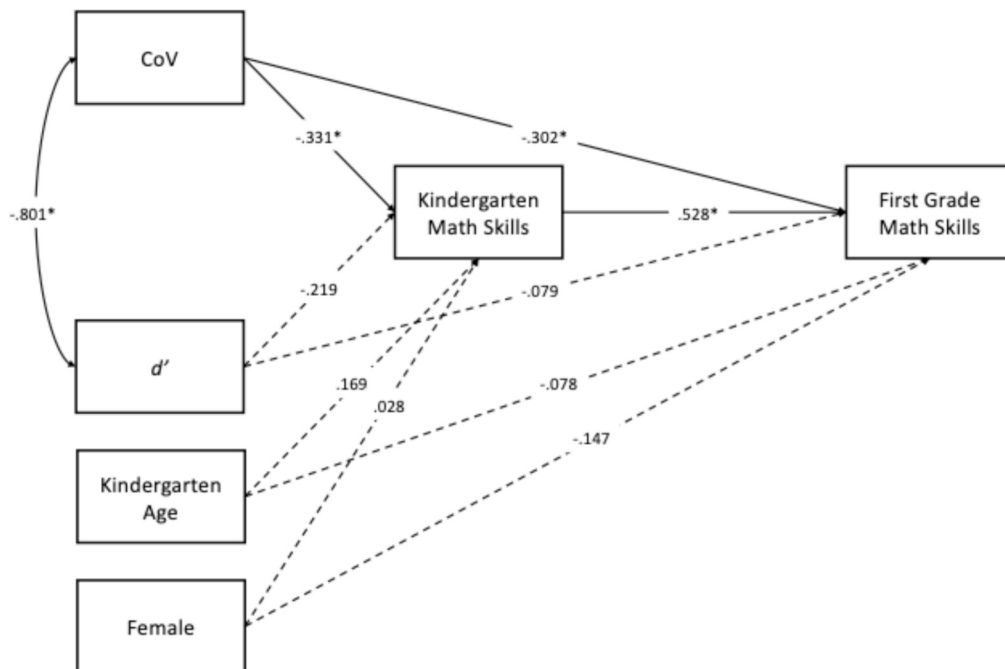


Fig. 2. Path model predicting math skills. CoV: coefficient of variation derived from correct Go trials, an index of cognitive control consistency. d' : discriminability index, an accuracy-based metric of task performance. Values are standardized coefficients. Statistically significant paths are solid lines. * $p < .050$.

Table 3
Estimates from the Path Models.

Model	Path	β	b	SE	95% Confidence Interval		p
					Lower	Upper	
Math Skills	Age (K) → Math skills (K)	0.169	6.187	3.489	−0.711	12.902	.076
	Age (K) → Math skills (1st)	−0.078	−3.054	3.245	−9.453	3.325	.347
	Female → Math skills (K)	0.028	0.820	2.884	−4.879	6.443	.776
	Female → Math skills (1st)	−0.147	−4.709	2.455	−9.586	−0.040	.055
	d' → Math skills (K)	−0.219	−4.300	3.020	−10.174	1.775	.155
	d' → Math skills (1st)	−0.079	−1.663	3.203	−7.746	4.853	.603
	CoV → Math skills (K)	−0.331	−48.020	22.597	−90.814	−2.221	.034*
	CoV → Math skills (1st)	−0.302	−47.022	21.809	−88.040	−2.735	.031*
	Math skills (K) → Math skills (1st)	0.528	0.566	0.090	0.391	0.752	<.001*
	CoV ↔ d'	−0.801	−0.062	0.010	−0.082	−0.043	<.001*
Literacy Skills	<i>Indirect associations</i>						
	CoV → Math skills (K) → Math skills (1st)	−0.175	−27.186	14.230	−57.296	−1.109	.056
	d' → Math skills (K) → Math skills (1st)	−0.115	−2.434	1.837	−6.323	0.943	.185
	Age (K) → Literacy skills (K)	0.354	30.206	8.298	14.813	47.252	<.001*
	Age (K) → Literacy skills (1st)	−0.272	−20.722	4.966	−30.658	−11.354	<.001*
	Female → Literacy skills (K)	−0.137	−9.524	5.840	−20.912	2.148	.103
	Female → Literacy skills (1st)	−0.167	−10.361	4.254	−18.751	−1.994	.015*
	d' → Literacy skills (K)	−0.088	−4.038	6.801	−17.255	9.826	.553
	d' → Literacy skills (1st)	−0.188	−7.714	4.936	−16.804	2.482	.118
	CoV → Literacy skills (K)	−0.259	−87.525	48.854	−183.603	10.216	.073
	CoV → Literacy skills (1st)	−0.180	−54.452	36.582	−126.542	17.631	.137
	Literacy skills (K) → Literacy skills (1st)	0.682	0.608	0.078	0.452	0.757	<.001*
	CoV ↔ d'	−0.801	−0.062	0.010	−0.082	−0.043	<.001*
	<i>Indirect associations</i>						
	CoV → Literacy skills (K) → Literacy skills (1st)	−0.176	−53.254	30.731	−115.685	6.162	.083
	d' → Literacy skills (K) → Literacy skills (1st)	−0.060	−2.457	4.190	−10.758	5.893	.558

Note. d' : discriminability index, an accuracy-based metric of task performance. CoV: coefficient of variation derived from correct Go trials, an index of cognitive control consistency. K: kindergarten; 1st: first grade. * $p < .050$.

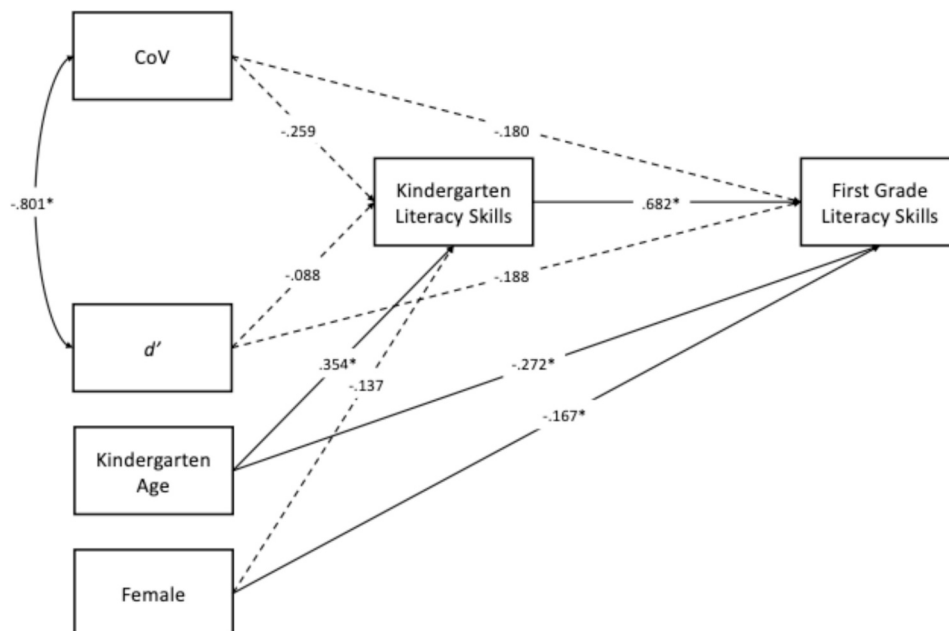


Fig. 3. Path model predicting literacy skills. CoV: coefficient of variation derived from correct Go trials, an index of cognitive control consistency. d' : discriminability index, an accuracy-based metric of task performance. Values are standardized coefficients. Statistically significant paths are solid lines. * $p < .050$.

cognitive control consistency on first-grade literacy skills via kindergarten literacy skills was not significant ($p = .083$). The indirect effect of d' on first-grade literacy skills via kindergarten literacy skills was also not significant ($p = .558$).

Discussion

This study examined how the ability to consistently engage cognitive control relates to academic skills across kindergarten and first grade, an important developmental period encompassing the transition and acclimation to formal schooling. We found that more consistent cognitive control, indexed by lower response time variability, related to better math skills concurrently in kindergarten and prospectively in first grade, above and beyond the accuracy-based metric, d' . This finding suggests that consistency is an important and distinct aspect of cognitive control that contributes to math performance in early school years. In contrast, cognitive control consistency did not relate to literacy skills in kindergarten or first grade, suggesting that the link between cognitive control consistency and academic skills may be domain-specific during the early school years.

Cognitive control consistency and math skills

In line with our prediction, more consistent engagement of cognitive control during a Go/No-Go task contributed to better math performance both concurrently in kindergarten and prospectively in first grade. These findings support previous work reporting concurrent links between cognitive control consistency and math performance in preschool (Isbell et al., 2018) and kindergarten (Michel et al., 2025), and extend prior research by providing initial evidence for a prospective link between cognitive control consistency in kindergarten and later math skills in first grade. The convergence of findings across these studies – despite differences in sample characteristics, math assessments, and analytical approaches – contributes to a growing body of evidence suggesting that consistency of cognitive control is associated with early math skills. Kindergarten is a foundational year that encompasses the transition to formal schooling and is characterized by greater demands on cognitive control and an emphasis on academic learning (Bassok et al., 2016; Posner & Rothbart, 2014). As such, cognitive control consistency during this period may be particularly consequential for the development of academic skills. During the kindergarten-to-first-grade transition, children gradually add more complex math skills to their repertoire, such as arithmetic and solving story problems. Successful learning and execution of these more sophisticated skills relies on cognitive control processes (Cragg & Gilmore, 2014; Rueda et al., 2010; Stevens & Bavelier, 2012). As such, frequent lapses in cognitive control may disrupt consistent goal maintenance and the execution of task-relevant behaviors, impairing the acquisition and application of more complex math skills. Our findings suggest that the ability to consistently control one's attention and actions contributes to the development of math skills across kindergarten and first grade.

Contrary to our expectations, cognitive control consistency did not relate to first-grade math skills indirectly through kindergarten math performance. Despite the absence of an indirect effect, we found that greater cognitive control consistency (indexed by lower response time variability) prospectively predicted better math skills in first grade, after accounting for kindergarten math performance. These findings suggest that the mechanism linking cognitive control consistency in kindergarten to later math performance may not operate through gains in math achievement. Instead, the ability to consistently control one's attention in the face of distractions, maintain goals, monitor contexts, and resolve conflict may primarily support moment-to-moment execution of goal-directed behaviors. Such consistent execution of goal-directed behaviors likely facilitates successful engagement and performance during academic assessments. Alternatively, cognitive control consistency may contribute to the development of academic skills in ways that emerge gradually and are not yet reflected in standardized math scores during the early years of math instruction. Additionally, response time variability is related to other cognitive abilities, such as cognitive flexibility, memory, and intelligence, in children (Decker et al., 2023a; Fernandez et al., 2014; Isbell et al., 2018) and is heightened in various clinical disorders during childhood (Ali et al., 2024; Gómez-Guerrero et al., 2011; Karalunas et al., 2014; van Belle et al., 2015). As such, it is possible that cognitive control consistency may relate to math performance indirectly through its association with other factors not assessed in this study, such as intelligence or (sub)clinical symptoms (Aristodemou et al., 2024; Fernandez et al., 2014; Karalunas et al., 2014; van Belle et al., 2015), which may be more proximal predictors of math performance.

Cognitive control consistency and literacy skills

We found that cognitive control consistency did not relate to literacy skills in either kindergarten or first grade. This lack of association contradicts previous work using the same literacy assessment, which found that lower response time variability was associated with better literacy skills concurrently in preschool (Isbell et al., 2018). It is possible that in preschool, prior to the start of formal literacy instruction, associations between performance on cognitive control tasks and literacy assessments may reflect broader individual differences in attentional engagement across various assessments. However, in kindergarten, individual differences in performance on literacy assessments may increasingly reflect knowledge acquired through instruction and practice rather than moment-to-moment consistency of cognitive control.

Our finding that cognitive control consistency related to math but not literacy skills in kindergarten and first grade suggests that the links between cognitive control consistency and academic skills may be domain-specific in early school years. Such domain-specific links have also been found in intervention work with young children. In particular, Cubillo and colleagues found that more consistent cognitive control (indexed by lower response time variability on a Go/No-Go task) following a cognitive training program related to better math but not literacy skills in first graders (Cubillo et al., 2023). These findings align with the assertion that early math development may rely more heavily on cognitive control than early reading development (Blair et al., 2015; Isbell et al., 2019). This

interpretation is also in line with the broader literature on executive functions – a construct closely related to cognitive control that emphasizes abilities, such as inhibition, working memory, and shifting, through which control is expressed (Badre, 2025). Such work has reported robust links between executive functions and early math skills but inconsistent results regarding the link between executive functions and early literacy skills (Ernst et al., 2022; Fuhs et al., 2014; Ribner et al., 2023; Valcan et al., 2020).

One reason for the domain-specific link observed here and in prior work may be that math tasks require children to maintain problem representations, retrieve relevant facts while suppressing irrelevant information, execute sequential operations and monitor the consequences of their actions (Cragg & Gilmore, 2014; Markant & Amso, 2022; Stevens & Bavelier, 2012), all of which may be disrupted when cognitive control is not consistently engaged. In contrast, early literacy skills such as letter recognition and word identification may rely more heavily on knowledge and memorization (Blair et al., 2015; Michel et al., 2025) and thus may not rely as heavily on consistent cognitive control. Together, these findings suggest that the ability to engage cognitive control consistently may be especially important for early math skills. In contrast, early literacy skills may depend more heavily on other aspects of cognitive development, such as vocabulary knowledge and early decoding skills.

While our findings suggest that the links between cognitive control consistency and academic skills may be domain-specific, we cannot rule out that characteristics of the academic assessments may have contributed to these findings. To assess literacy skills, we used the Letter-Word Identification subtest from the Woodcock-Johnson III Tests of Achievement (Woodcock, McGrew, & Mather, 2001). This assessment requires children to identify letters and words in expressive and receptive language – skills which are argued to index early reading and alphabetic decoding and rely more heavily on knowledge and rote memorization than on cognitive control (Michel et al., 2025). Cognitive control processes may be more relevant as reading skills become more sophisticated, for example, when children learn spelling-sound irregularities that conflict with frequently used phonics rules or when they must adjust the meaning of words based on context (Castles et al., 2018). Supporting this possibility, Michel et al. (2025) found that, among kindergartners, more consistent cognitive control was associated with better performance on a more demanding literacy assessment consisting of phoneme detection, synthesis, and analysis tasks. It is possible that associations between cognitive control consistency and reading outcomes may be more apparent in later school years, when reading skills become more advanced, and during more demanding reading tasks that require consistent attentional control and working memory maintenance.

Cognitive control consistency, accuracy-based task performance, and academic skills

Supporting our prediction, children who displayed more consistent cognitive control also exhibited better overall task performance. This finding is consistent with previous studies linking response time variability to both omission and commission errors (Decker et al., 2023a; Isbell et al., 2018; Simmonds et al., 2007). Together, these results suggest that when children consistently maintain relevant task goals and execute goal-directed behaviors, they are also better able to respond accurately and avoid errors. Notably, our measure of overall task performance, d' , reflects performance across both Go and No-Go trials, which place different demands on cognitive control. Thus, this association indicates that cognitive control (in)consistency contributes to overall task success in contexts requiring the coordinated engagement of multiple controlled processes.

We expected that cognitive control consistency would relate to academic skills, above and beyond overall task performance. Our results demonstrated that neither cognitive control consistency nor overall task performance was related to literacy skills in kindergarten or first grade. This finding suggests that how cognitive control is deployed on average, and how consistently it is engaged during a task may not contribute to literacy skills in the early school years. Such findings further support the assertion that early literacy skills may not rely heavily on cognitive control (Blair et al., 2015; Isbell et al., 2019). In line with our hypothesis, we found that cognitive control consistency independently contributed to math skills at both time points above and beyond overall task performance.

In contrast, overall task performance did not relate to math skills in kindergarten or first grade when cognitive control consistency was taken into account. Previous work linking consistency of cognitive control to early math skills did not examine whether this association persisted after controlling for accuracy-based metrics that capture how cognitive control is deployed on average during a task. (Isbell et al., 2018; Michel et al., 2025). While accuracy-based metrics capture instances in which cognitive control fluctuations lead to overt errors, response time variability may provide a more sensitive index of the full range of such fluctuations. Generally, the difficulty of experimental tasks designed for young children is calibrated to minimize frustration and sustain engagement. Although this approach is essential for obtaining valid behavioral data from young children, it can inadvertently constrain variability in accuracy and reduce its sensitivity to individual differences in cognitive control. Under these conditions, response time variability may serve as a complementary index of cognitive control by capturing fluctuations in performance even when overt errors are relatively infrequent. In sustained attention to response (SART) tasks, like the Go/No-Go paradigm used in this study, children may achieve high accuracy on frequent Go trials that require a prepotent response. Nonetheless, these trials require sustained attention and active goal maintenance to support the execution of goal-directed behavior. Inconsistent engagement of cognitive control, which may be driven by factors relating to attention, arousal, motivation, perceptual processing, and motor execution (Löffler et al., 2021; Mansouri et al., 2024; Unsworth, 2015; Unsworth & Miller, 2021; Welhaf & Kane, 2024), may result in less consistent goal-directed responding that manifests as variable response times rather than overt errors. Indeed, accumulating evidence suggests that these metrics reflect distinct aspects of performance and have unique developmental trajectories, causes, and consequences (Gómez-Guerrero et al., 2011; Judd et al., 2024; Kievit, 2025; Lewis et al., 2017; Michel et al., 2025). In line with this work, our findings suggest that a response-time-based metric of cognitive control consistency reflects a distinct aspect of goal-directed behavior that accuracy-based metrics may not fully index and contributes to children's math achievement in early school years.

Limitations and future directions

The present study assessed cognitive control consistency using a single task, which constrains the extent to which these findings can be generalized across task contexts. Different tasks and conditions within tasks vary in the demands placed on cognitive control. Our reliance on response time variability derived from a single task and trial type may not fully capture the range of fluctuations in cognitive control that children experience across varying task demands. Task-specific factors may also impact children's cognitive control. In the current study, feedback was provided to children after each block to maintain task engagement. Research with adults has demonstrated that feedback and reward, as well as the presence and duration of task breaks, can modulate response time variability and self-reported attention lapses during cognitive control tasks (Robison et al., 2021; Unsworth et al., 2024; Welhaf & Kane, 2024). It remains unclear how such factors may influence cognitive control consistency in young children. Further, as has been done with adults (e.g., Unsworth, 2015; Welhaf & Kane, 2024), examining whether a general ability to consistently engage cognitive control contributes to response time variability across tasks is needed to improve our conceptualization of this construct in childhood. Future work utilizing a battery of tasks to assess cognitive control consistency is needed to facilitate our understanding of how this construct manifests during childhood.

Additionally, the relatively modest sample size ($N = 112$) and complexity of the path models may have limited statistical power, particularly for detecting indirect effects. As such, the statistically non-significant effects observed in the present study should be interpreted with caution, as the absence of significant effects may reflect insufficient power. Future research with larger samples is needed to more precisely estimate direct and indirect pathways linking cognitive control consistency to academic outcomes.

Another limitation of the present study is that we did not directly control for processing speed in our analyses. Although the coefficient of variation (CoV) partially accounts for individual differences in mean response time by expressing variability relative to average speed, this approach does not fully isolate cognitive control consistency from processing speed. Given that processing speed and cognitive control consistency are related (Unsworth et al., 2021), and that average response time and response time variability from the same task are mathematically confounded (Wagenmakers & Brown, 2007), it remains plausible that some portion of the observed associations between CoV and math skills reflects individual differences in general processing speed. Future research should incorporate measures of processing speed derived from separate tasks, particularly tasks with minimal cognitive control demands, such as simple reaction time tasks, to more precisely disentangle the unique contributions of processing speed and cognitive control consistency to academic skills in young children.

While we demonstrated that more consistent engagement of cognitive control may have academic benefits, it is important to consider that less consistent cognitive control (indexed by greater response time variability) may also confer advantages for performance in particular contexts. It has been argued that cognitive variability, more broadly, is an important behavioral phenotype and that variability in certain contexts is not only adaptive but also necessary (Kievit, 2025). Certain tasks, such as visual search, involve exploration-versus-exploitation trade-offs. Individuals who adaptively employ exploratory strategies to gather information about the environment to support performance may exhibit greater response time variability as a result of such exploration. Further, there is evidence that when cognitive control was not tightly coupled to task goals (indexed via highly variable response times), adults demonstrated greater learning of irrelevant content that shared hidden probabilistic relationships with the relevant targets (Decker et al., 2023). Such findings suggest that flexible engagement of cognitive control may broaden the scope of learning and, in turn, indirectly support task performance. More work is needed that examines in which contexts and for whom fluctuations in cognitive control facilitate versus hinder goal-directed performance.

Finally, understanding how cognitive control consistency can be promoted through intervention is an important avenue for future research. Emerging evidence suggests that cognitive training programs may enhance cognitive control consistency in children. For instance, Cubillo et al. (2023) found that more consistent cognitive control (indexed by lower response time variability) following a working memory training intervention was associated with better math skills and well-being in first graders. Similarly, Anguera et al. (2023) demonstrated that a cognitive-physical intervention that integrated aerobic exercise with adaptive cognitive training tasks targeting attention, working memory, and cognitive flexibility, completed by 7–12-year-olds, led to reduced response time variability and improvements in parent-reported attention skills. Future work is needed to examine which interventions are effective in promoting cognitive control consistency in the early school years and whether intervention-related improvements in cognitive control consistency translate into meaningful gains in academic achievement across childhood.

Conclusions

In summary, our results provide evidence for concurrent and prospective associations between cognitive control consistency and math performance as children transitioned from kindergarten to first grade. Importantly, cognitive control consistency (indexed via response time variability) predicted math skills in kindergarten and first grade, above and beyond an accuracy-based metric (d'), suggesting that cognitive control consistency can provide unique insights regarding individual differences in academic skills in young children. Additionally, the lack of associations between cognitive control consistency and literacy skills implies that the role of cognitive control consistency in academic achievement may be domain-specific during early school years. Our results warrant further investigation into how cognitive control consistency may relate to children's development in early school years and beyond. Furthermore, in addition to examining the consequences of (in)consistent cognitive control, future work should investigate which neurobiological and contextual factors may contribute to individual differences in susceptibility to cognitive control fluctuations in children.

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CRediT authorship contribution statement

Amanda N. Peters: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Nicholas E. Waters:** Writing – review & editing, Investigation, Data curation. **Jennie K. Grammer:** Writing – review & editing, Supervision, Methodology, Funding acquisition. **Elif Isbell:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Due to the language used in the original parent consent forms, we cannot publicly share the data. However, the R analysis scripts used in this study are publicly available on OSF: <https://osf.io/z9hbs>

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