**Abstract**

Children's self-regulation is associated with their concurrent and long-term school achievement. Theorists have argued the importance of child-adult interactions in the development of children's self-regulatory skills. However, empirical findings are mixed and have produced small or modest effect sizes, which could be due to the low ecological validity of the self-regulation measures typically used. In this study, an adult-reported scale, the *Child Self-Regulation in Interaction Scale* (CSIS), was developed to measure preschoolers' behavioral self-regulation in their daily interactions with adults. The psychometric properties of CSIS were also examined. A total of 1015 children and their mothers from multiple regions in China participated in this study. Factor analysis indicated that a three-factor model (namely Inhibition, Updating, and Shifting) was the best fit for the data. The CSIS also had good internal consistency, test-retest reliability, and convergent and criterion validity. Additionally, the three-factor model showed satisfactory gender and longitudinal measurement invariance. The results suggest that the CSIS is a reliable and valid instrument. Children’s self-regulatory behaviors may vary in different contexts. A context-specific measure of self-regulation may have stronger ecological validity by tapping into context-specific behavioral demands and is thus likely to have greater value and utility.

***Keyword:*** Behavioral self-regulation; Child-adult interactions; Context; Psychometric properties; Ecological Validity

**Measuring Preschoolers' Behavioral Self-Regulation in the Contexts of**

**Child-Adult Interactions**

Self-regulation refers to an individual’s ability to monitor and manage their own thoughts, emotions, and actions to achieve a goal (McClelland & Tominey, 2015). Children's early self-regulatory abilities lay the foundation for their success in academic achievement and social adjustment (Robson et al., 2020). Self-regulation is a broad and contextualized construct (Bailey & Jones, 2019). The behavioral aspect of self-regulation (cf. emotional self-regulation; Montroy et al., 2016) involves the use of executive function skills in various situations, such as inhibiting misbehavior, holding multi-step instructions, and switching between tasks when needed (Blair & Raver, 2015; McClelland & Tominey, 2015). Children’s behavioral self-regulation skills go through a period of rapid development during the preschool years and are susceptible to environmental influences (Zelazo & Carlson, 2012). Adults play a crucial role in fostering preschoolers' self-regulation, and adult-scaffolded interactions help children transition from external regulation (e.g., parental) to internalized self-regulation. These interactions occur in a range of contexts, such as home care and formal schooling, and across the lifespan (Baumeister et al., 2007; Calkins, 2007; McCabe et al., 2004).

According to the relational developmental systems theory, the development of human behavior is shaped by the interactions between individuals and their environment (Lerner, 2018). Similarly, the bioecological model of human development suggests that children’s development is impacted by the relationships they have with their caregivers, and by broader social and contextual factors (e.g., culture, setting) (Bronfenbrenner & Morris, 2006). According to these theories, children’s behaviors should be interpreted within the physical environment and sociocultural context in which they occur. For example, children’s self-regulatory behaviors may vary in different scenarios (e.g., adult-led instruction *vs*. free play, interactions with adults *vs*. peers, home- *vs.* school-based interactions) (Korucu et al., 2019; Lunkenheimer et al., 2019; McClelland & Cameron, 2011). It follows that child-adult interactions should be associated with children’s self-regulation skills, and emerging supporting evidence from family- and school-based studies indicate that the quality of both parenting- and teacher-child interactions modestly predicts children’s gains in self-regulation (Diercks et al., 2022; Guerrero-Rosada et al., 2021; Pianta et al., 2020).

 The lack of stronger associations between child-adult interactions and children’s self-regulation may be partly explained by the limitations of existing self-regulation measures, especially low ecological validity (Burchinal et al., 2018; McClelland & Cameron, 2012; McCoy, 2019). Existing measures are typically decontextualized, often conceptualizing self-regulation as a stable behavioral trait across different situations, thereby masking potential variation in children's context-specific self-regulation behaviors. This study outlines the development and validation of a new rating scale, the *Child Self-Regulation in Interaction Scale* (CSIS), used to assess preschoolers' self-regulation behaviors during their daily interactions with significant adults. The development and validation of this tool may help us better understand preschoolers' behavioral self-regulation and inform new interventions that promote children’s self-regulatory skills.

**The Development of Behavioral Self-regulation in Preschoolers**

While there is no conclusive definition of self-regulation, it can broadly be described as a multidimensional and integrative domain-general construct that involves controlling, directing, and planning one's emotions, thoughts, and actions (Baumeister & Vohs, 2007; McClelland et al., 2018; Schunk & Zimmerman, 1997). Behavioral self-regulation enables children to regulate their thoughts and actions to develop more adaptive goal-directed behavior during learning and social interactions. For example, in early childhood classroom contexts, children regulate their behaviors to remember teachers’ instructions, shift attention, inhibit inappropriate responses, and comply with rules (McClelland et al., 2010).

 Emerging research suggests that behavioral self-regulation is particularly important for child outcomes (Zakszeski et al., 2020). As a vital domain-general skill, behavioral self-regulation enables children to regulate their thoughts and actions to develop more adaptive goal-directed behavior during learning and interactions. In the context of child-adult interactions, behavioral self-regulation can be observed when a child pays attention to an adult, remembers and follows instructions, inhibits impulses, and shifts toward more appropriate behaviors (Blair & Diamond, 2008; Morrison et al., 2010).

Preschoolers' behavioral self-regulation provides a building block for positive goal-related behaviors. There is substantial evidence that high levels of behavioral self-regulation in the preschool years are significantly related to children’s concurrent growth in academic skills and subsequent successes in school achievement and social adjustment. A rapid period of development in self-regulation occurs during the preschool years, which coincides with the maturation of the prefrontal cortex (Garon et al., 2008). Although self-regulatory skills continue to develop as children age, it is most apparent during early childhood, and the rate of growth depends on children’s characteristics (e.g., gender and temperament) and environmental contexts (Blair & Diamond, 2008; Blair & Raver, 2012). Children’s self-regulation follows different developmental trajectories, heavily depending on their environment (Duncan et al., 2017).

Child-adult interactions are considered a proximal determinant of child outcomes, and research studies have demonstrated that children's daily interactions with adults, in both family and school settings, foster gains in their self-regulation (Fay-Stammbach et al., 2014; Vandenbroucke et al., 2018). In the family, parenting practices are an important predictor of children's self-regulation. A parent who frequently engages children in verbal communication and provides high-quality scaffolding and language modeling may strengthen children's adaptive goal-oriented behaviors (Lewis & Carpendale, 2009). In contrast, negative parenting behaviors that are characterized by hostility, rejection, firm control, and inconsistent discipline, are associated with deficits in children’s self-regulation (e.g., Fay-Stammbach et al., 2014). In classrooms, teachers’ behavioral support in their interactions with children significantly matters for children’s progress in self-regulation (e.g., Bardack & Obradović, 2019). Children can make more progress in self-regulated learning behaviors when the caregiver maximizes their activity engagement (e.g., Rimm-Kaufman et al., 2009). Also, caregivers can provide more learning opportunities through meaningful tasks and interesting materials and deliver clear behavior expectations to facilitate the development of self-regulatory skills in classrooms (Rimm-Kaufman et al., 2009). Furthermore, by providing children with high-quality scaffolded instructions during learning activities, teachers may facilitate children’s growth in executive function (Bardack & Obradović, 2019; Walk et al., 2018). All in all, evidence consistently supports the significant role that adults play in the development of children’s self-regulation.

**The Theoretical Framework for Measuring Behavioral Self-regulation in Interaction Contexts**

The relational developmental system framework suggests that children's development arises from integrative and bidirectional relations between an individual and multiple levels of their environment (Lerner, 2006; Lerner & Overton, 2008; Overton, 2006). According to this view, children's overt behaviors emerge from the interplay between their characteristics (e.g., gender and temperament) and interactions with others (Calkins, 2007; Lengua & Kovacs, 2005). McClelland et al. (2014) argued that while the development of self-regulation is relatively stable overall, children’s self-regulatory performances may vary by context. Children’s self-regulation can be influenced by individual characteristics and aspects of the environment. For example, Rimm-Kaufman et al. (2002) found that children with high levels of social boldness showed more off-task behaviors in classrooms (indicating poorer self-regulation), but these children exhibited less anger, aggression, and non-task behavior in classrooms when supported by sensitive and responsive teachers. Also, children with higher levels of negative reactivity are more likely to be affected by harsh parenting than those with lower reactivity (Belsky et al., 2007). These findings suggest that behavioral self-regulation is interactive and context-specific (Calkins, 2004). Therefore, it is important that children’s regulatory behaviors are interpreted in the context of specific interactions and relationships.

There is a broad consensus that executive function underlies the self-regulation of individual behavioral responses (Koziol et al., 2012). Executive function refers to a set of high-level cognitive processes and has three key components: inhibitory control, working memory, and cognitive flexibility (Duncan et al., 2007). Each component supports the mechanisms through which children regulate their thoughts and behaviors in the pursuit of goals (McClelland et al., 2010). Inhibitory control (i.e., inhibition) is the ability to inhibit a dominant response in favor of a more adaptive one and is important for children controlling their impulses and following instructions. Working memory (i.e., updating) is the ability to hold and maintain (or otherwise manipulate) information during the course of ongoing mental activities, it enables children to hold instructions in mind as they carry them out. Finally, cognitive flexibility (i.e., shifting) is the ability to shift attention and adapt to changing goals while ignoring distractions, it enables children to persist during challenging tasks or instructions. Successful behavioral self-regulation typically involves the behavioral integration of all three executive functions (Spinola et al., 2017). For example, a child must seamlessly integrate the three components when following a series of instructions: holding the instructions in mind, updating them as they complete each step, shifting between tasks effectively, and ignoring distractions (Cameron et al., 2008; McClelland et al., 2007; Morrison et al., 2010). Evidence suggests that measures of self-regulation that capture all three executive function processes are more effective, as these functions underpin self-regulation in children (Caughy et al., 2013; McClelland et al., 2014). In this study, the basic principles of the relational developmental systems perspective and the multidimensional perspective on executive function (inhibitory control, working memory, and cognitive flexibility) were used to develop a measure of preschoolers' behavioral self-regulation in the contexts of child-adult interactions.

**Ecological Validity Issues of Self-regulation Measures**

There are several rating instruments of executive function that are widely used to assess children's self-regulation, such as the *Behavior Rating Inventory of Executive Functioning* (BRIEF; Gioia et al., 2003), the *Comprehensive Executive Function Inventory* (CEFI; Naglieri & Goldstein, 2013), and the *Child Self-Regulation and Behaviour Questionnaire* (Howard & Melhuish, 2017). These scales view children's executive functions or self-regulation as a stable behavioral trait and seek to assess this trait in a variety of situations. This may obscure potential variability in how children behave in different situations, therefore failing to capture a child’s actual functioning in a certain context. Moreover, in addition to measuring self-regulation, some of these scales (e.g., BRIEF) include items with statements concerning ADHD symptoms, such as "have a short attention span" and "is impulsive". The semantic overlap between the items and the symptom criteria for ADHD is likely to result in erroneous conclusions about self-regulation in typically developing children (Thorell & Catale, 2014).

Self-regulation is theorized to support children in suppressing impulsive responses, remembering information, and adapting to new developmental demands (McClelland & Tominey, 2015). However, evidence is mixed and indicates modest effect sizes in the associations between both parent- and teacher-child interactions and children's self-regulation (Cadima et al., 2016). This can be attributed in part to the low context-sensitivity of traditional executive function measures when applied to assessing self-regulation. Executive functions are a fundamental cognitive construct that supports self-regulation. Self-regulation, in contrast, usually made wider appearances in the literature with implications for real-world and situational functioning (Holleman et al., 2020). However, existing instruments are typically decontextualized and do not reflect the context-dependent nature of children's behavioral self-regulation (Deater-Deckard & Bell, 2017; Deater-Deckard et al., 2012; Parsons et al., 2017; Sturge-Apple et al., 2014). In addition, researchers have indicated the issues of high rater bias and low test-retest reliability of executive function measures (Enkavi et al., 2019; McClelland & Cameron, 2012; Pickering & Gathercole, 2004), which may also be related to the lack of ecological validity of these measures (McClelland & Cameron, 2012). Recently, scholars highlighted the value of examining context-specific cognitive functions and enhancing ecological validity by identifying the specific context where the process of interest unfolds (e.g., Holleman et al., 2020). Context is important for understanding how children regulate their behaviors in response to various demands. For example, a child may be good at inhibiting their impulses during free play but not be able to follow a teacher's instruction in classroom settings. Therefore, assessment should draw on the self-regulation skills required in a given context. In general, measuring behavioral self-regulation proves more effective within specific naturalistic contexts, where children are required to employ working memory, inhibitory control, and cognitive flexibility to carry out specific tasks.

**The Current Study**

As outlined previously, the daily interactions that preschool-age children engage in with adults are strongly associated with the development of their behavioral self-regulation and their subsequent school achievement. As a proximal determinant of child outcome, the context of child-adult interactions requires special attention when measuring behavioral self-regulation. Measures of self-regulation should directly tap into children's observable actions that closely approximate the regulatory demands of specific contexts (Raver et al., 2012). Improving the ecological validity of self-regulation measures may provide new insights into how and with whom children exhibit their regulatory behaviors and the extent to which these behaviors vary depending on the context demands. This work allows us to better understand the development and plasticity of self-regulation.

In this study, the *Child Self-Regulation in Interaction Scale* (CSIS) was developed to capture preschoolers' behavioral self-regulation in child-adult interactions. In this study, self-regulation is conceptualized as the product of an integrated developmental process that is shaped by the contexts in which development occurs (Blair & Raver, 2015). The validation of this instrument may help us better understand how preschoolers behave to achieve goals when interacting with adults and provide a better insight into interventions for behavioral self-regulation in early childhood. This study aimed to address the following research questions:

(1) Does the CSIS, a measure of preschoolers' context-specific self-regulation, have satisfactory validity?

(2) Does the CSIS have satisfactory reliability?

(3) Does the CSIS have satisfactory measurement invariance?

Children develop behavioral self-regulation in their interactions with adults, yet there was evidence that the link between adult-child interactions and children’s gains in behavioral self-regulation were sometimes "weaker than expected" (Diercks et al., 2022). This limited strength of associations could potentially be attributed, in part, to the constraints in existing measures of self-regulation. Specifically, these measures typically lack contextual relevance, conceptualizing children’s behavioral self-regulation as a stable behavioral trait across various contexts, making it difficult to detect the possible variation in self-regulatory behaviors exhibited by children in different situations (McClelland & Cameron, 2012).

Currently, a new perspective concerning self-regulation proposes a greater involvement of context (Doebel, 2020; Holochwost et al., 2023; Zelazo & Carlson, 2023). Inspired by this perspective, the items in the CSIS reflected children’s self-regulated behaviors in daily interactions between children and adults that were closed to real-world, specific contexts. To the best of our knowledge, CSIS is the first context-specific measure of behavioral self-regulation for preschoolers. Thus no studies have yet examined the psychometric properties of such measure. We proposed that the self-regulatory behaviors exhibited by children in a specific context are more stable. Adults can also capture and rate these behaviors more effectively when prompted by contextual cues. We therefore hypothesized that the CSIS could have good reliability, construct validity, and measurement invariance. A good reliability reflects a high degree of consistency in the results of multiple measurements of the CSIS. Good construct validity reflects that CSIS can effectively measure the concept and theoretical framework it was designed to assess. We also expected that the factor structure of the CSIS would not vary across multiple measurements. Finally, the CSIS was designed to assess the performance of children's self-regulatory behaviors in the contexts of adult-child interactions, and these behaviors may have strong associations with children’s relationships with their parents and their social and learning behaviors (Diercks et al., 2022; Doebel, 2020; Medrano & Prather, 2023), we thus hypothesized that the CSIS can significantly predict the child-adult relationships and children’s social and academic skills.

**Method**

**Sample and Procedure**

This study developed and validated the *Child Self-Regulation in Interaction Scale* (CSIS) through a stepwise procedure. Based on a comprehensive review of relevant instruments, literature, and focus-group interviews, an original-item pool was generated for the initial content of the CSIS. Several related scales were referenced, such as the *Comprehensive Executive Function Inventory* (CEFI; Naglieri & Goldstein, 2013). These instruments were all designed to measure children’s executive function or self-regulation. Next, the ambiguity and relevance of the original items were discussed through an item-by-item review with a panel of experts. We used a Delphi method to confirm the validity of each item through consensus among experts. A total of 16 experts were recruited and received a glossary of terms, a list of items, and a rating sheet. They were asked to consider the irrelevant or ambiguity of each item based on their experiences and to rate the items using a 9-point scale (1-3 were considered as weak; Idänpään-Heikkilä et al., 2006). A total of 26 items were excluded through 3 rounds of iterative process, resulting in an initial instrument comprising 18 items.

To establish the psychometric properties of CSIS while minimizing threats to external validity, we recruited participants from multiple regions across Southwest, Northwest, and Southeast China. Data were collected at three time points. A total of 825 children and their parents from three provinces (Sichuan, Fujian, and Xinjiang) participated in the study at time 1 (T1). A stratified random sampling approach was used in the two phases of preschool sampling and children sampling, respectively. In the first stage, we randomly selected 8 public and 7 private preschools from the 3 provinces. In the second stage, a sample of typically developing preschoolers aged 3-6 years and their parents were identified from the selected preschools. Upon obtaining permission from the directors of the preschools, the teachers assisted us in sending invitations to the identified parents. All the parents who agreed to participate in the study signed the informed consent form.

The factor structure, internal consistency reliability, and gender invariance were investigated using T1 data. The items of the initial version of CSIS would be revised based on the analysis results of reliability and validity. Children’s academic competencies and their relationships with parents were also assessed using a range of scales and questionnaires at T1 to examine the convergent and criterion validity of the CSIS. Next, we conducted a longitudinal study from time 2 (T2) to time 3 (T3) and recruited a total of 190 children and their parents from the Sichuan province. These sampled 190 children did not overlap with the sample at T1 (the original 825 children). The sampling process was the same as for the T1. Confirmatory factor analysis (CFA) was used to validate the factor structure of the CSIS with the data at both T2 and T3. We further examined the test-retest reliability and longitudinal invariance of the CSIS using the T2-T3 data. Table 1 presents the demographics of the participating children at T1-T3. The average age of the sampled children was 5.87 at T1, 5.55 at T2, and 5.93 at T3, respectively, and approximately half were boys at each time point (T1: 53.8%; T2: 50.5%; T3: 50.3%). Approximately half of the children were from urban areas (T1: 49.5%; T2: 55.8%; T3: 56.3%), and the rest were from rural areas.

**Measures**

***Child Self-Regulation in Interaction Scale***

The first author developed the *Child Self-Regulation in Interaction Scale* (CSIS) to assess preschoolers’ self-regulation performance in child-adult interactions. When completing the questionnaire, a parent or teacher must rate the extent to which a child has engaged in certain self-regulatory behaviors when following instructions, answering questions, or completing tasks over the past three months. The CSIS has 18 items, each rated on a 5-point Likert scale ranging from 1 (*never*) to 5 (*always*). Based on the multidimensional framework of executive function, the initial version of CSIS consisted of three theoretical dimensions (i.e., inhibitory control, working memory, and cognitive flexibility), each comprising 6 items. Items within the inhibitory control subscale aim to capture observable actions associated with the suppression of impulsive responses and the adoption of more adaptive behaviors when communicating with adults or following instructions (e.g., "Can't patiently listen to you finish"). Items related to the working memory subscale focus on observable actions associated with remembering and following adults' directions or instructions (e.g., "Tell him/her to do two things but they only remember one of them"). Finally, items corresponding to the cognitive flexibility subscale focus on observable behaviors related to shifting attention or mindsets in different situations while ignoring distractions to achieve goals (e.g., "Makes mistakes when your requirements or instructions change"). Based on the theoretical framework of the CSIS, the total scores represent the overall level of behavioral self-regulation. Higher scores on the items indicate lower levels of behavioral self-regulation in children.

***Child-parent Relationship Scale***

The Child-Parent Relationship Scale (CPRS; Pianta, 1992) was employed to assess the child-parent relationship at T1. The scale consists of 26 items rated on a 5-point scale to measure a parent’s perception of his/her relationships with their child. This scale can be organized into two subscales Closeness and Conflict. A higher score on the Closeness subscale indicates a close child-parent relationship, whereas a higher score on the Conflict subscale indicates a conflicted relationship between the child and their parent. The psychometric properties of the scale have been established in a Chinese context, with a reported Cronbach's α of 0.75 and 0.77 for Closeness and Conflict, respectively (Zhang & Nurmi, 2012). In this study, Cronbach's α for Closeness and Conflict subscales were 0.89 and 0.87, respectively.

***Child Self-regulation Questionnaire***

The *Child Self-regulation Questionnaire* (CSRQ) was employed to assess children’s self-regulation at T1 (Yang & Dong, 2005). This measure contains 22 items, each rated on a 5-point Likert scale. It is organized into four sub-domains: self-consciousness, self-regulation, persistence, and self-delayed gratification. A higher score represents a higher level of self-regulation. The total scores of CSRQ represent the overall level of self-regulation in children (Yang & Dong, 2005). The scale showed good internal consistency in Chinese children in a previous study (Cronbach’s α of 0.80 for the total scale; (Huang & Yang, 2015). In this study, Cronbach’s α was 0.85 for the total scale.

***Strengths and Difficulties Questionnaire***

The *Strengths and Difficulties Questionnaire* (SDQ) was used to measure children’s prosocial and problem behaviors at T1 (Goodman, 2001). This scale consists of 5 subscales: prosocial behavior, conduct problems, hyperactivity, emotional symptoms, and peer relationship problems, with each subscale containing 5 items. A total difficulties score is the sum of all subscale scores except the prosocial behavior score, with a higher score indicating more internalizing or externalizing problem behaviors exhibited by children. Also, a higher score on the prosocial behavior subscale suggests a higher level of prosocial behaviors in children. Prior studies have reported a good internal consistency of the scale in Chinese contexts (Du et al., 2008). In this study, Cronbach’s *α*s of the total difficulties score and prosocial behavior subscale were 0.88 and 0.78 respectively.

***Early Development Instrument***

The Literacy and Cognition subscale of the *Early Development Instrument* (Ip et al., 2013) was used to measure preschoolers’ academic skills at T1. The scale consists of 39 items related to literacy, numeracy skills, interest, and memory. All responses are rated on a 2-point scale: *Yes* (child masters the skills) and *No* (child does not master the skills). Previous studies have suggested that this scale had good internal consistency in Chinese preschoolers (Ip et al., 2013). In this study, Cronbach’s α for the Literacy and Cognition subscale was 0.95.

**Data Analysis**

Analyses took place in several sequential stages. First, descriptive statistics of the variables were obtained. Second, Bartlett’s Test of Sphericity and the Kaiser - Meyer - Olkin (KMO) test were performed to evaluate the sampling adequacy before factor analysis. Next, exploratory factor analysis (EFA) combined with parallel analysis was conducted to determine the factor structure of the CSIS using the T1 data. Parallel analysis is a resampling technique recommended as the most accurate method to identify the optimal number of factors (Thompson, 2004). Cronbach’s alpha (α) and McDonald’s omega (ω) were to establish internal consistency. Compared to Cronbach’s α, McDonald’s ω takes into account the strength of associations between items and constructs and item-specific measurement errors, thus providing more accurate estimates of consistency reliability (Wang & Ye, 2014).

After determining the factor structure of the CSIS, the convergent and criterion validity of the scale were assessed. Using the T1 data, the correlations between children’s self-regulation as measured by the Child Self-regulation Questionnaire and CSIS dimensions were calculated to establish convergent validity, and the correlations between the parent-child relationship as measured by CPRS and CSIS dimensions were calculated to establish criterion validity. The correlations between school adjustment and academic skills and CSIS dimensions were also tested to provide evidence for criterion validity. We further conducted a structural equation modeling analysis using the data collected at T1 to investigate the prediction of children’s behavioral self-regulation measured by the CSIS on their social behaviors, cognition skills, and relationship with parents, after controlling a series of covariates including children’s age, gender, location (urban/rural), and only children or not. The psychometric properties of the CSIS were also investigated using Confirmatory Factor Analysis (CFA) using the data collected at both T2 and T3. The solutions for a single-factor and three-factor structure were tested. The model fit was assessed using several widely used statistical indices, including the chi-square statistic (*χ*2/*df* < 5.0), comparative fit index (*CFI*;> 0.90 = acceptable fit; > 0.95 = good fit), Tucker-Lewis fit index (*TLI*; > 0.90 = acceptable fit; > 0.95 = good fit), and root-mean-square error of approximation (*RMSEA*; ≤ 0.08 = acceptable fit, < 0.05 = good fit) (Hu & Bentler, 1999). The intraclass correlation coefficient (ICC) between T2 and T3 was calculated to investigate the test-retest reliability of the scale.

The measurement invariance of the scale was assessed. Four nested CFA models that reflected increasingly stringent invariance conditions were successively tested (configural, metric, scalar, and error variance invariance). The measurement invariance of gender was examined using T1 data, and the longitudinal study was tested using the data collected at T2 and T3. First, to establish configural invariance (structural equivalence), factor loadings and intercepts are estimated freely. Next, metric invariance (equivalence of factor loadings) is tested by constraining factor loadings to be equal across groups. Scalar invariance (equivalence of intercepts) is then examined by also imposing equality constraints on the intercepts of the observed variables across groups. Finally, in an error variance invariance model, the error variances of the observed variables are constrained to be equal across groups. The relative fit of each increasingly constrained model compared to the previous (less-constrained) model was tested (i.e., configural vs. metric invariance; metric vs. scalar invariance; scalar vs. error variance invariance) using several fit indices, including ΔCFI < 0.01 and ΔTLI < 0.01 (Lee, 2016; Wang et al., 2021). All the models were estimated using Mplus (Version 8.0; Muthén & Muthén, 2019).

**Results**

**Exploratory Factor Analysis**

Sampling adequacy was identified through Kaiser–Meyer–Olkin (KMO) test (0.92＞0.50), and Bartlett’s Test of Sphericity (*χ* 2/*df* = 4.29, *p* < 0.001) was significant. While the CSIS was initially designed with three dimensions, no predictions were made about the number of factors that would emerge during analysis. EFA was performed using the oblique rotation approach. According to the Kaiser–Guttman criterion (eigenvalue > 1.00; Guttman, 1954), three factors were identified. Furthermore, parallel analysis (comparing eigenvalues of real versus random data; Widaman, 2012) suggested the retention of the three factors. Based on these results, three factors were retained, accounting for 67.88% of the total variance. Table 2 summarizes the three-factor solution structure, including factor loadings and measures of internal consistency.

We required that the factor loading of items were greater than 0.40 in the specific factors (Costello & Osborne, 2005). As shown in Table 2, the factor loading values ranged from 0.58 to 0.90, and no items were dropped. The resulting factor composition is consistent with the theoretical framework of this study and the three factors were labeled *Inhibition, Updating,* and *Shifting,* as they each contained items related to inhibitory control, working memory, and cognitive flexibility, respectively.

Internal consistency for all three dimensions and the total scale were excellent. McDonald’s ω coefficients were 0.90, 0.86, and 0.93 for Inhibition, Updating, and Shifting, respectively (total scale ω = 0.96). Cronbach αs ranged from 0.86 to 0.93, indicating strong internal consistency across the three dimensions (all > 0.60; ). Combined with EFA results, these findings suggest a clear three-factor structure for the CSIS.

**Convergent and Criterion Validity**

Convergent and criterion validity of the CSIS were assessed using the total scale score and three sub-scale scores (corresponding to the three factors identified in the EFA): Inhibition, Updating, and Shifting. Table 3 presents the results of these analyses. All correlation coefficients were significant (all *p*s < .05).

Correlation coefficients between children's CSIS sub-scores and their CSRQ score (a pre-existing validated test of self-regulation; Huang & Yang, 2015), suggesting good convergent validity for Inhibition (*r* = -0.31), Updating (*r* = -0.54), Shifting (*r* = -0.50), and the total scale score (*r* = -0.56). This indicates that children’s behavioral self-regulation in their interactions with adults was convergent with their self-regulation abilities.

Criterion validity was first tested by correlating the CSIS with the CPRS score (child-parent closeness/conflicts). Although parent-child relationships were significantly associated with children’s behavioral self-regulation, for both Closeness (*r*s: Inhibition = -0.15; Updating = -0.23; Shifting = -0.27; Total = -0.28 and Conflicts (*r*s: Inhibition = 0.08; Updating = 0.13; Shifting = 0.19; Total = 0.17), effect sizes were small to moderate (all *r*＜0.27). This finding indicated that behavioral self-regulation and the child-parent relationship are two interrelated but independent constructs. Then, correlations between children’s CSIS scores and their social and school adjustment and academic skills were computed. All CSIS dimensions were associated with children with problem behaviors (*r* ranged from 0.22 to 0.37), prosocial behaviors (*r* ranged from -0.23 to -0.48), and literacy and cognition (*r* ranged from -0.21 to -0.33). Moreover, as shown in Fig. 1, the results of the structural equation modeling revealed that the latent variable of behavioral self-regulation, composed of Inhibition, Updating, and Shifting, significantly predicted children's problem behaviors, prosocial behaviors, literacy and cognition skills, as well as their relationships with parents. Overall, these results supported the criterion validity of the CSIS.

**Construct validity**

CFA was performed to investigate the factor structure of the CSIS at T2 and T3 (construct validity). A single-factor model and a three-factor model were computed (see Table 4 for a summary of the fit indices for the two models at the two-time points). The single-factor model was a poor fit of the data at both T2 and T3, while the 3-factor model showed an acceptable fit at the two-time points. All item factor loadings in the three-factor models were significant, ranging from 0.56 to 0.86. Correlation coefficients at T2 and T3 were also calculated between Inhibition and Updating (T2 = 0.23; T3 = 0.36), Inhibition and Shifting (T2 = 0.34; T3 = 0.57), and Updating and Shifting (T2 = 0.75; T3 = 0.76).

**Test-Retest Reliability**

A total of 190 mothers responded to the CSIS at T2 and T3, with an interval of approximately 2 months. Correlation coefficients and ICC values between T2 and T3 are reported in Table 5. The correlation coefficients ranged from 0.59 to 0.75 (all *p*s＜0.05), and ICC values ranged from 0.73 to 0.86, indicating good test-retest reliability across all three CSIS dimensions.

**Measurement Invariance Testing**

Measurement invariance testing was used to assess whether the estimated factor structure holds across sub-groups of participants (male, female) and across different test times (T2, T3). Overall, configural, metric, scalar, and error variance measurement invariance were established for the three-factor CSIS model for both gender and times (all *ΔCFI*s＜0.01 and *ΔTLI*s＜0.01). Specifically, as shown in Table 6, in both gender and longitudinal invariance tests, the configural invariance model fit the data well (*CFI*= 0.94, *TFI=* 0.93, and *RMSEA*= 0.07 for gender invariance; *CFI*= 0.91, *TFI=* 0.90, and *RMSEA*= 0.08 for longitudinal invariance). Imposing the equality constraints did not result in a deterioration of model fit (Δ*CFI* < 0.01 and Δ*TLI* < 0.01 for both gender and longitudinal invariance), thus supporting the metric invariance. Then, imposing the equality constraints on the intercepts did not lead to a deterioration in model fit (Δ*CFI* < 0.01 and Δ*TLI* < 0.01 for both gender and longitudinal invariance). Therefore, the means of the dimension variables did not differ across gender groups and across times. Finally, constraints were imposed on the error variance of the items. This did not result in a decrement in model fit (Δ*CFI* < 0.01 and Δ*TLI* < 0.01 for both gender and longitudinal invariance), indicating that the error terms were homogeneous across gender groups and across times. Overall, the findings of measurement invariance tests suggested that there was strong factorial invariance in the measurement of CSIS.

**Discussion**

The current study developed and validated the *Child Self-Regulation in Interaction Scale* (CSIS), a new measure of behavioral self-regulation in preschoolers during child-adult interactions. Overall, CSIS demonstrated good psychometric properties. A three-factor model, with constructs corresponding to executive function components (*Inhibition*, *Updating*, and *Shifting*), was the best fit for the data. The factors showed good internal consistency. Additionally, this 3-factor model had satisfactory gender and longitudinal measurement invariance, as well as good test-retest reliability. These findings provided evidence for the context specificity of children's behavioral self-regulation that is conceptualized through the multidimensional framework of executive functions.

Self-regulation is a complex and multidimensional construct, which encompasses a broad range of skills and is often defined diversely across disciplines, such as developmental psychology, educational sciences, and cognitive psychology. This variance in conceptualizations reflects the diverse developmental and contextual framework in which self-regulation is studied (e.g., Blair, 2016). Strong psychometric properties and the stability of the CSIS supported that preschoolers’ behavioral self-regulation is a contextualized construct, consisting of the 3 executive function subcomponents that support children’s regulatory behaviors in interactions with adults. Children’s self-regulatory behaviors may vary depending on different contextual factors. A child may be able to self-regulate their behavior in one scenario, but not another (McClelland et al.,, 2014). For example, when transitioning from free play to adult-led instruction, a child may have to resist a dominant tendency to continue playing, listen to the adult's instructions, and keep them in mind. These real-time self-regulatory behaviors can be influenced by multiple factors, such as the adult's behaviors, the child's individual characteristics, and the child-adult relationships. Children's daily interactions with caregivers shape their relatively stable self-regulatory behaviors in various situations over time, and this situated self-regulation manifests in an embodied way when similar interactions occur. These processes are supported by integrated multimodal representation and simulation of objects, actions, introspections, and settings tailored to specific contexts (Barsalou, 2014). Therefore, we believed that a context-specific measure that reflects the interactive, integrated, and contextualized nature of behavioral self-regulation may have better ecological validity.

Preschoolers' self-regulatory behaviors were associated with their relationships with adults, supporting the plausibility of measuring self-regulation from a context-specific perspective. For example, a child who has a conflicting relationship with their mother may be less likely to listen to instructions patiently, or to remember them accurately, and is therefore likely to make mistakes when instructions change. In contrast, a warm and sensitive mother who has a close relationship with a child tends to provide supportive interactions in which the child is more willing to follow the mother's instructions, express their ideas, and challenge the new environment. Such a mother may also support children’s self-regulation development by creating child-centered learning environments that are full of creative activities, reinforcing clear behavioral expectations, asking open-ended questions, and providing timely and contingent support (Pianta et al., 2020).

Moreover, consistent with previous findings (e.g., Blair & Raver, 2015), this study revealed significant correlations between children's self-regulation as measured by the CSIS and their academic and behavioral skills, with moderate to large effect sizes. Also, the results from the structural equation model demonstrated that the CSIS significantly predicted children’s problem behaviors and social and academic skills. Behavioral self-regulation was broadly recognized as the domain-general components that underlie individuals' complex goal-directed behaviors (Diamond, 2013; Miyake et al., 2000). Correspondingly, there was a growing consensus that behavioral self-regulation should be best understood in relation to the specificity of task situations and goals (Doebel, 2020; Medrano & Prather, 2023). Children may use behavioral self-regulation to achieve a specific goal in a specific context, and adult-child interactions play a crucial role in guiding and regulating children toward specific goals. The specific goals may activate relevant knowledge, values, beliefs, norms, and motivations that children acquire as they develop within a specific sociocultural context (Doebel, 2020). Social interactions between children and adults were the most important mechanism through which children acquire the cultural tools and shape their social emotions and self-regulated behaviors simultaneously in a specific context. A large body of evidence has revealed that children who regulate their emotions and behaviors effectively, and actions are more likely to navigate learning and social environments successfully, whereas children who struggle with self-regulation may be at greater risk for later school difficulties (McClelland et al., 2010). This may be a significant factor contributing to the strong associations observed between CSIS and children's academic and social skills.

Finally, the findings indicated that the same constructs of CSIS were obtained in the same way psychometrically across gender groups and across times. The self-regulatory behaviors exhibited by children may be more stable in a specific context. Also, the CSIS considered specific contexts (e.g., social interactions and situation features) and allowed adults to gain a deeper grasp of children’s self-regulatory processes involved in adult-child interactions, therefore capturing these behaviors more effectively when prompted by contextual cues. This may be one reason why CSIS showed factorial measurement invariance across sample populations and across times.

Overall, the CSIS demonstrated strong psychometric properties. The results support the contextual specificity of children's behavioral self-regulation, in line with the theoretical perspective of the relational developmental systems theory. Children’s behaviors are embodied in the contexts. They may use different self-regulatory strategies contingent upon the interplay between the children and context characteristics (McClelland et al., 2015; Zimmermann & Stansbury, 2003). Within the classrooms or other real-world settings, children regulate their behaviors to achieve particular goals, with a significant number of these goals being determined by adults. The contexts of adult-child interactions thus play a pivotal role in capturing children's self-regulatory skills as conceptualized within the framework of executive functions. Moreover, over the last decade, there has been a growing interest in the ecological validity of the measures of executive function and self-regulation, with increased reflection on the limitations of laboratory measures (Belsky et al., 2001; McClelland et al., 2015). A growing number of studies on self-regulatory processes emphasized the role of context (McClelland et al., 2010). A context-specific measure of children’s self-regulation can show better ecological validity and is thus likely to have greater value and utility. Additionally, the CSIS described a range of self-regulatory behaviors exhibited by children during their interactions with adults. This may aid adults in gaining a better understanding of children’s self-regulatory skills and serve as inspiration for interventions aimed at enhancing these skills.

**Limitations and Future Research**

The current study has several limitations. First, the CSIS was theoretically designed to assess children's behavioral self-regulation in their interactions with primary caregivers including parents and teachers. However, the current study only examined parent-reported data, and teachers’ ratings in a classroom context remain to be investigated. Future studies could investigate the psychometric properties of CSIS with teacher-reported data.

To better understand how children’s self-regulatory behaviors vary across different contexts, several other dimensions could be considered, such as the setting (e.g., home, school) or broader social context (e.g., whether the interaction involves other children). Another important factor to consider is the sociocultural context in which the interaction takes place. For example, the cross-cultural study found that Asian children show better self-regulation than their counterparts in Western countries (e.g., Sabbagh et al., 2006), suggesting the importance of considering cultural contexts when developing ecologically valid measures of self-regulation. The CSIS was developed in a Chinese context and further testing is needed to establish whether it is generalizable to children in other countries and cultures.

Finally, adult-reported questionnaires are a widely used method for assessing child outcomes, often due to this approach being fast and simple to administer (Connelly & Ones, 2010). Nevertheless, adult-reported measures have several drawbacks that may substantially impair their ability to accurately assess children’s behaviors (e.g., memory bias, inconsistent answers, misunderstood questions, and social desirability; Connelly & Ones, 2010). Future research could develop an observational instrument based on the framework of CSIS to measure behavioral self-regulation in child-adult interactions.

**Conclusion**

In this study, an adult-reported scale CSIS was developed to measure preschoolers' behavioral self-regulation in their interactions with adults. The CSIS had good internal consistency, test-retest reliability, and criterion validity. The 3-factor structure of the CSIS in line with the multidimensional framework of executive function has been confirmed. The findings indicated that a context-specific measure of self-regulation may have stronger ecological validity by tapping into context-specific behavioral demands and is thus likely to have greater value and utility.

**References**

Bailey, R., & Jones, S. M. (2019). An integrated model of regulation for applied settings. *Clinical Child and Family Psychology Review, 22*(1), 2-23. doi:10.1007/s10567-019-00288-y

Bardack, S., & Obradović, J. (2019). Observing teachers' displays and scaffolding of executive functioning in the classroom context. *Journal of applied developmental psychology, 2019*(62), 205-219. doi:<https://doi.org/10.1016/j.appdev.2018.12.004>

Baumeister, R., & Vohs, K. (2007). Self‐regulation, ego depletion, and motivation. *Social and Personality Psychology Compass, 1*(1), 115-128. doi:10.1111/j.1751-9004.2007.00001.x

Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science, 16*(6), 351-355. doi:10.1111/j.1467-8721.2007.00534.x

Belsky, J., Vandell, D. L., Burchinal, M., Clarke-Stewart, K. A., McCartney, K., Owen, M. T., & Network, T. N. E. C. C. R. (2007). Are there long-term effects of early child care? *Child Development, 78*(2), 681-701. doi:<https://doi.org/10.1111/j.1467-8624.2007.01021.x>

Belsky, J., Friedman, S. L., & Hsieh, K.-H. (2001). Testing a core emotion-regulation prediction: Does early attentional persistence moderate the effect of infant negative emotionality on later development? *Child Development*, 72(1), 123–133.

Blair, C. (2016). Developmental science and executive function. *Current Directions in Psychological Science, 25*(1), 3-7. doi:10.1177/0963721415622634

Blair, C., & Diamond, A. (2008). Biological processes in prevention and intervention: The promotion of self-regulation as a means of preventing school failure. *Development and Psychopathology, 20*(3), 899-911. doi:10.1017/S0954579408000436

Blair, C., & Raver, C. C. (2012). Child development in the context of adversity: Experiential canalization of brain and behavior. *American psychologist, 67*(4), 309-318. doi:10.1037/a0027493

Blair, C., & Raver, C. C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology, 66*, 711-731. doi:10.1146/annurev-psych-010814-015221

Bronfenbrenner, U., & Morris, P. A. (2006). The bioecological model of human development. In *Handbook of child psychology: Theoretical models of human development, Vol. 1, 6th ed.* (pp. 793-828). Hoboken, NJ, US: John Wiley & Sons Inc.

Burchinal, M., Carr, R. C., Vernon-Feagans, L., Blair, C., & Cox, M. (2018). Depth, persistence, and timing of poverty and the development of school readiness skills in rural low-income regions: Results from the family life project. *Early Childhood Research Quarterly, 45*, 115-130. doi:<https://doi.org/10.1016/j.ecresq.2018.07.002>

Cadima, J., Enrico, M., Ferreira, T., Verschueren, K., Leal, T., & Matos, P. M. (2016). Self-regulation in early childhood: the interplay between family risk, temperament and teacher–child interactions. *European Journal of Developmental Psychology, 13*(3), 341-360. doi:10.1080/17405629.2016.1161506

Calkins, S. D. (2004). Temperament and emotional regulation: Multiple models of early development. In M. Beauregard (Ed.), *Consciousness, Emotional Self-Regulation and the Brain* (pp. 35-60). Amsterdam, Netherlands: John Benjamins Publishing Company.

Calkins, S. D. (2007). The emergence of self-regulation: Biological and behavioral control mechanisms supporting toddler competencies. In *Socioemotional development in the toddler years: Transitions and transformations.* (pp. 261-284). New York, NY, US: The Guilford Press.

Cameron, C., McClelland, M., Jewkes, A., Connor, C., Farris, C., & Morrison, F. (2008). Touch your toes! Developing a direct measure of behavioral regulation in early childhood. *Early Childhood Research Quarterly, 23*, 141-158. doi:10.1016/j.ecresq.2007.01.004

Caughy, M. O., Mills, B., Owen, M. T., & Hurst, J. R. (2013). Emergent self-regulation skills among very young ethnic minority children: a confirmatory factor model. *J Exp Child Psychol, 116*(4), 839-855. doi:10.1016/j.jecp.2013.07.017

Connelly, B. S., & Ones, D. S. (2010). An other perspective on personality: meta-analytic integration of observers' accuracy and predictive validity. *Psychological bulletin, 136*(6), 1092-1122. doi:10.1037/a0021212

Costello, A. B., & Osborne, J. (2005). Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis. *Practical assessment, research, and evaluation, 10*(1), 7. doi:<https://doi.org/10.7275/jyj1-4868>

Deater-Deckard, K., & Bell, M. A. (2017). Maternal executive function, heart rate, and EEG alpha reactivity interact in the prediction of harsh parenting. *Journal of Family Psychology, 31*(1), 41-50. doi:10.1037/fam0000286

Deater-Deckard, K., Wang, Z., Chen, N., & Bell, M. A. (2012). Maternal executive function, harsh parenting, and child conduct problems. *Journal of Child Psychology and Psychiatry, 53*(10), 1084-1091. doi:<https://doi.org/10.1111/j.1469-7610.2012.02582.x>

Diamond, A. (2013). Executive functions. *Annu Review Psychology, 64*, 135-168. doi:10.1146/annurev-psych-113011-143750

Diercks, C. M., Gunther, K. E., Teti, D. M., & Lunkenheimer, E. (2022). Ecological validity in measuring parents’ executive function. *Child Development Perspectives, 16*(4), 208-214. doi:<https://doi.org/10.1111/cdep.12464>

Doebel, S. (2020). Rethinking executive function and its development. *Perspectives on Psychological Science, 15*(4), 942-956. doi:10.1177/1745691620904771

Du, Y., Kou, J., & Coghill, D. (2008). The validity, reliability and normative scores of the parent, teacher and self report versions of the Strengths and Difficulties Questionnaire in China. *Child adolescent psychiatry mental health, 2*(1), 1-15. doi:<https://doi.org/10.1186/1753-2000-2-8>

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., . . . Brooks-Gunn, J. J. D. p. (2007). School readiness and later achievement. *Developmental Psychology, 43*(6), 1428-1446. doi:<https://doi.org/10.1037/0012-1649.43.6.1428>

Duncan, R. J., McClelland, M. M., & Acock, A. C. (2017). Relations between executive function, behavioral regulation, and achievement: Moderation by family income. *Journal of applied developmental psychology, 49*, 21-30. doi:<https://doi.org/10.1016/j.appdev.2017.01.004>

Enkavi, A. Z., Eisenberg, I. W., Bissett, P. G., Mazza, G. L., MacKinnon, D. P., Marsch, L. A., & Poldrack, R. A. (2019). Large-scale analysis of test–retest reliabilities of self-regulation measures. *Proceedings of the National Academy of Sciences, 116*(12), 5472-5477. doi:<https://doi.org/10.1073/pnas.1818430116>

Fay-Stammbach, T., Hawes, D. J., & Meredith, P. (2014). Parenting influences on executive function in early childhood: A review. *Child Development Perspectives, 8*(4), 258-264. doi:<https://doi.org/10.1111/cdep.12095>

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological bulletin, 134*(1), 31-60. doi:10.1037/0033-2909.134.1.31

Gioia, G. A., Espy, K. A., & Isquith, P. K. (2003). *Behavior Rating Inventory of Executive Function- Preschool Version. Odessa*. FL: Psychological Assessment Resources.

Goodman, R. (2001). Psychometric properties of the strengths and difficulties questionnaire. *Journal of the American Academy of Child Adolescent Psychiatry, 40*(11), 1337-1345. doi:<https://doi.org/10.1097/00004583-200111000-00015>

Guerrero-Rosada, P., Weiland, C., McCormick, M., Hsueh, J., Sachs, J., Snow, C., & Maier, M. (2021). Null relations between CLASS scores and gains in children’s language, math, and executive function skills: A replication and extension study. *Early Childhood Research Quarterly, 54*, 1-12. doi:<https://doi.org/10.1016/j.ecresq.2020.07.009>

Holleman, G. A., Hooge, I. T. C., Kemner, C., & Hessels, R. S. (2020). The ‘Real-World Approach’ and Its Problems: A Critique of the Term Ecological Validity. *Frontiers in Psychology, 11:721*. doi:10.3389/fpsyg.2020.00721

Holochwost, S. J., Winebrake, D., Brown, E. D., Happaney, K. R., Wagner, N. J., & Mills-Koonce, W. R. (2023). An ecological systems perspective on individual differences in children’s performance on measures of executive function. *Journal of Cognition and Development, 24*(2), 223-240. doi:10.1080/15248372.2022.2160721

Howard, S. J., & Melhuish, E. (2017). An early years toolbox for assessing early executive function, language, self-regulation, and social development: Validity, reliability, and preliminary norms. *Journal of Psychoeducational Assessment, 35*(3), 255-275. doi:10.1177/0734282916633009

Huang, W., & Yang, Z. (2015). Goal Orientation, Self-efficacy, and Self-control among 3 ~ 6 Years Old Children [3~ 6 岁幼儿目标取向, 自我效能感与自我控制的关系]. *Psychological Development and Education, 31*(5), 547-554. doi:10.16187/j.cnki.issn1001-4918.2015.05.05

Idänpään-Heikkilä, U. M., Lambie, L., Mattke, S., McLaughlin, V., Palmer, H., & Tu, J. V. (2006). Selecting indicators for the quality of cardiac care at the health system level in Organization for Economic Co-operation and Development countries. *International Journal for Quality in Health Care, 18*(suppl\_1), 39-44. doi:10.1093/intqhc/mzl028

Ip, P., Li, S. L., Rao, N., Ng, S. S. N., Lau, W. W. S., & Chow, C. B. (2013). Validation study of the Chinese early development instrument (CEDI). *BMC pediatrics, 13*(1), 1-8. doi:<https://doi.org/10.1186/1471-2431-13-146>

Korucu, I., Rolan, E., Napoli, A. R., Purpura, D. J., & Schmitt, S. A. (2019). Development of the Home Executive Function Environment (HEFE) Scale: Assessing its relation to preschoolers' executive function. *Early Childhood Research Quarterly, 47*, 9-19. doi:<https://doi.org/10.1016/j.ecresq.2018.09.001>

Koziol, L. F., Budding, D. E., & Chidekel, D. (2012). From Movement to Thought: Executive Function, Embodied Cognition, and the Cerebellum. *The Cerebellum, 11*(2), 505-525. doi:10.1007/s12311-011-0321-y

Lee, E. J. (2016). Endorsement of achievement goals across secondary school years: Applying a state-trait framework. *Journal of Research in Personality, 64*, 21-33. doi:<https://doi.org/10.1016/j.jrp.2016.07.004>

Lengua, L. J., & Kovacs, E. A. (2005). Bidirectional associations between temperament and parenting and the prediction of adjustment problems in middle childhood. *Journal of applied developmental psychology, 26*(1), 21-38. doi:<https://doi.org/10.1016/j.appdev.2004.10.001>

Lerner, R. M. (2006). Developmental Science, Developmental Systems, and Contemporary Theories of Human Development. In R. M. Lerner & W. Damon (Eds.), *Handbook of child psychology: Theoretical models of human development* (pp. 1-17). Hoboken, NJ, US: John Wiley & Sons Inc.

Lerner, R. M. (2018). *Concepts and Theories of Human Development (4th ed.)*: Routledge.

Lerner, R. M., & Overton, W. F. (2008). Exemplifying the integrations of the relational developmental system:Synthesizing theory, research, and application to promote positive development and social justice. *Journal of Adolescent Research, 23*(3), 245-255. doi:10.1177/0743558408314385

Lewis, C., & Carpendale, J. I. M. (2009). Introduction: Links between social interaction and executive function. *New Directions for Child and Adolescent Development, 2009*(123), 1-15. doi:<https://doi.org/10.1002/cd.232>

Lunkenheimer, E., Panlilio, C., Lobo, F. M., Olson, S. L., & Hamby, C. M. (2019). Preschoolers’ self-regulation in context: Task persistence profiles with mothers and fathers and later attention problems in kindergarten. *Journal of abnormal child psychology, 47*(6), 947-960. doi:10.1007/s10802-019-00512-x

McCabe, L. A., Cunnington, M., & Brooks-Gunn, J. (2004). The development of self-regulation in young children: Individual characteristics and environmental contexts. In *Handbook of self-regulation: Research, theory, and applications.* (pp. 340-356). New York, NY, US: The Guilford Press.

McClelland, M., Geldhof, J., Morrison, F., Gestsdóttir, S., Cameron, C., Bowers, E., . . . Grammer, J. (2018). Self-regulation. In *Handbook of Life Course Health Development* (pp. 275-298): Springer International Publishing.

McClelland, M. M., & Cameron, C. E. (2011). Self-regulation and academic achievement in elementary school children. *New Directions for Child and Adolescent Development, 2011*(133), 29-44. doi:<https://doi.org/10.1002/cd.302>

McClelland, M. M., & Cameron, C. E. (2012). Self-Regulation in early childhood: Improving conceptual clarity and developing ecologically valid measures. *Child Development Perspectives, 6*(2), 136-142. doi:<https://doi.org/10.1111/j.1750-8606.2011.00191.x>

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. J. D. p. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology, 43*(4), 947-959. doi:<https://doi.org/10.1037/0012-1649.43.4.947>

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: the head-toes-knees-shoulders task. *Frontiers in Psychology, 5*(599), 1-14. doi:10.3389/fpsyg.2014.00599

McClelland, M. M., Ponitz, C. C., Messersmith, E. E., & Tominey, S. (2010). Self-regulation: Integration of cognition and emotion. In W. F. Overton & R. M. Lerner (Eds.), *The handbook of life-span development, Vol 1: Cognition, biology, and methods.* (pp. 509-553). Hoboken, NJ, US: John Wiley & Sons, Inc.

McClelland, M. M., & Tominey, S. L. (2015). *Stop, think, act: Integrating self-regulation in the early childhood classroom (1st ed.)*. New York: Routledge.

McCoy, D. C. (2019). Measuring young children’s executive function and self-regulation in classrooms and other real-world settings. *Clinical Child and Family Psychology Review, 22*(1), 63-74. doi:10.1007/s10567-019-00285-1

Medrano, J., & Prather, R. W. (2023). Rethinking executive functions in mathematical cognition. *Journal of Cognition and Development, 24*(2), 280-295. doi:10.1080/15248372.2023.2172414

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. doi:10.1006/cogp.1999.0734

Montroy, J. J., Bowles, R. P., Skibbe, L. E., McClelland, M. M., & Morrison, F. J. (2016). The development of self-regulation across early childhood. *Developmental Psychology, 52*(11), 1744-1762. doi:<https://doi.org/10.1037/dev0000159>

Morrison, F. J., Ponitz, C. C., & McClelland, M. M. (2010). Self-regulation and academic achievement in the transition to school. In S. D. Calkins & M. A. Bell (Eds.), *Child development at the intersection of emotion and cognition* (pp. 203-224). Washington, DC, US: American Psychological Association.

Muthén, L. K., & Muthén, B. O. (2019). *Mplus User’s Guide*. Los Angeles, CA: Muthén & Muthén.

Naglieri, J. A., & Goldstein, S. (2013). *Comprehensive Executive Function Inventory*. NorthTonawanda, NY: Multi-Health Systems.

Overton, W. F. (2006). Developmental Psychology: Philosophy, Concepts, Methodology. In R. M. Lerner & W. Damon (Eds.), *Handbook of child psychology: Theoretical models of human development* (pp. 18-88). Hoboken, NJ, US: John Wiley & Sons Inc.

Parsons, T. D., Carlew, A. R., Magtoto, J., & Stonecipher, K. (2017). The potential of function-led virtual environments for ecologically valid measures of executive function in experimental and clinical neuropsychology. *Neuropsychological Rehabilitation, 27*(5), 777-807. doi:10.1080/09602011.2015.1109524

Pianta, R. C. (1992). Child-parent relationship scale. *Unpublished measure, University of Virginia, 427*.

Pianta, R. C., Whittaker, J. E., Vitiello, V., Ruzek, E., Ansari, A., Hofkens, T., & DeCoster, J. (2020). Children's school readiness skills across the pre-K year: Associations with teacher-student interactions, teacher practices, and exposure to academic content. *Journal of applied developmental psychology, 66*, 101084. doi:<https://doi.org/10.1016/j.appdev.2019.101084>

Pickering, S. J., & Gathercole, S. E. (2004). Distinctive working memory profiles in children with special educational needs. *Educational Psychology, 24*(3), 393-408. doi:10.1080/0144341042000211715

Raver, C. C., Carter, J. S., McCoy, D. C., Roy, A., Ursache, A., & Friedman, A. (2012). Testing models of children's self-regulation within educational contexts: implications for measurement. *Advances in Child Development Behavior, 42*, 245-270. doi:10.1016/b978-0-12-394388-0.00007-1

Rimm-Kaufman, S. E., Curby, T. W., Grimm, K. J., Nathanson, L., & Brock, L. L. (2009). The contribution of children’s self-regulation and classroom quality to children’s adaptive behaviors in the kindergarten classroom. *Developmental Psychology, 45*(4), 958-972. doi:<https://doi.org/10.1037/a0015861>

Rimm-Kaufman, S. E., Early, D. M., Cox, M. J., Saluja, G., Pianta, R. C., Bradley, R. H., & Payne, C. (2002). Early behavioral attributes and teachers' sensitivity as predictors of competent behavior in the kindergarten classroom. *Journal of applied developmental psychology, 23*(4), 451-470. doi:[https://doi.org/10.1016/S0193-3973(02)00128-4](https://doi.org/10.1016/S0193-3973%2802%2900128-4)

Robson, D. A., Allen, M. S., & Howard, S. J. (2020). Self-regulation in childhood as a predictor of future outcomes: A meta-analytic review. *Psychological bulletin, 146*, 324-354. doi:10.1037/bul0000227

Sabbagh, M. A., Xu, F., Carlson, S. M., Moses, L. J., & Lee, K. (2006). The development of executive functioning and theory of mind. A comparison of Chinese and U.S. preschoolers. *Psychological Science, 17*(1), 74-81. doi:10.1111/j.1467-9280.2005.01667.x

Schunk, D. H., & Zimmerman, B. J. (1997). Social origins of self-regulatory competence. *Educational Psychologist, 32*(4), 195-208. doi:10.1207/s15326985ep3204\_1

Spinola, S., Maisto, S. A., White, C. N., & Huddleson, T. (2017). Effects of acute alcohol intoxication on executive functions controlling self-regulated behavior. *Alcohol, 61*, 1-8. doi:<https://doi.org/10.1016/j.alcohol.2017.02.177>

Sturge-Apple, M. L., Suor, J. H., & Skibo, M. A. (2014). Maternal child-centered attributions and harsh discipline: The moderating role of maternal working memory across socioeconomic contexts. *Journal of Family Psychology, 28*, 645-654. doi:10.1037/fam0000023

Thompson, B. (2004). *Exploratory and confirmatory factor analysis: Understanding concepts and applications*. Washington, DC, US: American Psychological Association.

Thorell, L. B., & Catale, C. (2014). The assessment of executive functioning using the Childhood Executive Functioning Inventory (CHEXI). In S. Goldstein & J. A. Naglieri (Eds.), *Handbook of Executive Functioning* (pp. 359-366). New York, NY: Springer New York.

Vandenbroucke, L., Spilt, J., Verschueren, K., Piccinin, C., & Baeyens, D. (2018). The classroom as a developmental context for cognitive development: A meta-analysis on the importance of teacher–student interactions for children’s executive functions. *Review of Educational Research, 88*(1), 125-164. doi:10.3102/0034654317743200

Walk, L. M., Evers, W. F., Quante, S., & Hille, K. (2018). Evaluation of a teacher training program to enhance executive functions in preschool children. *PloS one, 13*(5), e0197454. doi:10.1371/journal.pone.0197454

Wang, S., Hu, B. Y., Curby, T., & Fan, X. (2021). Multiple approaches for assessing within-day stability in teacher-child interactions. *Early Education and Development, 32*(4), 553-571. doi:10.1080/10409289.2020.1760040

Weiland, C., Ulvestad, K., Sachs, J., & Yoshikawa, H. (2013). Associations between classroom quality and children's vocabulary and executive function skills in an urban public prekindergarten program. *Early Childhood Research Quarterly, 28*(2), 199-209. doi:<https://doi.org/10.1016/j.ecresq.2012.12.002>

Widaman, K. F. (2012). Exploratory factor analysis and confirmatory factor analysis. In *APA handbook of research methods in psychology, Vol 3: Data analysis and research publication.* (pp. 361-389). Washington, DC, US: American Psychological Association.

Yang, L., & Dong, G. (2005). A Study on the Structure of Self-regulation of Children Aged between 3 and 5 years [3~5 岁幼儿自我控制能力结构研究]. *Psychological Development and Education, 21*(4), 7-12. doi:DOI :10.16187/j .cnki .issn1001-4918.2005.04.002

Zakszeski, B., Hojnoski, R. L., Dever, B. V., DuPaul, G. J., & McClelland, M. M. (2020). Early elementary trajectories of classroom behavior self-regulation: Prediction by student characteristics and malleable contextual factors. *School Psychology Review, 49*(2), 161-177. doi:10.1080/2372966X.2020.1717373

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives, 6*(4), 354-360. doi:<https://doi.org/10.1111/j.1750-8606.2012.00246.x>

Zelazo, P. D., & Carlson, S. M. (2023). Reconciling the context-dependency and domain-generality of executive function skills from a developmental systems perspective. *Journal of Cognition and Development, 24*(2), 205-222. doi:10.1080/15248372.2022.2156515

Zhang, X., & Nurmi, J.-E. (2012). Teacher–child relationships and social competence: A two-year longitudinal study of Chinese preschoolers. *Journal of applied developmental psychology, 33*(3), 125-135. doi:<https://doi.org/10.1016/j.appdev.2012.03.001>

Zimmermann, L. K., & Stansbury, K. (2003). The influence of temperamental reactivity and situational context on the emotion-regulatory abilities of 3-year-old children. *Journal of Genetic Psychology*, 164(4), 389–409.

**Table 1**

*Child Demographics and its Associations with Behavioral Self-regulation*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | *Mean* (*SD*) | *N* (*%*) | *ES* | *VE* | *IC* |
| T1 (*N*=825) |  |  |  |  |  |
| Age | 5.87 (1.50) | 825 | -0.23\*\* | -0.10\*\* | -0.06 |
| Boys |  | 446 (53.8%) | -0.06 | -0.07\* | -0.05 |
| Only Child |  | 198 (23.9%) | -0.03 | -0.05 | -0.01 |
| Urban |  | 410 (49.5%) | -0.03 | -0.01 | 0.07\* |
| T2 (*N*=190) |  |  |  |  |  |
| Age | 5.55 (1.82) | 190 | 0.06 | -0.10 | -0.13 |
| Boys |  | 96 (50.5%) | 0.03 | -0.05 | -0.06 |
| Only Child |  | 87 (45.8%) | 0.39\*\* | 0.08 | 0.08 |
| Urban |  | 106 (55.8%) | 0.57\*\* | 0.07 | 0.22\*\* |
| T3 (*N*=183) |  |  |  |  |  |
| Age | 5.93 (1.84) | 183 | -0.04 | -0.10 | -0.18\* |
| Boys |  | 92 (50.3%) | -0.01 | 0.01 | -0.04 |
| Only Child |  | 84 (45.9%) | 0.16\* | 0.08 | 0.04 |
| Urban |  | 103 (56.3%) | 0.37\*\* | 0.12 | 0.24\*\* |

**Table 2**

*Descriptive Information and Factor Loadings of Items from Factor Analysis (T1)*

|  |  |  |
| --- | --- | --- |
|  | *Factors* | *Descriptive Statistics* |
|  | *Inhibition* | *Updating* | *Shifting* | *Min* | *Max* | *M* | *SD* | *Skewness* | *Kurtosis* |
| ***Factors Analysis*** |  |  |  |  |  |  |  |  |  |
| Inhibition |  |  |  | 1.00  | 4.00  | 1.86  | 0.66  | 0.35  | -0.69  |
| Item 1 | 0.85 |  |  | 1.00  | 5.00  | 1.91  | 0.85  | 0.40  | -0.91  |
| Item 4 | 0.65 |  |  | 1.00  | 5.00  | 2.19  | 0.84  | -0.06  | -0.72  |
| Item 7 | 0.79 |  |  | 1.00  | 5.00  | 1.93  | 0.83  | 0.36  | -0.77  |
| Item 10 | 0.69 |  |  | 1.00  | 5.00  | 1.62  | 0.80  | 0.99  | 0.00  |
| Item 13 | 0.89 |  |  | 1.00  | 5.00  | 1.78  | 0.79  | 0.59  | -0.47  |
| Item 16 | 0.73 |  |  | 1.00  | 5.00  | 1.75  | 0.74  | 0.59  | -0.24  |
| Updating  |  |  |  | 1.00  | 5.00  | 2.69  | 0.71  | 0.13  | 0.40  |
| Item 2 |  | 0.60 |  | 1.00  | 5.00  | 2.41  | 0.90  | 0.71  | 0.42  |
| Item 5 |  | 0.72 |  | 1.00  | 5.00  | 2.86  | 0.96  | 0.07  | -0.56  |
| Item 8 |  | 0.65 |  | 1.00  | 5.00  | 2.76  | 0.99  | 0.25  | -0.51  |
| Item 11 |  | 0.88 |  | 1.00  | 5.00  | 2.73  | 0.93  | 0.22  | -0.40  |
| Item 14 |  | 0.70 |  | 1.00  | 5.00  | 2.68  | 0.89  | 0.30  | -0.09  |
| Item 17 |  | 0.58 |  | 1.00  | 5.00  | 2.69  | 0.89  | 0.39  | -0.20  |
| Shifting |  |  |  | 1.00  | 5.00  | 2.69  | 0.75  | 0.09  | 0.42  |
| Item 3 |  |  | 0.58 | 1.00  | 5.00  | 2.79  | 0.89  | 0.01  | -0.06  |
| Item 6 |  |  | 0.75 | 1.00  | 5.00  | 2.70  | 0.94  | 0.22  | -0.23  |
| Item 9 |  |  | 0.87 | 1.00  | 5.00  | 2.78  | 0.91  | 0.17  | -0.19  |
| Item 12 |  |  | 0.79 | 1.00  | 5.00  | 2.64  | 0.90  | 0.29  | 0.00  |
| Item 15 |  |  | 0.90 | 1.00  | 5.00  | 2.52  | 0.78  | 0.33  | 0.26  |
| Item 18 |  |  | 0.90 | 1.00  | 5.00  | 2.72  | 0.78  | 0.01  | 0.18  |
| Eigenvalue  | 7.51 | 3.45 | 1.26 |  |  |  |  |  |  |
| Percentage of variance | 41.69 | 19.19 | 7.00 |  |  |  |  |  |  |
| ***Internal Consistency*** |  |  |  |  |  |  |  |  |  |
| Cronbach's αs (95% CI) | 0.90 (0.89-0.91) | 0.86 (0.84-0.88) | 0.93 (0.92-0.94) |  |  |  |  |  |  |
| McDonald’s Omega (95% CI) | 0.90 (0.89-0.91) | 0.85 (0.83-0.87) | 0.94 (0.93-0.95) |  |  |  |  |  |  |

The Global Omega is 0.963 (0.962-0.964)

**Table 3**

*Correlations of CSIS with Children’s Behavioral and Academic Skills, and Parent-Child Relationships (T1)*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Inhibition  | Updating  | Shifting  | behavioral self-regulation  |
| Self-regulation | -0.31\*\* | -0.54\*\* | -0.50\*\* | -0.56\*\* |
| Parent-child Closeness | -0.15\*\* | -0.23\*\* | -0.27\*\* | -0.28\*\* |
| Parent-child Conflict | 0.08\* | 0.13\*\* | 0.19\*\* | 0.17\*\* |
| Problem Behavior | 0.22\*\* | 0.30\*\* | 0.34\*\* | 0.37\*\* |
| Prosocial Behavior | -0.23\*\* | -0.44\*\* | -0.45\*\* | -0.48\*\* |
| Literacy and Cognition | -0.21\*\* | -0.27\*\* | -0.28\*\* | -0.33\*\* |

**Table 4**

*Evaluation of the factor structure of the CSIS at T2 and T3*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | *χ*2 | *df* | *CFI* | *TLI* | *RMSEA* |
| T2 (*N* = 190) |  |  |  |  |  |
| One-Factor Model | 1004.084 | 135 | 0.508 | 0.442 | 0.184 |
| Three-Factor Model | 290.001 | 132 | 0.911 | 0.896 | 0.079 |
| T3 (*N* = 183) |  |  |  |  |  |
| One-Factor Model | 653.499 | 135 | 0.672 | 0.628 | 0.145 |
| Three-Factor Model | 265.475 | 132 | 0.916 | 0.902 | 0.074 |

**Table 5**

*The Test-Retest Reliability at T2 and T3*

|  |  |  |
| --- | --- | --- |
|  | *r* (T2 with T3) | ICC (95% CI) |
| Inhibition  | 0.59\*\* | 0.73 |
| Updating  | 0.75\*\* | 0.85 |
| Shifting | 0.75\*\* | 0.86 |

**Table 6**

*Fit indices for Measurement Invariance Test*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | *χ*2 | *df* | *CFI* | *TLI* | *RMSEA* | *ΔCFI* | *ΔTLI* |
| Invariance Test for Gender |  |  |  |  |  |  |  |
| Configural Invariance  | 864.65 | 264 | 0.941 | 0.932 | 0.074 | -- | -- |
| Metric Invariance  | 882.22 | 279 | 0.941 | 0.935 | 0.072 | 0 | 0 |
| Scalar Invariance  | 903.23 | 294 | 0.940 | 0.938 | 0.071 | 0.001 | 0.003 |
| Error Variance Invariance  | 919.98 | 312 | 0.941 | 0.942 | 0.069 | 0.001 | 0.005 |
| Longitudinal Invariance Test |  |  |  |  |  |  |  |
| Configural Invariance  | 556.20 | 264 | 0.913 | 0.899 | 0.077 | -- | -- |
| Metric Invariance  | 574.22 | 279 | 0.912 | 0.904 | 0.075 | 0.001 | 0.005 |
| Scalar Invariance  | 597.23 | 294 | 0.910 | 0.906 | 0.074 | 0.002 | 0.002 |
| Error Variance Invariance  | 619.11 | 312 | 0.909 | 0.910 | 0.073 | 0.001 | 0.004 |



Fig.1. Predicting children’s developmental skills from

behavioral self-regulation and covariates.

*Note*. The children’s age, gender, location (rural/urban), only children or not

were controlled in the model.