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Contributions of Hot and Cool Self-Regulation to Preschool Disruptive Behavior and Academic Achievement

Michael Willoughby,

FPG Child Development Institute, University of North Carolina at Chapel Hill, Carrboro, North Carolina

Janis Kupersmidt,

Innovation Research and Training, Durham, North Carolina

Mare Voegler-Lee, and

FPG Child Development Institute, University of North Carolina at Chapel Hill, Carrboro, North Carolina

Donna Bryant

FPG Child Development Institute, University of North Carolina at Chapel Hill, Carrboro, North Carolina

Abstract

The construct of self-regulation can be meaningfully distinguished into hot and cool components. The current study investigated self-regulation in a sample of 926 children aged 3–5 years old. Children's performance on self-regulatory tasks was best described by two latent factors representing hot and cool regulation. When considered alone, hot and cool regulation were both significantly correlated with disruptive behavior and academic achievement. When considered together, cool regulation was uniquely associated with academic achievement, while hot regulation was uniquely associated with inattentive-overactive behaviors. Results are discussed with respect to treatment studies that directly target improvement in children's self-regulation.

Self-regulation, which is one of the one of the major achievements of early childhood, refers to the process through which children increasingly acquire the ability to regulate their own arousal, emotion, and behavior (Kopp, 1982; Shonkoff & Phillips, 2000). More specifically, the development and integration of neurophysiologic, cognitive, and behavioral processes over the first five years of life help children transition from being primarily "other-regulated" (by parents) as infants and toddlers to increasingly "self-regulated" as preschoolers (Calkins & Fox, 2002; Posner & Rothbart, 2000; Schore, 1994). Self-regulated emotion, behavior, and cognition provide the foundation for the social and academic demands required for the successful transition to formal schooling (Blair, 2002).

For much of the last three decades, the development of self-regulatory abilities has been assumed to parallel the development of the prefrontal cortex (Chelune & Baer, 1986; Fuster,

1997; Levin et al., 1991; Luciana & Nelson, 1998; Welsh, Pennington, & Groisser, 1991). Within the early childhood period, the initial support for the idea that changes in self-regulation were due to corresponding changes in the prefrontal cortex (PFC) was derived from indirect evidence, primarily studies using neuropsychological assessments (Carlson, 2005; Espy, 1997, 2004). However, the increasing use of electrophysiologic assessment methods with young children has begun to provide direct evidence of the central role of PFC activity and emerging self-regulatory abilities (Bell & Wolfe, 2007; Rueda, Rothbart, McCandliss, Saccamanno, & Posner, 2005; Szucs, 2005; Thatcher, 1997).

A clear benefit of construing the PFC as the neurological substrate that supports the acquisition of self-regulatory abilities is that it provides a “bridge” for linking the results from developmental-behavioral studies, which typically use indirect methods, to neuroscientific studies, which use direct methods. In other words, a shared PFC model may facilitate the multidisciplinary study of self-regulation. However, to the extent that developmental and behavioral researchers adopt an overly simplistic perspective of the role of the PFC in the acquisition of self-regulation, the value of this model is lost. For example, equating changes in self-regulation to changes in the structure or functioning of the PFC is in no way explanatory and has the potential to devolve into reductionism and actually hamper multidisciplinary research (Oliver, Johnson, Karmiloff-Smith, & Pennington, 2000; Quartz & Sejnowski, 1997).

Recent proposals that distinguish “hot” and “cool” aspects of self regulation both guard against over-simplifications of PFC-mediated regulatory processes and facilitate more precise thinking the diversity of functions subsumed under the rubric of self regulation (Zelazo & Mueller, 2002). Hot regulatory tasks require the resolution of novel problems that are emotionally arousing, including tasks with appetitive demands, and are understood to engage the orbitofrontal cortex (OFC), an area with strong connections to the limbic system (Happaney, Zelazo, & Stuss, 2004). Effortful control (including delay of gratification) tasks have traditionally been used to index hot regulation. In contrast, cool regulatory tasks require the resolution of novel problems that are emotionally neutral and are understood to engage the dorsolateral prefrontal (DL-PFC) cortex (Happaney et al., 2004). Executive function tasks have traditionally been used to index cool regulation. The OFC and DL-PFC are interconnected areas that are components of a larger pre-frontally mediated system of self regulation. Their coordination underscores how a shared set of neural substrates are involved in the regulation of cognitive and emotional processes (Bell & Wolfe, 2004; Posner & Rothbart, 2000). Although there are no purely hot or cool regulatory tasks, differentiating hot and cool regulation provides a heuristically useful way of thinking about the diversity of functions that fall under the general rubric of self regulation.

Researchers from a variety of disciplines have advocated for distinguishing hot and cool aspects of self regulation. For example, Metcalfe and Mischel (1999) proposed a neural network model that distinguished two complementary subsystems that enable self-control—the cool, cognitive “know” and the hot, emotional “go” system. The cool system was described as affectively neutral, reflective, slow acting, late developing, and the “seat of self-regulation.” The hot system was described as affectively engaged (due to appetitive or fear-inducing stimuli), reflexive, fast acting, early developing, and under stimulus control. At

about the same time, Nigg (2000) provided an authoritative review of inhibitory control as studied in both cognitive neuroscientific and personality/temperament literatures. He proposed that a major distinction could be drawn between “executive inhibition” and “motivational inhibition,” which correspond closely to Metcalfe and Mischel’s (1999) cool and hot systems, respectively.

A growing number of neuroimaging studies have also demonstrated that whereas the DL-PFC and *anterior* cingulate cortex (ACC) are associated with cool, cognitive processing, the orbitofrontal/ventral lateral PFC and *posterior* ACC are associated with hot, emotional processing (Bush, Luu, & Posner, 2000; McClure, Laibson, Loewenstein, & Cohen, 2004; Sakagami & Pan, 2007). Moreover, a meta-analysis of 27 neuroimaging studies provided support for the hypothesis that distinct neural circuits are drawn upon during risky (hot) versus ambiguous (cool) decisionmaking tasks (Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006). These results undermine the frequent conceptualization by developmental and behavioral researchers that the PFC serves a unitary function. Moreover, although most researchers tend to conceptualize the PFC as serving a “top down” or integrative control function in the brain, the PFC also receives “bottom up” input from the limbic system (Derryberry & Tucker, 1991; Tucker & Derryberry, 1992). The hot-cool distinction attends to this structural and functional diversity.

There is also empirical support for distinguishing hot and cool aspects of self regulation. At least seven studies have factor analyzed children’s performance on tasks that differed with respect to the affective valence and the nature of the conflict to be resolved (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Carlson, Moses, & Breton, 2002; Dalen, Sonuga-Barke, Hall, & Remington, 2004; Murray & Kochanska, 2002; Olson, Schilling, & Bates, 1999; Smith-Donald, Raver, Hayes, & Richardson, 2007; Sonuga-Barke, Dalen, & Remington, 2003). In every case, there was evidence that tasks involving cool, cognitive processes factored separately from tasks that had appetitive or temporal (delay) demands. However, with one exception, all of these studies used either principal components analysis or imposed varimax rotations in their factor analysis which resulted in orthogonal factors. Although useful for purposes of data reduction, this is inconsistent with the theoretical formulation of hot and cool processes as distinct but *correlated* processes.

Brock and colleagues (2009) used confirmatory factor analysis to distinguish children’s performance on four tasks drawn from the Preschool Self-Regulation Assessment (Smith-Donald et al., 2007). Specifically, they used the Balance Beam and Pencil Tapping tasks as indicators of cool regulation (both emotionally neutral) and the Toy Sort and Gift Wrap tasks as indicators of hot regulation (both appetitive in nature, as children had to manage desire not to play with desirable toys or to look at a desirable gift). Brock et al. (2009) demonstrated that these four tasks were better represented by separate latent variables for hot and cool regulation than by a single factor and reported that hot and cool latent variables were positively and moderately correlated ($\phi = .50$). An initial goal of the present study was to similarly test whether children’s performance on a battery of self-regulatory tasks would factor into the expected hot and cool dimensions, as well as to determine how highly correlated children’s performance was on these two constructs. We hypothesized that model

children's self-regulation would be best explained by two factors that were positively moderately correlated.

Beyond factor analytic studies, the hot-cool distinction has also proven useful for studies of disruptive behavior disorders (DBDs). For example, prenatal exposure to smoking is a well-known risk factor for DBDs, though the specific processes through which this association occurs are poorly understood (Wakschlag, Pickett, Cook, Benowitz, & Leventhal, 2002). One recent study demonstrated that prenatal exposure to smoking predicted poorer performance on hot but not cool self-regulatory tasks (Huijbregts, Warren, de Sonnevile, & Swaab-Barneveld, 2008). This raises the possibility that it is hot, not cool, self-regulatory abilities that mediate the association between prenatal smoking and disruptive behavior outcomes. The hot-cool distinction is also the basis of Sonuga-Barke's dual pathway hypothesis of the etiology of attention deficit hyperactivity disorder (ADHD; Sonuga-Barke, 2002, 2005). Within the heterogeneous category of ADHD, there is evidence that some children are better characterized as exhibiting deficits in (cool) executive functions, while others are characterized by deficits in (hot) delay aversion and altered motivation style (Kuntsi, Oosterlaan, & Stevenson, 2001; Solanto et al., 2001; Sonuga-Barke et al., 2003; Wahlstedt, Thorell, & Bohlin, 2009). A second goal of the proposed study was to provide additional tests of whether children's performance on hot and cool tasks was uniquely predictive of behavioral functioning including inattentive-overactive behaviors that are characteristic of ADHD, as well as oppositional-defiant and aggressive behaviors that frequently co-occur with ADHD (Waschbusch, 2002). We hypothesized that children's performance on both hot and cool tasks would be predictive of inattentive-overactive, oppositional defiant, and aggressive behaviors.

Most of what is known about the association between self regulation and academic functioning in early childhood comes from studies that measured regulation using exclusively cool (Blair & Razza, 2007; Espy et al., 2004; McClelland et al., 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010) or hot (Mischel, Shoda, & Rodriguez, 1989; Shoda, Mischel, & Peake, 1990) tasks—but not both. To the extent that children's performance on hot and cool tasks is correlated, either of these results may be spurious (e.g., the association between delay of gratification and subsequent academic functioning may reflect a shared association with cool, inhibitory control or vice versa). We are only aware of two previous studies that provided direct comparisons of children's performance on hot versus cool tasks as they relate to *academic* functioning in early childhood. Specifically, in two similarly sized studies ($N = 145, 173$) involving kindergarten-aged students, individual differences in cool but not hot regulation were uniquely associated with performance on academic functioning (Brock et al., 2009; Thorell, 2007). In addition, Hongwanishkul and colleagues demonstrated that performance on cool regulatory tasks were more strongly correlated with children's cognitive (intellectual) functioning than were hot tasks (Hongwanishkul, Happaney, Lee, & Zelazo, 2005). Based on these results, we hypothesized that cool processes would be uniquely predictive of academic performance.

In this study, individual differences in hot and cool regulation were evaluated using four tasks from the Preschool Self-Regulation Assessment (PSRA; Smith-Donald et al., 2007), a new test battery that was developed to facilitate direct child assessments of self regulation in

the context of large scale studies. Because task performance was linked to the receipt of tangible and desirable rewards (and hence were affectively engaging), the snack delay and tongue tasks were considered potential indices of hot regulation. In contrast, because performance was unrelated to the receipt of rewards, the pencil tapping and balance beam tasks were considered indices of cool regulation. Our selection of tasks occurred prior to our awareness of the study by Brock and colleagues (2009). We hypothesized that children's performance on these four regulatory tasks would factor into the expected hot and cool dimensions, with a two-factor model providing superior fit to a one-factor model. In addition, we hypothesized that while children's performance on both hot and cool tasks would be significantly associated with teacher-rated IO and ODA behaviors, only performance on cool tasks would be uniquely and significantly associated with academic achievement.

METHODS

Study Design

Data from the current study are drawn from the Building Bridges kindergarten readiness intervention study (Kupersmidt et al., submitted). This study used a stratified randomized design to test the efficacy of a newly developed intervention curriculum that was designed to enhance preschool children's social, behavioral, and academic functioning. The study recruited teachers and children from two strata including child care programs, which served low-income populations, as well as Head Start settings. The current study is restricted to assessments that occurred at the pre-test assessment, prior to the start of the intervention that was directed toward children.

Participants

Head Start and child care programs within a 60-mile radius of the University of North Carolina–Chapel Hill were identified and contacted to discuss the study and the requirements for participation. Eligible programs were those that had one or more classrooms comprised of at least 50% of 4-year-old children. Head Start programs were deemed eligible if they had not previously participated in the Preschool Behavior Project, the intervention program on which the current Building Bridges project was based. Of the five Head Start programs who were identified as eligible, four (80%) agreed to participate; the fifth program was undergoing administrative changes that precluded participation. These Head Start programs were located in both urban and rural counties.

Once the participating Head Start programs were identified, child care centers were identified in these counties in order to reflect the same geographic locations as the Head Start populations. To match the socioeconomic status of the Head Start population, child care centers were identified as eligible if 50% or more of their students were low-income or enrolled in subsidized slots, as identified by the Center Director. In addition, in order to ensure that minimum standards were in place such that teachers would be most able to implement and benefit from the intervention program, eligible centers were required to have a three-star rating or higher (based on North Carolina's five-star quality rating system). Identical to the inclusion criteria for Head Start classrooms, eligible child care classrooms

were those that enrolled 50% or more 4-year-olds. Of the 98 child care programs that were identified as eligible and invited to participate in the study 59 (60.2%) agreed to participate. Data were not collected for centers that declined participation, hence no comparisons were possible. It is best to consider the combined Head Start and child care centers a large convenience sample. In total, 135 classrooms located in 75 centers participated in the study.

Parents in participating classrooms were sent home a letter that described the study and invited their participation. Parents returned signed consent forms to their children's centers or directly to the project office in a pre-addressed, stamped envelope. Of the 1,997 parents/children invited to participate, 1,004 (50.3%) parents consented to participate and have their children participate. Of these, 79 children did not participate due to their meeting exclusionary criteria (e.g., primary language not English; disability that precluded participation in the assessment; child was no longer enrolled at the center at the time of the assessment; and attending the center only in the afternoon), resulting in a final sample of 926 children. Participating children were four years old in the Fall of the intervention year ($M = 4.6$, $SD = 0.4$). Fifty-eight percent of the sample was African-American, 31% was Caucasian, 10% was Hispanic, and 1% identified themselves as from another racial group. The sample was evenly distributed by child sex (50% male) and setting (50% Head Start, 50% community child care).

Due to budget and time constraints associated with direct child assessments, only 759 of the 926 children with consent participated in the assessment of self-regulation. The choice of children was intended to identify 6–10 children per classroom with equal proportion of males and females and representing a racially diverse sample. On average, children who participated in self-regulation assessments ($N = 759$ vs. $N = 167$) were older (4.6 vs. 4.5 years, $p < .0001$) and had higher teacher-rated social skills ($M_s = 1.43$ vs. 1.37 , $p = .002$) than children who did not participate in self-regulation assessments, though the magnitude of these differences was trivial. Moreover, those tested did not differ from those who were not tested with respect to teacher-rated inattentive-overactive ($M_s = 1.02$ vs. 0.97 , $p = .38$), oppositional-defiant ($M_s = 0.68$ vs. 0.61 , $p = .28$), or total aggressive behaviors ($M_s = 1.70$ vs. 1.64 , $p = .40$).

Procedure

Child assessments were conducted in a private setting at the center the child attended. Assessments were conducted over the course of two sessions, for 30–45 minutes at each session. The academic performance measures that were included in the current study were administered during the first session, and the self-regulatory tasks that were included in the current study were administered during the second session. Teacher ratings were conducted as part of interviews conducted at the centers scheduled at each teacher's convenience.

Measures

Self-Regulation—Preschool Self-Regulation Assessment—(PSRA; Smith-Donald et al., 2007). The PSRA represents a collection of brief, direct assessments of children's self-regulatory and compliance behaviors. Smith-Donald, Raver, and colleagues did not develop these assessments; rather, they selected tasks that had a proven track record from

other investigators, especially Kochanska and colleagues (Murray & Kochanska, 2002). Tasks were then modified so that they could be administered and coded “in vivo” by an assessor in preschool settings. The current study utilized four of the PSRA tasks including the Balance Beam, Pencil Tapping, Snack Delay, and Tongue Tasks.

In the Balance Beam task children are asked to walk a 6' line (masking tape on floor) three times. The first time they are instructed to “walk on the balance beam.” The second time children are instructed to repeat this but to “see how slow you can walk.” The third time they are instructed to do this again but to “walk as sloooow as possible.” At each time the assessor records the number of seconds it takes for the child to walk the length of the line. The difference between the fastest and shortest walk times was used as an index of cool regulation/motor inhibition ($N = 756$; $M = 4.4$; $SD = 5.3$; Range 0–46).

In the Pencil Tapping task, the assessor and the child each have a pencil. Children are instructed that when the assessor taps her pencil one time, the child is to tap his/her pencil two times, and conversely, that when the assessor taps her pencil two times, the child is to tap his/her pencil one time. After a series of (up to six) practice trials, in which the assessor provides feedback and correction to the child, 16 scored trials are administered in which no feedback is provided to the child. The number of correct responses was used as an index of cool regulation/cognitive inhibition ($N = 757$; $M = 9.2$; $SD = 4.9$; Range 0–16).

In the Snack Delay, children are instructed that they are to put their hands flat on the table as they watch a snack (e.g., M&M) being placed under a cup in front of them. They are told that if they can wait until the assessor tells them that “time is up” that they can have the snack. During a 10-second practice round, if the child reaches for the snack prior to the time being up, he/she is prompted to wait before he/she can have the snack (the assessor holds the cup down if necessary to ensure that the child does not take the snack until the 10-second wait is complete). Following this practice, the assessor administers three scored trials, which last 10-, 20-, and 30-seconds, respectively. The assessor scores each trial using a four point rating (1 = Eats M&M, 2 = Touches M&M, 3 = Touches cup or timer, 4 = Waits for “Time” and does not touch cup or timer), using the lowest applicable score possible. The mean score across four trials served as one dependent variable ($N = 748$; $M = 3.8$; $SD = 0.4$; Range 1–4). In addition, the assessor recorded whether the child kept his/her hands flat on the table while waiting. The mean proportion of trials in which hands were kept flat provided an additional source of variation among children who waited the entire time ($N = 755$; $M = 0.8$; $SD = 0.3$; Range 0–1). Both sets of scores were used to index hot regulation.

In the Tongue Task, children are told they are going to play a game to see “who can hold a candy (e.g., M&M) on their tongue the longest without chewing it, sucking it, or swallowing it.” In a 10-second teaching trial, the assessor and the child each place a piece of candy on their tongues, leaving their mouths open. The assessor watches the child and prompts him/her to keep his mouth open if it closes for three seconds or more. If the child waits for the full length of the trial, the assessor tells the child that s/he wins the game. The point of the practice is only to demonstrate the game, not to provide feedback to children who eat the candy early. Following the 10-second teaching trial, a 40-second test trial is administered.

The number of seconds that the child waited before eating the candy was used to index hot regulation ($N = 738$; $M = 37.4$; $SD = 7.8$; Range 0–40).

Behavioral Outcome—IOWA Conners Rating Scale—(Loney & Milich, 1982). The IOWA Conners is a 10-item rating scale completed by teachers and that was used to measure HIA and oppositional defiant behaviors. Each item is rated on a 4-point Likert scale (0 = not at all, 1 = just a little, 2 = pretty much, 3 = very much). The 10 items yield two, 5-item subscales including Inattention/Overactivity (I/O) and Oppositional/Defiance (O/D). The predictive and criterion validity for I/O and O/D subscales is well established (Atkins, Pelham, & Licht, 1989; Johnston & Pelham, 1986; Waschbusch & Willoughby, 2008). The internal consistencies for I/O and O/D scales in this sample were $\alpha = .80$ and $\alpha = .87$, respectively.

Behavioral Outcome—Types of Aggression Rating Scale—(Kupersmidt, Bryant, & Willoughby, 2000; Murphy et al., 2006). The TOA is a 12-item rating scale completed by teachers and that was used to measure aggression. Each item is rated on a 5-point Likert scale (1 = Once a month or less; 2 = Once a week; 3 = 2–4 times a week; 4 = Once a day; 5 = Many times a day). The 12 items yield two, 6-item subscales of overt (e.g., hits or kicks others) and covert (e.g., does sneaky things) aggression, as well as an overall aggression score that was used in the current study. This measure has been demonstrated to exhibit acceptable test–retest and inter-rater reliability, as well as demonstrated criterion validity for general measures of conduct problems, hyperactivity, and adult and peer conflict in the classroom setting (Willoughby, Kupersmidt, & Bryant, 2001). The internal consistency of the total aggression score in the sample was good ($\alpha = .91$).

Cognitive Outcome—Woodcock-Johnson III: Tests of Achievement—(WJ-III; Woodcock, McGrew, & Mather, 2001). Three subtests of the WJIII tests of achievement were administered: Letter-Word Identification, Applied Problems, and Sound Awareness (Rhyming). The Letter-Word Identification subtest is a measure of the child's ability to identify letters and words. The Applied Problems subtest assesses the child's mathematical skills. The Sound Awareness (Rhyming) subtest assesses phonological awareness. The rhyming section has some initial items that require a pointing response. Later items require an examinee to provide a word that rhymes with a stimulus word. Split-half reliabilities for Letter-Word, Applied Problems, and Rhyming subtests for 4-year old children were reported .97, .94, and .71, respectively (Woodcock et al., 2001).

Analytic Strategy

All of the motivating questions were answered using structural equation modeling (SEM) methods. SEMs were fit using *Mplus* version 5.2 (Muthén & Muthén, 1998–2008). All models utilized the cluster option in *Mplus*, which implements sandwich variance estimates, in order to accommodate the non-independence of observations due to the fact that children were nested in classrooms (Muthén & Satorra, 1995). SEM models used a robust full information maximum likelihood (rFIML) estimator. The rFIML estimator accommodated the non-normality of latent variable indicators and behavioral outcomes and is an empirically supported best practice for handling missing data (Satorra & Bentler, 2001;

Schafer & Graham, 2002). To be clear, rFIML methods do not impute scores when they are missing. Rather, each case contributes as much information as is available (via an individual likelihood) to estimate model parameters. Functionally, this means that children who did not participate in self-regulation assessments (i.e., $N = 167$) could still contribute to analyses by virtue of their having non-missing data on other variables (e.g., demographic covariates; achievement). We elected to report the number of observations that contributed to each analysis in lieu of restricting analyses to complete cases, which has the potential to introduce bias in parameter estimates. Given the dependency of the likelihood ratio test statistic on sample size (MacCallum, 1990), model fit was primarily evaluated using a combination of absolute (standardized root mean residual, SRMR; Root mean squared error of approximation, RMSEA) and comparative (comparative fit index, CFI) fit indices. Following Hu and Bentler (1999), good fitting models were defined as having the SRMR $\leq .08$, CFI $\geq .95$, and RMSEA $\leq .05$.

The first research question was evaluated using confirmatory factor analysis (CFA). One- and two-factor models were fit to the four self-regulatory tasks. The one-factor model posited that self-regulatory tasks were best conceptualized as unitary; the two-factor model posited that self-regulatory tasks were best conceptualized as cohering to dissociable but correlated hot and cool dimensions. A likelihood ratio difference test was used to evaluate which model provided a better fit to the data, including the adjustments developed by Satorra and Bentler (1999, 2001) given our use of the robust maximum likelihood estimator. The second research question was evaluated using a SEM in which teacher rated disruptive behavior and child academic achievement scores were regressed on hot and cool latent variables, as well as covariates (child gender and age; child care setting of Head Start or Community Child Care).

RESULTS

Descriptive Statistics for Indicators of Hot and Cool Regulation

Bivariate correlations, as well as means and standard deviations, for all of the observed variables included in structural equation models are summarized in Table 1. In general, the sample exhibited academic achievement generally consistent with that expected by normative data (WJ Letter-Word $M = 104.7$; WJ Applied Problems $M = 97.7$). Mean scores for the Snack Delay and Tongue (hot) tasks indicated that most children did quite well on these tasks. Mean scores on teacher behavior ratings indicated that most children exhibited low levels of disruptive behavior. Child performance on self-regulatory tasks exhibited positive, albeit modest, correlations (r s range .05–.63 with most in the .1–.2 range). In general, self-regulatory tasks were more strongly correlated with child academic outcomes than they were with teacher-rated behavioral outcomes.

Factor Structure of Self-Regulatory Tasks

Data were available for 759 children who completed one or more self-regulatory tasks. A one-factor CFA model fit the data poorly, $\chi^2(5) = 51.0$, $p < .0001$, CFI = .88, RMSEA = .11, SRMR = .05. In contrast, a two-factor CFA model fit the data well, $\chi^2(3) = 7.5$, $p = .058$, CFI = .99, RMSEA = .04, SRMR = .01. A likelihood ratio difference test confirmed

that the two-factor model fit better than the one-factor model, $\chi^2(1) = 56.5, p < .0001$. Inspection of parameter estimates from the two-factor model indicated that (1) all of the factor loadings were statistically significant and in the expected direction, (2) both of the latent variances were statistically significant, and (3) the delay of gratification (hot) and inhibitory control (cool) latent variables were positively correlated ($\phi = .47, p < .001$). A synopsis of standardized parameter estimates is provided in Figure 1. Standardized factor loadings indicated that the pencil tapping task made a stronger contribution to the (cool) inhibitory control latent variable than did the balance beam task and that the snack delay indicators made a stronger contribution to the (hot) delay of gratification latent variable than did the tongue task. The differential contribution of individual tasks to their respective latent variables was not problematic. In fact, using latent variables to represent individual differences in hot and cool regulation guarded against problems that may have arose had we relied exclusively on manifest scores to test our motivating questions. These results supported our first hypothesis and are consistent with numerous other studies that have demonstrated that the hot and cool dimensions of inhibitory control are best conceptualized as separate but correlated factors.

Bivariate Correlations between Latent Variables and Outcomes

Prior to estimating models that included directional relations from the hot and cool latent variables to child outcomes, we estimated a model in which these latent variables were intercorrelated with each child outcome. This model fit the data well, $\chi^2(21; N = 898) = 36.4, p = .02$, CFI = .99, RMSEA = .03, SRMR = .02. Cool and hot latent variables were both significantly correlated with every child outcome—including inattention-overactivity ($\phi = -0.23$ and $\phi = -.28, ps < .001$, for cool and hot, respectively), oppositional defiance ($\phi = 0.13, p = .02$ and $\phi = -.15, p = .003$, respectively), aggression ($\phi = -0.11, p = .049$ and $\phi = -.13, p = .02$, respectively), rhyming ($\phi = 0.58$ and $\phi = .26, ps < .001$, respectively), letter-word ($\phi = 0.42$ and $\phi = .27, ps < .001$, respectively), and applied problems ($\phi = 0.55$ and $\phi = .29, ps < .001$, respectively).

Two points are noteworthy. First, despite children's especially strong performance on the regulatory tasks that indexed hot regulation (snack delay, tongue time), individual differences in hot regulation were significantly correlated with all six outcomes. This indicated that restriction of range in scores could not account for a lack of significant unique associations. Second, consistent with hypotheses, children's performance on hot and cool tasks appeared to be equally related to disruptive behaviors, while their performance on cool tasks appeared to be more strongly related performance on academic tasks. To test these observations, the model was re-estimated constraining the correlations between hot and cool latent variables with each of the behavioral indicators to be equal. This model continued to fit the data well, $\chi^2(24; N = 898) = 35.7, p = .06$, CFI = .99, RMSEA = .02, SRMR = .02. A likelihood ratio difference test confirmed that equating the association between hot and cool factors with behavioral outcomes in no way degraded model fit, $\chi^2(3) = 0.4, p = .93$. The model was re-estimated a second time imposing the association between hot and cool latent variables with each of the academic achievement variables to be equal. This model continued to fit the data reasonably well, $\chi^2(27; N = 898) = 62.8, p < .0001$, CFI = .98, RMSEA = .04, SRMR = .03. However, a likelihood ratio difference test confirmed that

equating the association between hot and cool factors with achievement outcomes resulted in a statistically significant worse fitting model— $\chi^2(3) = 25.3, p < .0001$ —indicating that achievement scores were more strongly correlated with cool than hot regulation.

Unique Associations Between Self-Regulatory Tasks and Behavioral and Academic Outcomes

None of the above results tested the unique contribution of hot and cool regulation to child behavior and achievement outcomes. A SEM, in which teacher rated behavior and achievement tasks were regressed on hot and cool latent variables including covariates (child age, gender, Head Start), was estimated to answer the second research question (see Figure 2). Factor loadings for hot and cool tasks were freely estimated and latent variances for both latent variables were fixed to 1. As such, unstandardized regression coefficients represented the change in outcomes that were associated with a one-standard deviation unit increase in the latent variable(s). This was particularly useful for some of the academic outcomes that had a meaningful metric (i.e., standard scores). Unstandardized coefficients were reported in the text, while standardized coefficients were reported in tables.

The SEM fit the data well, $\chi^2(30; N = 926) = 40.5, p = .09$, CFI = .99, RMSEA = .02, SRMR = .02. The hot ($b = -.14, p = .013$) but not cool ($b = -.08, p = .14$) latent variable was uniquely associated with inattentive-overactive behaviors. Neither latent variable was uniquely predictive of oppositional-defiant ($b_{hot} = -.07, p = .20$; $b_{cool} = -.05, p = .35$) or aggressive ($b_{hot} = -.08, p = .23$; $b_{cool} = -.05, p = .47$) behaviors. Hot and cool latent variables, along with child and center covariates, explained very modest amounts of variation in behavioral outcomes (R^2 from .05–.13). In contrast to behavioral outcomes, the cool (but not hot) latent variable was uniquely and positively associated with Woodcock-Johnson Rhyming ($b_{cool} = 1.9, p < .001$; $b_{hot} = -.01, p = .45$), Letter-Word ($b_{cool} = 6.7, p < .001$; $b_{hot} = 1.0, p = .37$), and Applied Problems ($b_{cool} = 8.6, p < .001$; $b_{hot} = 0.3, p = .77$) scores. Cool and hot latent variables jointly explained between one fourth and nearly one half of the observed variation in academic outcomes (R^2 from .25–.44). Standardized regression coefficients and R^2 for all outcomes are summarized in Table 2.

DISCUSSION

The primary goal of this study was to test whether preschool children's performance on self-regulatory tasks could be distinguished into hot and cool components, as well as whether individual differences in hot and cool regulation were differentially associated with individual differences in behavioral and academic functioning. Results supported the hypothesis that preschool children's performance on self-regulatory tasks was better represented using a two-factor (hot vs. cool) than single-factor (undifferentiated) model. Children's performance on hot and cool tasks was moderately and positively correlated ($\phi = .47$). Our results are consistent with those of Brock et al. (2009), who independently asked the same question using identical indicators of cool but not hot regulation and reported a latent correlation between hot and cool factors of $\phi = .50$.

Individual differences in children's performance on hot and cool tasks were negatively correlated with inattentive-overactive, oppositional-defiant, and aggressive behaviors.

Although the bivariate associations between hot and cool regulation with behavior were equivalent, when considered simultaneously, only hot regulation was uniquely associated with inattentive-overactive behavior. This result is counter to previous studies that demonstrated that both cool (executive function) and hot (delay aversion) regulation make unique contributions to ADHD behaviors. One explanation for this discrepancy involves the relatively brief assessment of inattentive-overactive behaviors in this study (five items from the IOWA Conners rating scale) compared to the more elaborate assessment of ADHD behaviors in previous studies (e.g., 18 items from the ADHD checklist). In addition to better reliability, more elaborate assessments of HIA behaviors would facilitate tests of whether the association between cool regulation and inattentive-overactive behaviors is specific to inattentive versus hyperactive-impulsive behaviors (Wahlstedt et al., 2009). Despite significant bivariate associations, neither hot nor cool regulation was uniquely related to oppositional-defiant or aggressive behaviors. One explanation for this finding is that the bivariate associations between hot and cool regulation variables with oppositional and aggressive behaviors, reflected common (overlapping) variation that was shared between hot and cool regulation.

In contrast to behavioral outcomes, only cool regulation was uniquely related to children's performance on academic achievement tasks. These results are consistent with Thorell (2007) and Brock et al. (2009) who also found cool regulation to be uniquely associated with academic functioning. Moreover, it provides indirect support for the previously drawn conclusions regarding the role of cool regulation and academic performance in studies that did not include measures of hot regulation (Blair & Razza, 2007; Espy et al., 2004; McClelland et al., 2007).

Throughout this article, we have been intentionally general in our discussion of "self-regulation." Most of the research in this area is more precisely described as falling under the rubrics of Effortful Control (EC), Executive Function (EF), or Executive Attention (EA). Although the cognitive processes that are implicated by EC, EF, and EA are highly overlapping, these constructs are typically studied by researchers who come from different disciplines, with corresponding differences in language (jargon) and measurement preferences. These differences in language and measurement complicate the ability to talk uniformly about research in EC, EF, and EA. It is our supposition that hot and cool aspects of self-regulation span EC, EF, and EA literatures and methods. Hence, although research on EC has often emphasized the volitional control of behavior under conditions involving reward (Kochanska, Murray, & Harlan, 2000; Murray & Kochanska, 2002), while research on EF and EA has often emphasized the ability to detect and resolve conflict in what are typically affectively neutral conditions (e.g., Diamond, Kirkham, & Amso, 2002; Durston et al., 2002; Welsh et al., 1991), it would be erroneous to assume that EC is always synonymous with "hot" regulation or that EF/EA is always synonymous with "cool" regulation. Rather, the constructs of hot and cool regulation are broader than the more narrowly defined dimensions of EC, EF, or EA. Posner and colleagues' description of how the Anterior Cingulate Cortex, a structure involved in the resolution of conflict, is differentially involved in the regulation of both emotional (hot) and cognitive (cool) information emphasizes this point (Bush et al., 2000).

This study has added to a growing literature that has documented the benefits of differentiating children's performance on direct assessments of self regulation into hot and cool domains. Others have emphasized an alternative partitioning of children's performance on self regulatory tasks as a function of whether the task involves the resolution of conflict versus tolerating a delay (Carlson & Moses, 2001; Murray & Kochanska, 2002). From our vantage, the hot-cool distinction highly overlaps with the delay-conflict distinction. However, the former has been more clearly linked to neural substrates. Children's performance on hot and cool tasks may facilitate inferences, albeit indirect, about the structural and functional integrity of OFC and DL-PFC substrates, respectively. For developmental and behavioral scientists whose primary interest involves the role of self regulation as it related to social, behavioral, and academic functioning, we believe that the hot-cool distinction may serve as a better heuristic than the conflict-delay distinction; however, either perspective is preferable to the still common view of self regulation as an undifferentiated process that relies on an exclusive top-down organization from the PFC.

This study suffered from at least five limitations. First, all of the associations reported in this study were based on cross-sectional data. Although models imposed directional associations going from regulatory task performance to behavior and academic performance, the cross-sectional design does not permit any inferences regarding the true directional (causal) associations between the constructs under study. Second, the sample consisted of a large convenience sample of primarily low income children. It is unclear whether these results would generalize to broader populations of young children. Third, although the sole unique association between hot regulation and child functioning was with inattentive-overactive behaviors (and the magnitude of this association was modest), it would be inappropriate to conclude that hot regulation is somehow less important than cool regulation in early childhood. The current dataset did not include the types of measures that may be more ecologically relevant to hot processes (e.g., managing behavior following peer conflict in a playground setting; completion of academic task that is perceived as too difficult and that evokes frustration). Fourth, individual differences in hot and cool regulation were measured using child performance on four tasks. Future studies would benefit from the inclusion of a greater number of indicators of hot and cool functioning. Fifth, developmental researchers have typically characterized tasks that involve a delay component as indexing hot regulation. However, it is important to point out that children's poor performance on delay tasks may represent either an inability (potentially reflecting cognitive dysfunction) or an unwillingness (potentially reflecting motivational dysfunction) to exert delay-related behaviors (see, e.g., Reynolds & Schiffbauer, 2005). To the extent that children who perform poorly on hot regulatory tasks do so for different reasons (cognitive vs. motivational processes), associations between hot regulation and behavioral and achievement-related outcomes may be confounded.

One potential direction for future research involves considering the potentially differential enhancement of hot and cool aspects of self-regulation. Although there is an emerging experimental literature demonstrating that children's regulatory capacities can be improved, most of this work has focused on children's performance on cool regulatory tasks (Diamond, Barnett, Thomas, & Munro, 2007; Klingberg et al., 2005; Rueda et al., 2005). It is unclear to what extent these existing curricula have comparable effects on hot regulatory functioning.

Beyond existing curricula, it would be informative to delineate the specific everyday experiences and strategies in the lives of young children that might differentially contribute to individual differences in hot versus cool regulatory processes.

In conclusion, this study adds to a growing literature indicating that children's performance on hot and cool self-regulatory tasks is dissociable. This is consistent with the idea that different neural substrates and associated cognitive functions underlie performance on these tasks. Performance on cool regulatory tasks was uniquely associated with academic achievement, while performance on hot regulatory tasks was uniquely associated with inattentive-overactive behaviors. Collectively, these results emphasize that self-regulation is not a unitary phenomenon. Distinguishing hot and cool components may serve as an important organizing function for social and behavioral researchers whose primary interest involves behavioral and academic development in early childhood but who would also like to ensure that their work is at least consistent with a growing neuro-scientific literature of regulatory processes.

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FIGURE 1.
Confirmatory factor analysis supporting hot and cool latent factors.

FIGURE 2.
Structural equation model hot and cool latent factors.

TABLE 1

Bivariate Correlations and Descriptive Statistics

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1. Pencil Tapping	—													
2. Walk Line	.25	—												
3. SD-Wait	.25	.12	—											
4. SD-Hand	.24	.04	.63	—										
5. Tongue Time	.17	.05	.31	.23	—									
6. IOWA-I/O	-.17	-.08	-.18	-.22	-.08	—								
7. IOWA-O/D	-.08	-.03	-.10	-.11	-.03	.62	—							
8. TOA-Aggression	-.07	-.07	-.07	-.11	-.07	.55	.68	—						
9. WJ-Rhyme	.42	.21	.15	.13	.18	-.14	-.04	-.07	—					
10. WJ-Letter Word	.31	.13	.19	.16	.09	-.10	-.03	-.03	.33	—				
11. WJ-Appl Prob	.39	.20	.18	.16	.17	-.14	-.03	-.04	.38	.49	—			
12. Male	-.09	-.04	-.08	-.09	-.04	.22	.21	.15	-.10	-.09	-.07	—		
13. Head Start	-.08	-.04	-.03	-.07	.01	-.04	-.08	-.11	-.06	-.13	-.33	-.05	—	
14. Age	.26	.12	.11	.11	.12	-.08	.00	-.03	.21	-.08	-.09	.01	.14	—
Mean	9.2	4.4	3.8	0.8	37.3	1.0	0.6	1.7	2.5	104.8	97.8	0.5	0.5	4.6
Standard Deviation	4.9	5.3	0.4	0.3	7.8	0.7	0.7	0.8	3.2	14.4	14.0	0.5	0.5	0.4

N = 926; Variables 1–5 are indicators of cool (1–2) and hot (3–5) self-regulation; estimates are from the robust full information maximum likelihood estimator; correlations .065 are significant at *p* .05. I/O = IOWA Conners Inattentive-Overactive scale; O/D = IOWA Conners Oppositional-Defiant scale; SD = Snack Delay; TOA = Types of Aggression scale; WJ = Woodcock-Johnson.

TABLE 2

Predicting Teacher-Rated Disruptive Behavior and Academic Achievement from Cool (Inhibitory Control) and Hot (Delay of Gratification) Latent Variables (Standardized Coefficients)

	I/O	O/D	TOA	WJ-RY	WJ-LW	WJ-AP
Cool	-.11	-.07	-.07	.60***	.47***	.61***
Hot	-.21*	-.10	-.10	-.05	.07	.02
Age	.00	.06	.03	.00	-.25***	-.29***
Male	.18***	.19***	.12**	-.03	-.03	-.00
Head Start	-.05	-.09	-.12*	.00	-.05	-.23***
R ²	.13	.07	.05	.34	.25	.44

N = 927;

* p < .05,

** p < .01,

*** p < .001;

IC = Inhibitory Control; DG = Delay of Gratification; I/O = Iowa Conners Inattentive-Overactive scale; O/D = Iowa Conners Oppositional-Defiant scale; TOA = Type of Aggression scale; WJ = Woodcock Johnson; RY = Rhyming; LW = Letter-Word; AP = Applied Problems.