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Exploring the Relationship Between Emotion Regulation and Executive Functions in Children

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Abstract

The present research addresses how emotion regulation and executive functions may be related in 7- and 8-year-old children, allowing us to probe the question of whether these two constructs may have shared, rather than specialized, cognitive underpinnings. To do this, we explored whether specific temperamental traits (i.e. internalizing and externalizing) relate to different types of cognitive control (i.e. inhibitory and proactive control) through individual differences. Temperament was measured through a parent-report survey and inhibitory and proactive control were measured through two cognitive tasks standardly used for measuring those constructs, the Antisaccade task and the AX-continuous performance task (respectively). We did not find evidence that specific externalizing and internalizing temperamental traits reliably predict cognitive control. In post hoc analyses, we found that a combined measure of externalizing and internalizing measures (i.e. Total Problem Behavior) significantly predicted worse inhibitory control, while controlling for age and gender, suggesting that worse emotion regulation is related to worse inhibitory control. From these results, we were able to conclude that there may indeed be shared cognitive mechanisms between emotion regulation and certain executive functions, such as inhibitory control, though we cannot make any specific claims about what those mechanisms may be, given that emotion regulation does not appear to be related to proactive control.

Keywords: Temperament, Emotion Regulation, Executive Functions

Exploring the Relationship Between Emotion Regulation and Executive Functions in Children

Starting at a young age, children must learn how to react appropriately when a toy is taken from them, when a parent or teacher scolds them, or when an art project they are working on does not turn out well. As children develop, they are better able to control both their emotions and their actions related to their emotions – i.e. self-regulate. But self-regulation is also needed for many other contexts outside of controlling one's emotions: we must regulate behavior when problem solving, navigating social interactions, and maintaining attention. Adequate development of both emotional and cognitive regulation is important for advantageous functioning and favorable developmental outcomes such as health, wealth, and academic success (Moffitt et al., 2011). It is unclear, however, whether the cognitive mechanisms that support these varied domains of emotional and executive self-regulation are specialized or recruited from a common source. The present research aims to investigate whether there is a shared relationship between the mechanisms that underlie both emotional and cognitive self-regulation by looking at how measures of each co-vary on an individual basis.

The manner in which children regulate their emotions and their resulting behaviors is known as emotion regulation (ER) and it is often explored by looking at temperaments, or the individual differences in how children react to their environments (Rothbart, Ellis, Rueda, & Posner, 2003). There are two dimensions of temperament made up of either primarily *externalizing* or primarily *internalizing* behaviors (Murray & Kochanska, 2002). A child is said to have an externalizing temperament if they tend to express their emotions outwardly (Eisenberg et al., 2001). This may appear in the form of aggression, defiance, impulsivity, or hyperactivity. Alternatively, a child is said to have an internalizing temperament if they tend to direct their emotions inwardly, often in the form of depression, anxiety, or somatic symptoms (Eisenberg et al., 2001). Temperament, by definition, refers to individual differences in emotional-reactivity and self-regulation, so it is often used as a proxy to measure ER and the underlying cognitive mechanisms that help regulate emotions (Eisenberg, Spinrad, & Eggum, 2010). A variety of work, ranging from similar developmental trajectories to positive correlations in ability on an individual basis, suggests a positive relationship between measures of ER, such as temperament, and broader measures of cognitive regulation.

As children develop better ER, they simultaneously develop a better ability to regulate their goal-oriented behavior. For example, if a five-year-old child is given two dollars for allowance, he or she may immediately spend it on candy because it is something they want at the present moment. However, a ten-year-old child who is given two dollars for allowance is much more likely to save that money for a more expensive toy that he or she wants to buy in the future. The higher-order cognitive processes that regulate our actions in favor of larger goal-directed behaviors are known as executive functions (EF). EF progressively develops throughout childhood (Schoemaker, Mulder, Deković, & Matthys, 2013) and encompasses several other cognitive processes including the ability to make plans, pay attention, and exercise inhibitory control (Chatham et al., 2012; Munakata et al., 2011).

Previous research has found indirect evidence of a relationship between inhibitory control (IC), the suppression of a prepotent response coupled with a replacement behavior (Chevalier, Chatham, & Munakata, 2014), and ER. Deficits in both IC and ER are core components of several mental disorders, such as attention-deficit hyperactivity disorder (ADHD), mood disorders, antisocial behavior, schizophrenia, and obsessive-compulsive disorder (OCD)

(Carlson & Wang, 2007; Nigg, 2000). Additionally, ER and EF show similar developmental trajectories, both beginning to emerge during early preschool years (Carlson & Wang, 2007).

Previous research has also found evidence of more direct links between ER and EF. One study in which preschool aged children completed both inhibitory control and emotional regulation tasks found that the higher children scored on measures of inhibitory control, the higher they tended to score on measures of emotion regulation (Carlson & Wang, 2007). Measures of IC all required the suppression of a dominant response and included three distinct cognitive tasks: 1) Simon Says, which assessed whether children stopped mimicking an action on trials where the project runner did not preface an instruction with “Simon says”, 2) Forbidden Toy, which assessed whether children were able to refrain from playing with a cool toy while alone in a room, and 3) Gift Delay, which assessed a child’s ability to suppress the urge to sneak a peak at a gift as it was being wrapped for them. Emotion regulation was also assessed through three tasks: 1) Secret Keeping, which assessed children’s’ ability to suppress positive emotions, 2) Disappointing Gift, which assessed children’s’ ability to suppress negative emotions, and 3) Emotion Understanding, which assessed how well each participant could infer others’ emotions given a hypothetical story. Children that were better at inhibiting their actions tended to also be better at regulating their emotions. The results of this study suggest that individual differences in emotion regulation are significantly correlated with inhibitory control and may be an indicator of shared cognitive mechanisms between these two processes.

Further research provides evidence not only for a general correlation between temperament and IC, but for specific opposing relationships between the dimensions of temperament and performance on inhibition measures (Murray & Kochanska, 2002). Specifically, children who engage in externalizing behaviors tend to perform worse on measures of IC, while those who engage in internalizing behaviors tend to perform better on these same measures. In a sample of 103 neurotypical preschool children, those with lower cognitive abilities, including inhibitory control, tended to have more externalizing problems, while those with higher cognitive abilities tended to have more internalizing problems (Murray & Kochanska, 2002). A meta-analysis of twenty-two studies including 4021 children found that those who were better able to inhibit automatic reactions also tended to engage in fewer externalizing behaviors, and those who were worse at inhibiting automatic responses tended to have more externalizing symptoms (Schoemaker, Mulder, Deković, & Matthys, 2013). Moreover, in a study of 108 children, those who had the early internalizing trait of being more hesitant when engaging in new environments (also known as inhibition to novelty) performed better on IC tasks compared to children who did not express this trait (Aksan & Kochanska, 2004). Those who had the internalizing trait were also slower to respond to stimuli in laboratory tasks requiring cognitive control, specifically inhibition. The researchers suggest that inhibition to novelty, and possibly other internalizing traits, may facilitate a capacity for better IC due to the slower speed of approach to the task. These opposing relationships between externalizing versus internalizing temperaments and inhibitory control provide further evidence to suggest that there may be shared cognitive mechanisms between ER and EF.

While prior research has focused on relating inhibitory control to emotion regulation and temperament, there is little additional work demonstrating whether this relationship holds between ER and other EF constructs. Consider the Dual-Mechanisms of Control (DMC) framework, which proposes that there are two distinct but complementary modes of control within the domain of executive function: proactive and reactive control (Braver, 2012). Proactive control is the active maintenance of goal-related information that relies on anticipation of an upcoming event requiring a response (Burgess & Braver, 2012). Reactive control, comparatively, is recruited on an as-needed basis and relies on response to an event after its onset (Burgess & Braver, 2010). A person who is behaving proactively might check that they have all the ingredients for a recipe, before beginning to prepare a meal, while a person behaving reactively might have to run to the store in the middle of cooking to purchase an ingredient they did not have at home.

Variability of use between the two mechanisms is intrinsic within the DMC framework. Specifically, there are three levels of variation: intra-individual, inter-individual, and between group differences. Intra-individual variation (variation within a single person) may occur based on the cognitive task. That is, the same person may switch from reactive to proactive control when performing different cognitive tasks, or even between subtle differences within the same task. People are more likely to use reactive control when performing more cognitively demanding tasks, while people tend to be better able to use proactive control on less cognitively demanding tasks (Braver, 2012). Inter-individual differences (variation between persons), such as working memory capacity and intelligence, may also affect which cognitive control strategy is recruited while performing tasks that demand high levels of cognitive control. Individuals may vary in what tasks they use based on inherent traits; for example, individuals with higher fluid intelligence tend to utilize proactive control when performing a battery of tasks involving inhibitory control, while individuals with low fluid intelligence tend to use reactive control (Burgess & Braver, 2010). Lastly, the preferred method of cognitive control may vary between groups, such as in clinical and developing populations. The DMC framework proposes that clinical populations might primarily employ reactive control whereas normally developed populations might primarily employ proactive control. The variance in cognitive control models has been observed in a variety of populations, including children (Chatham, Frank, & Munakata, 2009), people with schizophrenia (Barch et al., 2001), and people with ADHD (Burgess et al., 2010). Because people with more externalizing temperaments and people who primarily employ a reactive control strategy have both been shown to have lower response inhibition, there is reason to suspect that reactive cognitive control may co-occur with externalizing symptoms on an individual basis. Similarly, people with internalizing temperaments and people who are primarily proactive are both separately linked with better response inhibition, giving further reason to suspect that these variations may reflect common underlying cognitive mechanisms between ER and EF.

The current project aims to explore the relationship between the Dual-Mechanisms of Control framework and temperament, as a measure of ER, within an unselected population thereby testing the relationship between ER and EF with a novel EF construct. Specifically, the present study will investigate whether externalizing and internalizing traits co-vary with reactive and proactive control, respectively. For the purposes of this study, we are most interested in the inter-individual differences in cognitive control that may vary based on temperament in children. We predict that participants who score higher on measures of externalizing behavior will also be more likely to engage in a reactive control strategy when exerting cognitive control because low EF ability has been related to both externalizing behaviors and reactive control. We also predict that those who score higher on measures of internalizing symptoms will be more likely to employ a proactive control strategy during cognitive tasks because high EF ability has been linked to both internalizing behaviors and proactive control. Additionally, we will test the replicability of these prior findings on temperament and inhibition (Eisenberg et al., 2001; Murray & Kochanska, 2002). If measures of individuals' temperament and model of cognitive control are indeed related, it may be an indicator of shared, rather than specialized, mechanisms between these regulatory constructs. This relationship could provide further understanding of how emotion the cognitive deficits observed in clinical and developing populations and perhaps inform future interventions.

Method

Participants

Forty-three 7 and 8-year-olds participated in the study (Mean age = 8.23 years old; range = 7.15 – 8.95 years old; males = 21). This number is excluding four children dropped for not completing the tasks or parents not completing the questionnaire assessing temperament. This age group was selected for the current study because according to previous research, normally developing children at this age should all be capable of engaging in proactive cognitive control but still demonstrate a range of proactive abilities (Munakata, Snyder, & Chatham, 2012). All participants were recruited from a laboratory subject pool that included residents of Boulder, Colorado and the surrounding areas. Informed consent was obtained from all parents and informed assent was obtained from all child participants. All parents and participants were notified that they were able to withdraw their consent or assent at any point during the session. Participants received a small prize and a book regardless of completion, and parents were compensated five dollars for travel expenses.

Procedure

The data used for this study was collected over the course of a larger individual differences study that involved a questionnaire and four cognitive tasks. However, only the questionnaire and the two tasks relevant to the present study are described below. After obtaining written parental consent and written and verbal assent from each participant, all participants were taken to the same standard laboratory room. Participants completed four lab tasks in the same order, while parents were asked to fill out the questionnaire. After the completion of the first two tasks used for the present study, participants were required to take a three - five minute break, in addition to having the option to take short breaks between each individual task. After all four tasks were completed participants were allowed to pick a small prize and a book. Parents were debriefed with more information about the tasks their child completed and received five dollars compensation for travel expense.

Measures

Strengths and Difficulties Questionnaire (SDQ). The parent-report version of the Strengths and Difficulties Questionnaire (Muris, Meesters, & Berg, 2003) was used to measure individual differences in temperament. The SDQ is made up of 25 items, commonly divided equally into five subscales: emotional problems, conduct problems, hyperactivity-inattention, peer problems, and prosocial behavior (Muris, Meesters, & Berg, 2003). A sixth subscale is also commonly calculated for total problem behaviors, which is made up by summing the scores of the emotional problems, conduct problems, hyperactivity-inattention, and peer problems subscores.

For the purposes of this study, these sub-scores were differentiated into three alternative factors, including the two dimensions of temperament: externalizing problems, internalizing problems, and prosocial problems. This three-factor method of scoring has been validated as a more stable model of scoring within American populations when considering the latent dimensions of temperament that underlie responses. A structural analysis including representative samples of American and European parents determined that, due to cultural differences, American and European parents may conceptualize and respond to items on the questionnaire differently, specifically regarding conduct and peer problems (Dickey & Blumberg, 2004). This may lead to an inability to compare results when scoring on a five-factor model, though the total problem behavior score should not be affected. Within this three-factor model, the hyperactivity-inattention and conduct problem scales relate to the externalizing subscale, the emotional and peer problem scales relate to the internalizing subscale, and the prosocial behavior scale relates to the prosocial subscale. Each question on the survey is worth between zero and two points and responses are summed to produce scores between zero and twenty for the externalizing and internalizing subscales, and between zero and ten for the prosocial subscale, with higher scores indicating greater prevalence of those respective traits.

AX - Continuous Performance Task (AX-CPT). The AX-CPT was used to assess rates of proactive control based on relative error rates to different trial conditions (Chatham et al., 2009). Participants were presented with a series of stimuli containing target trials and non-target trials. Participants were instructed to respond to target trials by pressing the left button, and non-target trials by pressing the right button (or vice versa). A target trial consisted of the ‘A’ cue followed by the ‘X’ probe. Non-target trials consisted of a valid cue followed by an invalid probe (‘AY’), an invalid cue followed by a valid probe (‘BX’), or an invalid cue followed by an invalid probe (‘BY’). Performance was assessed based on accuracy and reaction time. Performance on this task determines individual rates of proactivity and reactivity based on the types of errors made during the task. For example, it is inferred that a participant is principally engaging in proactive control if they error on more ‘AY’ trials, relative to ‘BX’ trials, as they are prematurely anticipating a target trial based on the 'A' probe. Similarly, it can be expected that participants who error on more 'BX' trials, relative to 'AY' trials, are engaging in reactive control, as they are reactively responding to the valid 'X' probe. Errors involving 'BY' trials can be attributed to inattention and/or misinterpretation of the task because neither the 'B' cue, nor the 'X' probe indicates a target trial. Similarly, if a child incorrectly responds to an 'AX' trial as a non-target trial, it is also attributed to inattention or misinterpretation of the task.

For the purposes of this study, we used a child-adapted version of the task. The cartoon characters SpongeBob and Blue from Blue's Clue's take the place of the A and B cues, and a watermelon and a slinky replace the X and Y probes, respectively. Subjects were instructed that because SpongeBob likes watermelon, they should press the left button every time a watermelon appears after SpongeBob and press the right button for all other combinations. The pairings were counterbalanced to avoid any possible selection bias. To determine individual rates of proactivity and reactivity, the Proactive Behavioral Index was used to calculate a normalized difference score of accuracy rates between 'AY' and 'BX' trials (i.e., [AY-BX]/[AY+BX]), with higher scores indicating more proactive control and lower scores indicating more reactive control.

Antisaccade Task. The anti-saccade task is commonly used to measure the ability to inhibit prepotent responses, or inhibitory control. Subjects were positioned to sit 60 cm away from a computer monitor and were instructed to focus their attention on a plus-sign in the middle of the screen. A black square appeared on one side of the screen for a variable delay. The black square was followed by a number between 1 and 9 on the opposite side of the plus-sign, then quickly disappeared. The subject was asked to report the number that was presented. Accurate reporting of the number required successful inhibition of the automatic response to fixate on the black square and replacing it with an anti-saccade toward the number. The prepotent response was established when the participants were asked to first complete a set of 10 prosaccade trials, in which the subject simply looks in the same direction of the initial stimulus (the black square), also known as a prosaccade. This is followed by a set of 6 warm up anti-saccade trials and 3 sets of 18 antisaccade test trials, in which the participant is instructed to look in the opposite direction of the initial stimulus. A benefit of this task is its relative simplicity in instruction, making it usable for a variety of samples, including children. Moreover, it is not sensitive to ceiling effects, even for adults, as it is difficult to perform accurately (Roberts, Hager, & Heron, 1994).

Analyses and Results

All analyses were conducted in R studio (RStudio Team, 2015). We first tested correlations between each measure of interest (i.e. temperament, inhibitory control, and proactive control) after which we assessed how age and gender affected each of our measures of interest. In the primary analyses we tested our *a priori* hypotheses. We ran four linear regression models assessing whether dimensions of temperament are able to predict both inhibitory control and proactive control. Based on the results of these models, we conducted *post hoc* analyses utilizing an alternative, combined temperamental measure (i.e. Total Problem Behavior) to assess whether a broader measure of ER might predict inhibitory control and/or proactive control.

Correlations Between Measures of Temperament, Inhibitory Control, and Proactivity.

Spearman two-tailed correlations were conducted for all pairs of the collected measures (see Table 1). We found a significant, negative correlation between measures of externalizing behavior and accuracy on the Antisaccade ($r = -0.36$, $p = 0.01$). This suggests that children that engage in more externalizing behaviors performed worse on the Antisaccade task. All other pair-wise correlations between measures of EF, i.e. AXCPT and Antisaccade, and measures of

ER, i.e. SDQ temperament dimensions, were not significant (see Table 1). However, measures of externalizing behaviors and internalizing behaviors showed a trending relationship (r = 0.27, p = 0.07). Participants who scored higher on the externalizing behavior scale also tended to score higher on the internalizing behavior scale, indicating comorbidity within our sample (see Figure 1).

Table 1. *Correlations Between Measures of Interest*

	Externalizing	*Internalizing*	*Proactivity*
Externalizing			
Internalizing	0.27 (p = .07)		
Proactivity	-0.06 (p = .67)	-0.06 (p = .69)	
Antisaccade	-0.36 (p = .01*)	-0.10 (p = .49)	0.08 (p = .59)

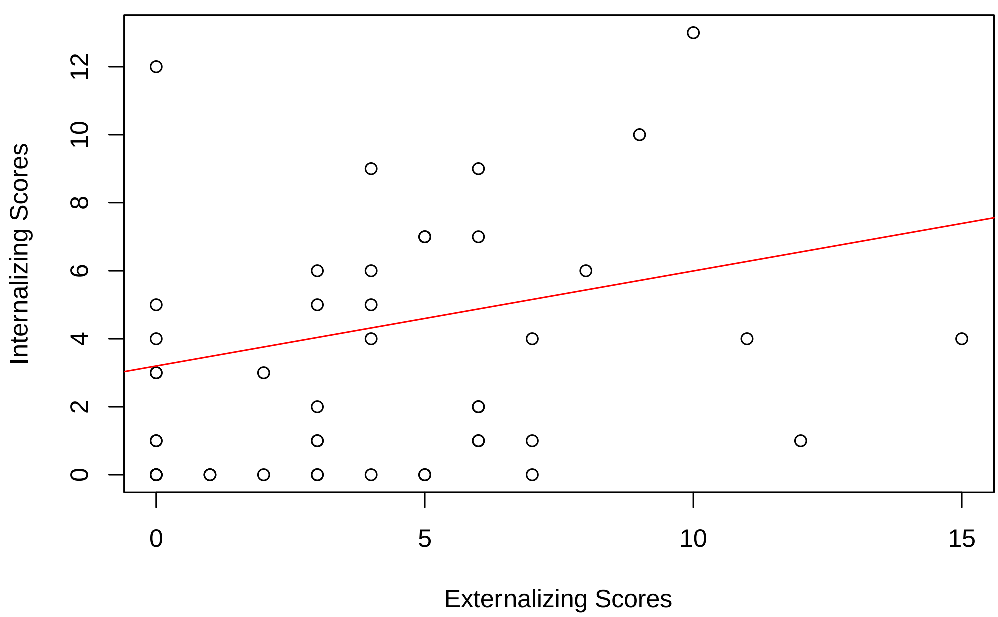

Figure 1: Scatter plot depicting the correlation between externalizing and internalizing scores.

Gender and Age as Covariates Between Temperament, Inhibitory Control, and Proactivity.

Prior to implementing our main analyses, we tested our measures of interest (dimensions of temperament, inhibitory control, and proactive control) for relationships with age and gender to investigate whether these variables should be included as covariates in later models.

Gender effects. We ran a series of linear regression models to assess how gender relates to each respective dimension of temperament as well as our measures of inhibitory and proactive control. We found no significant relationships, which indicates that within our sample, gender is not predictive of an internalizing temperament ($F(1,41) = 0.14$, $p = .71$), an externalizing temperament ($F(1,41) = 1.65$, $p = .21$), Antisaccade performance ($F(1,41) = 1.46$, $p = .23$), or AXCPT performance ($F(1,41) = 0.03$, $p = .86$).

Age effects. Four linear regression models were conducted to test for the effects of age on temperament, inhibitory control, and proactive control. Age predicted inhibitory control ($F(1,41) = 17.11$, $p < .001$) such that older participants had significantly better inhibitory control than younger participants. Age did not predict internalizing scores ($F(1,41) = 2.99$, $p = .09$), externalizing scores ($F(1,41) = 0.62$, $p = .43$), or proactive control ($F(1,41) = 2.55$, $p = .12$).

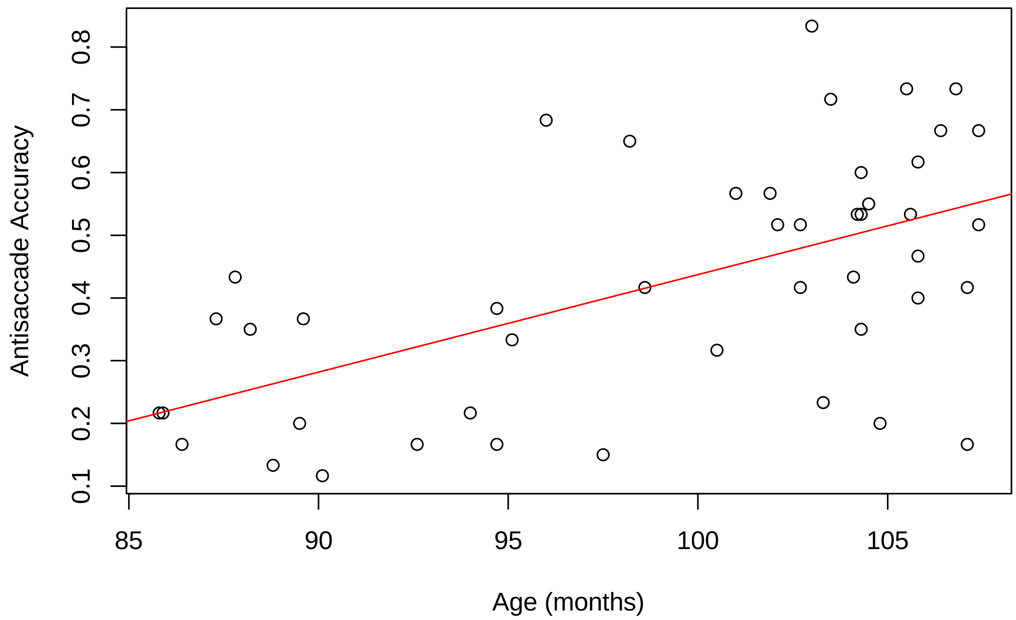

Figure 2: Scatter plot depicting the significant relationship between Age (in months) and performance on the Antisaccade task.

Primary Analyses

All following analyses were also run using linear regression models.

Model 1: Temperament and Inhibitory Control. Model 1 (see Table 2) tested the effects of internalizing (see Figure 3) and externalizing (see Figure 4) scores on Antisaccade performance using a linear regression model. We found that the model as a whole showed trending significance ($F(2, 40) = 3.17$, $p = 0.05$), and within the model, externalizing scores were a significant predictor of inhibitory control ($t = -2.41$, $p = 0.02$). In model 1.1 (see Table 3), we tested the effects of internalizing and externalizing scores on Antisaccade performance, our measure of IC, with age and gender as covariates. We did this given that preliminary analyses revealed age accounted for some of the variation in inhibitory control and previous literature has included gender in similar analyses (Eisenberg, Spinrad, & Eggum, 2010; Murray & Kochanska, 2002). This model remained significant compared to a model testing only the intercept ($F(4, 38) = 7.96$, $p < .001$), however age was the only individually significant predictor ($t = 4.37$, $p < .001$). Although, there was also a trend towards significance for externalizing scores as a predictor of inhibitory control ($t = -1.97$, $p = 0.06$) such that children who engage in more externalizing behaviors also perform with less accuracy on the Antisaccade task.

Table 2
Model 1: Predicting Inhibitory Control Based off Externalizing and Internalizing Scores

Inhibitory Control ~ Externalizing + Internalizing

Coefficients	t value	P
Internalizing	-0.05	0.96
Externalizing	-2.41	0.02*
Total	3.17	0.05

Table 3
Model 1.1: Predicting Inhibitory Control Based off Internalizing and Externalizing Scores, controlling for Gender and Age

Inhibitory Control ~ Externalizing + Internalizing + Gender + Age

Coefficients	t value	P
Internalizing	-1.04	0.30
Externalizing	-1.97	0.06
Gender	-1.29	0.21
Age	4.37	< .001
Total	7.96	< .001

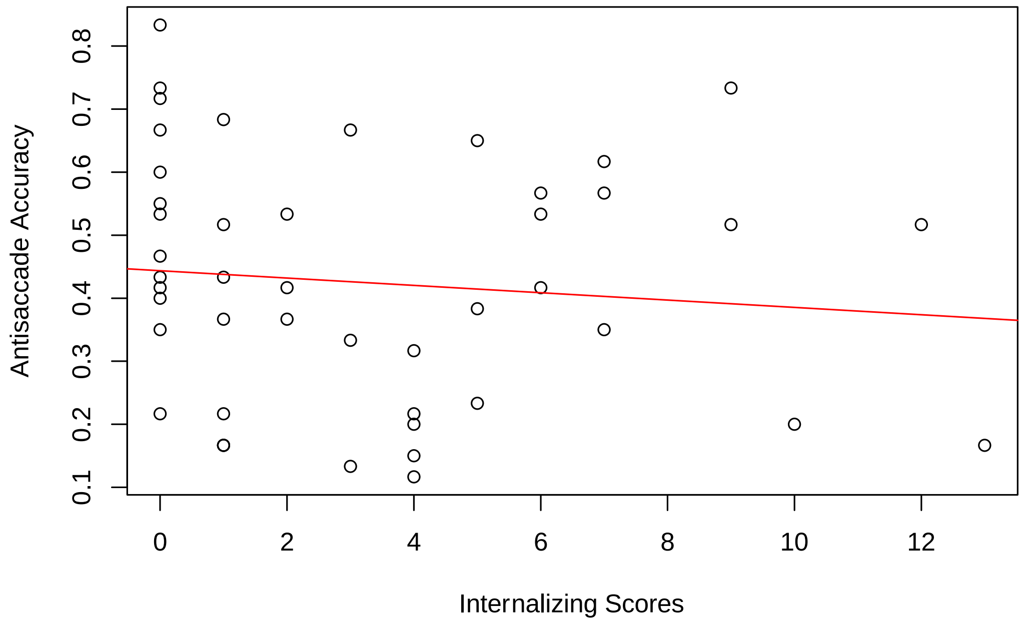

Figure 3: Scatter plot depicting the relationship between internalizing scores and performance on the Antisaccade task.

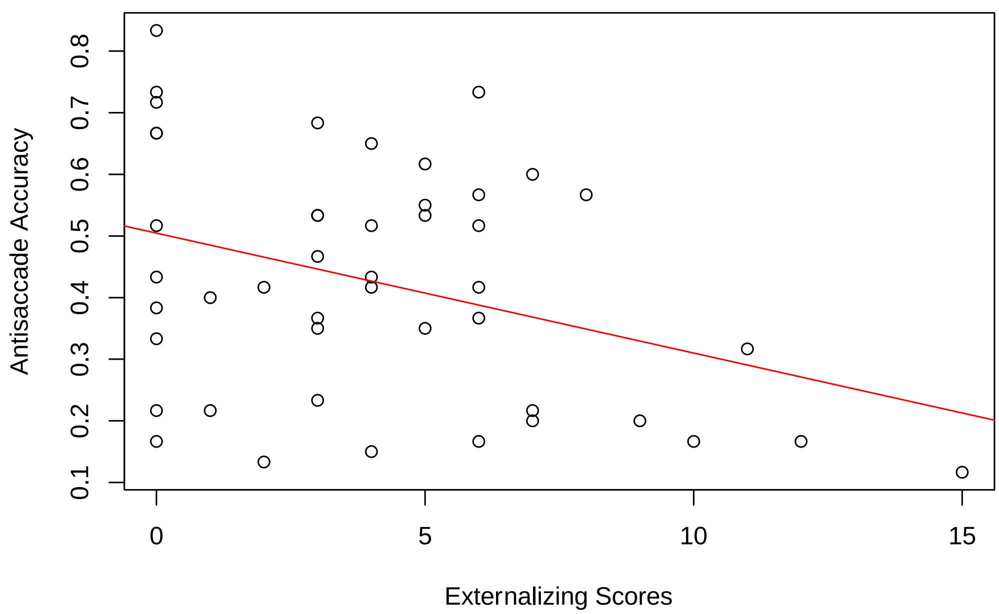

Figure 4: Scatter plot depicting the relationship between externalizing scores and performance on the Antisaccade task.

Model 2: Temperament and Proactivity. First, we assessed a model of internalizing and externalizing scores on proactive index scores (Model 2, see Table 4). Measures of temperament did not predict proactive control better than a simple model of proactivity utilizing only the intercept as a predictor (F (2, 40) = 0.13, p = 0.88). Additionally, neither predictor (i.e., internalizing scores or externalizing scores) showed a significant relationship with Proactive Behavioral Index scores (see Figures 5 and 6).

Following this, we tested the simple effects of internalizing and externalizing scores on proactive index scores, when including covariates for gender and age (Model 2.1; see Table 5). Based on this model, age and gender covariates did not contribute to the predictability of the model over all (F (4, 38) = 0.79, p = 0.54) as compared to the intercept only model. The individual effects of gender and age were also not significant predictors within this model.

Table 4
Model 2: Predicting Proactive Control Based Off Externalizing and Internalizing Scores

Proactive Control~ Externalizing + Internalizing

Coefficients	t value	P
Internalizing	-0.30	7.66
Externalizing	-0.32	0.75
Total	0.13	0.88

Table 5

Model 2.1: Predicting Proactive Control Based Off Internalizing and Externalizing Scores, Controlling for Gender and Age

Proactive Control~ Externalizing + Internalizing + Gender + Age

Coefficients	t value	P
Internalizing	0.18	0.86
Externalizing	-0.83	0.41
Gender	-0.56	0.58
Age	-1.66	0.11
Total	0.79	0.54

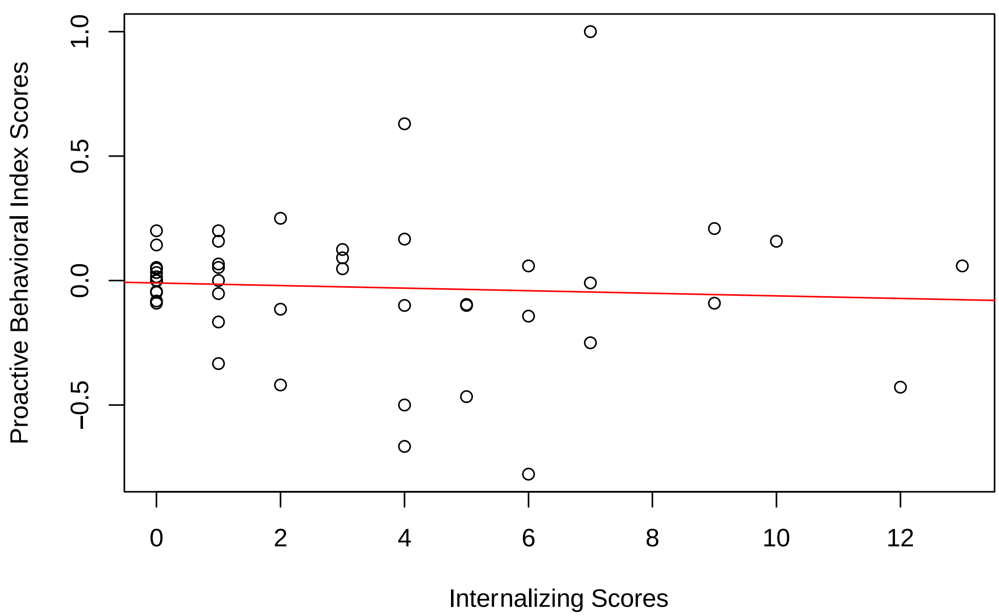

Figure 5: Scatter plot depicting the relationship between internalizing scores and Proactive Behavioral Index Scores.

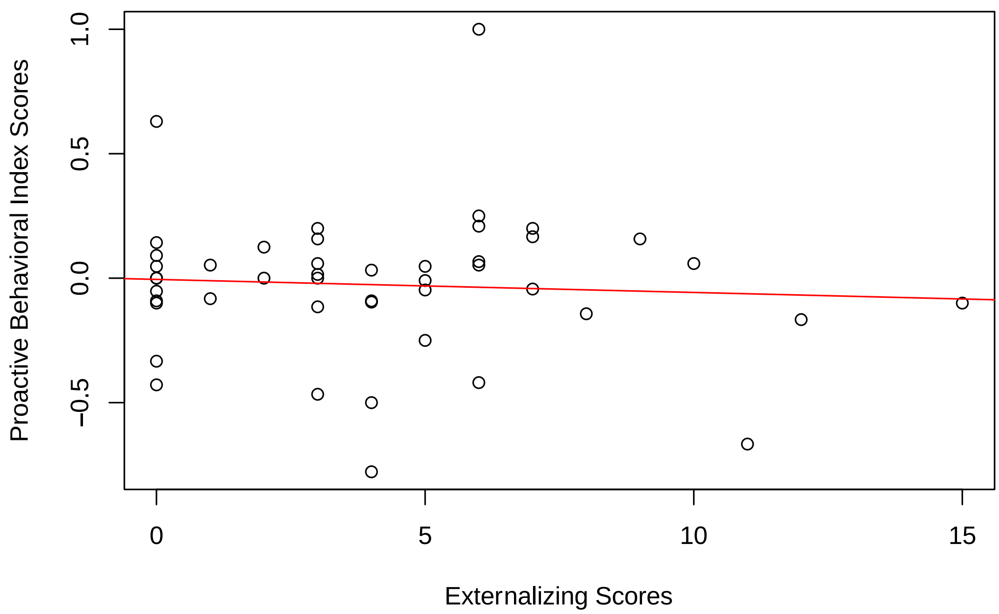

Figure 6: Scatter plot depicting the relationship between externalizing scores and Proactive Behavioral Index Scores.

Post Hoc Analyses

Total Problem Behaviors Measure. Given our trending results that internalizing and externalizing scores are positively correlated and that externalizing behaviors may predict Antisaccade performance, we evaluated validated approaches by which we might combine these measures in order to look for a relationship between more general measures of emotion regulation with executive functions. In previous literature examining the dimensions of temperament, children are typically classified into one of three temperament groups: primarily internalizing, primarily externalizing, or comorbid (Eisenberg et al., 2005). Due to the smaller size of this sample, we were unable to utilize this method, though it is likely that these three groups occur within these data to an extent given that some participants received only internalizing scores and some received only externalizing scores (see Figure 1). Since visual inspection suggests most of our participants fell into the comorbid range, we instead utilized the Total Problem Behavior subscale, which is the summation of the externalizing and internalizing subscales. The rationale was to use a more inclusive measure that might capture a relationship between emotion regulation and executive functions in response to the correlational evidenced above.

Total Problem Behavior and Executive Function. We ran two separate linear regression models assessing the relationship between Total Problem Behaviors with both Antisaccade accuracy (Model 3) and with Proactive Behavioral Index scores (Model 4). We found that in Model 3 (see Table 6), problem behavior scores did significantly predict inhibitory control while including covariates for age and gender. Within this model, both age ($t = 4.85$, $p < .001$) and Total Problem Behavior scores ($t = -3.49$, $p = .01$) were significant predictors of inhibitory control. This indicates that children who reportedly engage in more problem behaviors tended to perform worse on the Antisaccade task ($F(3, 39)$, $p < .001$) (see Figure 7). We also saw the same age effects that we saw in previous models, such older kids performed predictably better than younger kids in the measure of inhibitory control. Model 4 indicated that, consistent with Model 2 testing predictors of internalizing and externalizing scores, Total Problem Behavior scores did not significantly predict proactive control in the AXCPT while controlling for gender and age ($F(3, 39)$: 0.94, $p = .43$) (see Figure 8). The individual predictors of Problem Behavior Scores, Gender, and Age were not significant predictors of proactive control.

Table 6
Model 3: Predicting Inhibitory Control Based Off Total Problem Behavior Scores, Controlling for Gender and Age

Inhibitory Control ~ Problem Behavior + Gender + Age

Coefficients	t value	P
Problem Behavior	-2.64	0.01*
Gender	-1.20	0.24
Age	4.85	< .001
Total	10.68	< .001

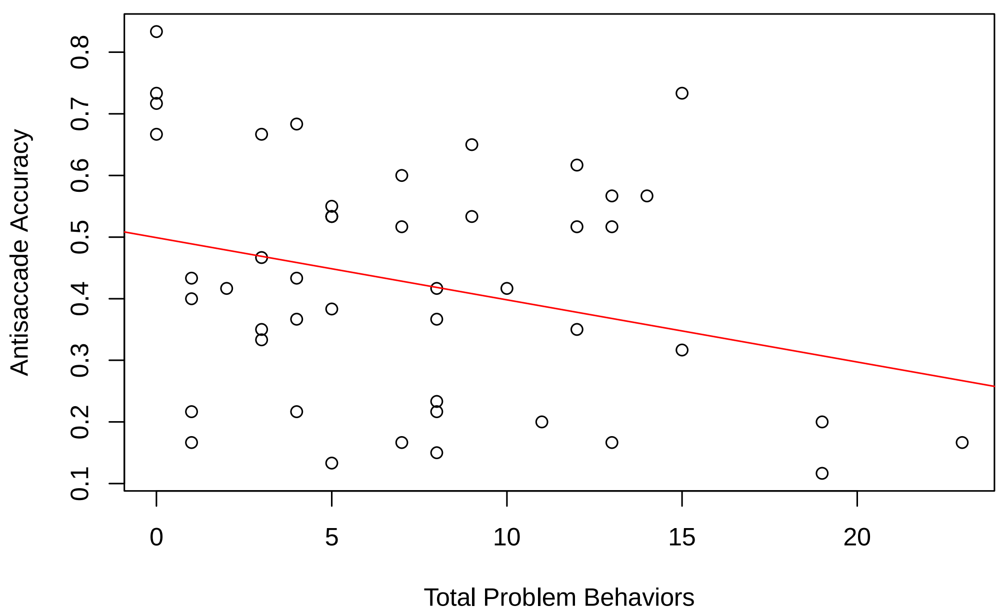

Figure 7: Scatter plot depicting the relationship between Total Problem Behavior scores and Antisaccade Accuracy.

Table 7

Model 4: Predicting Proactive Control Based Off Total Problem Behavior Scores, Controlling for Gender and Age

Proactive Control~ Problem Behavior+ Gender + Age

Coefficients	t value	P
Problem Behavior	-0.57	0.58
Gender	-0.43	0.67
Age	-1.55	0.13
Total	0.94	0.43

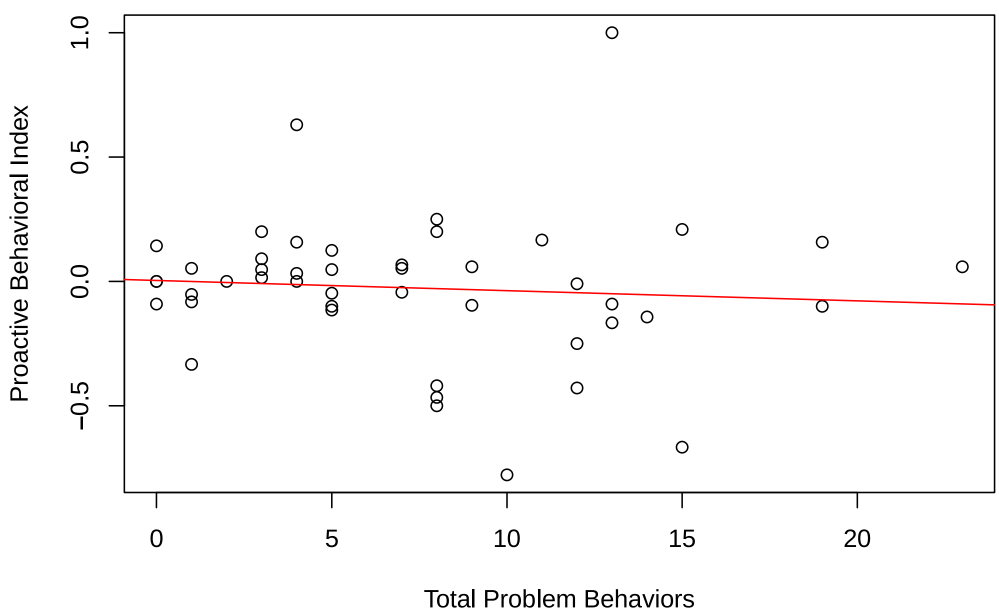

Figure 8: Scatter plot depicting the relationship between Total Problem Behavior scores and Proactive Behavioral Index Scores.

Discussion

The present study explored whether the Dual Mechanisms of Control framework (Braver, 2012) relates to individual differences in temperament to investigate how executive functions and emotional regulation may be related. We first attempted to replicate prior findings showing that inhibitory control and temperament are linked, such that better inhibitory control positively correlates with an internalizing temperament and worse inhibitory control positively correlates with an externalizing temperament. In other words, children with externalizing temperaments perform worse on measures of inhibitory control, and children with internalizing temperaments preform better on those same measures. Second, we tested the novel hypotheses that proactive control would positively correlate with an internalizing temperament and reactive control would positively correlate with an externalizing temperament. In other words, children with externalizing temperaments should engage in proactive control less frequently than children with internalizing temperaments.

For the first of these questions we found that neither internalizing temperaments nor externalizing temperaments were significant predictors of inhibitory control when controlling for age and gender. It is worth noting, however, that externalizing scores were trending towards significant. These results fail to provide a strong replication of prior work that the dimensions of temperament are related to inhibitory control in opposite ways, such that externalizing behaviors predict worse inhibitory control (Eisenberg et al., 2001; Murray & Kochanska, 2002) and internalizing behaviors predict better inhibitory control (Aksan & Kochanska, 2004; Murray & Kochanska, 2002). They further do not strongly support our hypotheses that internalizing and externalizing behaviors would predict better and worse performance on the Antisaccade respectively. These results instead indicate that, though externalizing scores may have accounted for some of the variance in Antisaccade scores, age was the most significant predictor of inhibitory control, such that older participants performed better on inhibitory control measures than younger participants. Additional factors that may have contributed to this finding are discussed further in the Limitations section.

Furthermore, we found that neither externalizing nor internalizing temperaments were significant predictors of proactive control. Model fit did not improve with the inclusion of gender and age. Given these results, it is possible that contrary to our hypothesis, emotion regulation is not related to proactive control. Instead, each of these constructs may have more specialized, rather than shared cognitive mechanisms. This would mean that when we are regulating our emotions, we are not tapping proactive control, and when we are engaging in proactive control, it may not involve emotion regulation.

Given our result that internalizing and externalizing scores were positively correlated and they each did not respectively predict inhibitory control (Model 1, see Tables 2 and 3) or proactive control (Model 2, see Tables 4 and 5), we decided to combine these measures into the validated Total Problem Behaviors subscale score to explore whether there was a detectable relationship between emotion regulation and measures of EF. We conducted a series of post-hoc analyses testing whether measures of problem behaviors were predictive of performance on both the Antisaccade task and the AXCPT.

We found that Model 3 (Table 6) assessing the relationship between total problem behavior scores with inhibitory control was significant when including age and gender covariates. Within this model, both age and Total Problem Behavior scores were significant predictors of inhibitory control, such that older age predicted better inhibitory control and more problems behaviors predicted worse inhibitory control. To summarize, children in our sample who engaged in more problem behaviors and presumably have worse emotion regulation tended to perform worse on measures of inhibitory control. This in part replicates prior work that deficits in ER relate to deficits in IC (Eisenberg et al., 2005), though critically we still did not see the predicted patterns of significant relationship between each dimension of temperament and IC such that better IC would positively correlate with an internalizing temperament and negatively correlate with an externalizing temperament.

In Model 4 (see Table 7), assessing the relationship between total problem behavior scores with proactive control as measured by the AXCPT, we found no significant results. This persisted when controlling for age and gender. These results do not provide any evidence to suggest that ER, as a broader construct, relates to measures of proactive control. This is consistent with our findings in Model 2 (Table 5) that our measures of the individual temperament dimensions do not relate to rates of proactive control. While it is difficult to interpret a null result, the present evidence could indicate that ER and Proactive Control, as a construct of EF, may not be cognitively linked and instead are unique and specialized cognitive mechanisms. Alternative explanations for this result could be due to the size and limited variability within our sample or to the limited scope of our measure of ER, discussed in detail below.

In summary, these results do not provide support for either of our hypotheses: (1) that internalizing and externalizing temperaments would be significantly related to better and worse inhibitory control, respectively, and (2) that the dimensions of temperament would relate to the DMC framework. They do however prompt novel questions such as how emotion regulation, as a broader construct, may relate to both inhibitory control and the DMC framework. In our post-hoc analyses, we found the combined measure of the dimensions of temperament, Total Problem

Behavior, was better able to replicate results about poor ER and inhibition than the dimensions were able to separately. Additionally, we did not have an a priori prediction that the correlation between the dimensions of temperament to be significant, which may indicate that within an unselected population temperament may exist on more of a spectrum best captured by the Total Problem Behaviors measure, than as dichotomous internalizing and externalizing dimensions.

Limitations

Several methodological limitations may also explain why the present research did not replicate past findings of temperament relating to measures of inhibitory control. First, our measure of temperament (the SDQ) may not have been sufficient for capturing the complexities of temperament, especially within an unselected population. Though it is a well validated and reliable measure for screening and detecting externalizing and internalizing problems (Goodman & Scott, 1999; Muris, Meesters, & Berg, 2003), it is typically used in clinical research, rather than for detecting individual differences within an unselected population. Because the SDQ was constructed with the original purpose of discriminating between clinical and normal populations, it is entirely possible that more complex, individual temperamental traits may not have been fully captured with this measure alone.

Furthermore, although several studies have suggested that parents' report of emotion and cognitive regulation are fairly accurate (Carlson & Wang, 2007; Eisenberg et al., 2001; Murray & Kochanska, 2002), our measure of temperament still might be vulnerable to social desirability bias as well as context-dependent biases. As parents are aware that their child is performing cognitive tests at a research facility, they might feel pressure to report their child's behavior in a way that they think will be viewed most favorably. Additionally, research has shown that parents' and teachers' reports of children's emotional and cognitive regulation vary significantly, suggesting that children do not behave the same way in the classroom or formal settings as they do in the home or with their parents – or that parents and teachers do not similarly report such behaviors when prompted (Eisenberg et al., 2005). It is also possible that parents may not see their child's externalizing or internalizing behaviors at home – but that they occur at school or in other settings. Both biases may contribute to inconsistent results between how the child behaves and how the parent reports their behavior and therefore may affect our results.

Moreover, our measure of temperament may not have been as sensitive to individual differences in temperament as previous trait measures that have been related to the DMC framework. Other works looking at inter-individual differences within the DMC framework typically use multiple measures of their construct of interest. For example, researchers who found significant differences in rates of proactivity between individuals with low versus high fluid intelligence used several memory-related tasks to detect such differences (Braver, 2012). However, in the present study we used only one measure. Perhaps, if we had been able to construct an aggregate measure of each dimension of temperament utilizing multiple questionnaires that were specifically designed to measure temperament within an unselected population, we would have produced a more sensitive measure capable of detecting more subtle individual differences.

Finally, our results may be vulnerable to self-selection bias in that parents who choose to sign their kids up to participate in research may differ in certain ways from the general population. For example, parents that are interested in having their children contribute to research are more likely to be of higher education, and therefore higher SES. Because our sample is likely biased to be from families of higher education and SES, it is a possible that we would have found a greater range of results from all measures if our sample were randomly selected (e.g., in schools), rather than having families self-select to participate.

Future Directions

In future studies examining how temperamental traits relate to the DMC framework, it would be beneficial to address the methodological and practical considerations we have discussed. A more extensive set of measures of temperament should be used to detect individual differences within a normal population so that children can be classified as internalizers, externalizers, or comorbid. A larger sample size is also necessary for this consideration such that analyses using this grouping approach have sufficient statistical power to detect effects. Additionally, measures of temperament should limit social desirability and context-dependent biases. This could be addressed by using behavioral measures or multiple reports from both parents and teachers, or other caregivers. Finally, a more diverse sample is necessary for capturing trends between individual differences in executive functions and temperament. Future research should use a broader range of ages to look for specific relationships between ER and EF, and to investigate whether that relationship is stable or variable over time.

Conclusion

Our findings regarding whether the two dimensions of temperament are predictors of inhibitory and proactive control are inconclusive, given that we did not find statistically significant results to provide evidence for or against these relationships. Due to the various methodological and practical limitations described above, we cannot make any claims that emotion regulation is or is not related to the DMC framework, and therefore the predictions should not be discounted. We did, however, see significant results between measures of Total

Problem Behavior and inhibitory control, such that children who engaged in more problem behavior, also likely had worse emotion regulation, and performed worse on a measure of inhibitory control. This finding may be indicative of shared cognitive mechanisms between emotion regulation and inhibitory control, as a construct of EF, though we cannot make any claims about what those mechanisms may be, especially since we did not find evidence of a link between ER and proactive control. Future research exploring the relationship between the dimensions of temperament and proactive control should consider using more comprehensive measures of temperament. Additionally, it would be beneficial to include children from a wider age range, to investigate whether the relationships between temperamental traits and cognitive control vary or remain consistent over time.

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