The Costs and Benefits of Transitioning from Reactive to Proactive Control in Young Children

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The Costs and Benefits of Transitioning from Reactive to Proactive Control in Young Children

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Abstract

Cognitive control refers to the mental processes (often termed ‘executive functions’, or EFs) that allow us to regulate our emotions, actions, and thoughts in order to carry out goals and plans. In early childhood, children transition from a reactive form of cognitive control, characterized by responding ‘in the moment’, to a proactive form of control, characterized by maintaining information in preparation for future responses. Previous research has established that this transition may confer costs as well as benefits. The present study investigates how cognitive control relates to response inhibition, delay of gratification, memory retrieval, and subclinical symptoms of Attention Deficit Hyperactive Disorder (ADHD) in 5 and 6 year old children who have recently undergone (or are undergoing) the reactive-to-proactive transition. Consistent with our hypotheses, children with better proactive control waited longer on a delay of gratification task, and scored lower on a measure assessing ADHD traits, than reactive children. We did not find evidence of hypothesized links between proactive control and memory retrieval, or proactive control and response inhibition.
The Costs and Benefits of Transitioning from Reactive to Proactive Control in Young Children

Young children have notorious difficulty regulating their emotions, actions and thoughts to achieve goals. For example, a child may continue to play outside without a coat even as rain begins to fall and the temperature drops, despite having every intention of staying warm and dry. Cognitive control refers to the mental processes (often termed ‘executive functions’, or EFs) that allow us adapt our behaviors in response to changing environmental circumstances, instead of persisting in behaviors that are no longer relevant or advantageous (Cohen, Dunbar, & McClelland, 1990; Davidson et. al., 2006; Munakata et. al., 2012). Strong cognitive control is advantageous, and predicts better life outcomes (Moffitt et. al, 2011; Valiente et. al., 2013; Tangney, Baumeister, & Boone, 2004). Across development, children improve in their ability to exercise cognitive control when planning and completing future actions.

In young children, difficulty in tasks requiring cognitive control may reflect a failure to proactively prepare for future actions. Children tend to behave reactively, responding to events in the moment, instead of maintaining goal-relevant thoughts and plans so that they are ready to respond appropriately when events occur (Chatham et al., 2009). Child improvements in planning behavior may reflect a qualitative shift in early childhood from a reactive to a proactive mode of cognitive control. For example, a reactive child might wait until they are called on to formulate an answer to a classroom question, whereas a proactive child might anticipate being called on and prepare an answer in advance.

Children and adults who exercise proactive control attempt to maintain task-
information across time, which can benefit task performance when there are few distractions in the environment. In adults, the ability to proactively prepare future responses predicts better prospective memory, or the ability to follow through with a specific goal at a specific time, under low working memory demand conditions (Cohen, Lewis-Peacock & Norman, 2012). Under these conditions, task-relevant information can be proactively maintained without interference from other, competing demands. In children, behaviors consistent with proactive planning predict performance on a delayed match to sample task, where children are required to recall a previously presented image, under conditions of low interference (Blackwell and Munakata, 2013). Children who were classified as being proactive showed faster reaction times than reactive children on the delay match to sample task. As an assessment of cognitive control, children completed a card sort task, where they were instructed to switch from sorting a card by one dimension (e.g., shape) to sorting by another dimension (e.g., color). Children were categorized as reactive when they perseverated on the first dimension instead of switching to the new dimension, and proactive when they correctly switched to the new sorting dimension. Children who were more proactive on the card sort task were more likely to use visible strategies to recall the image, such as holding their hand in the shape of the image, during the delayed match to sample task. Although this study provides promising support for a link between proactive control and recall under conditions of low interference, interpretation is confounded by the use of the card sort measure to index proactive control, which also taps other cognitive processes, such as the ability to flexibly switch between rules (cognitive flexibility). Thus, other cognitive abilities may have contributed to the observed relationship between proactive control and recall.
Another behavior that might benefit from proactive control is inhibitory control, or the ability to inhibit a strong automatic, or prepotent, response in order to carry out an appropriate action (Logan, Schachar & Tannock, 1997). In adults, proactive monitoring of the environment (continuous monitoring for change) for cues has been shown to produce neural signatures associated with response inhibition, contrary to the belief that the motoric stopping demand is what necessitates cognitive control (Chatham et al., 2012; Munakata, Herd, et. al., 2011). In children, training in proactive monitoring using a double-go task, where children are instructed to adjust their responses (‘go and stop’, or ‘go, then go again’) based on environmental cues, leads to greater improvements in response inhibition than training motoric stopping (Chevalier, Chatham, & Munakata, 2014), establishing the importance of proactive monitoring in supporting response inhibition. However, no study has investigated whether individual differences in child proactive control predict corresponding differences in inhibitory control. Therefore, we consider this relationship in the present study.

Proactive control may also contribute to performance on delay of gratification tasks, where individuals are asked to choose between an immediate small reward and a larger future reward. During such tasks, individuals must inhibit the impulse to take/consume the smaller reward. Therefore, proactive control may benefit delay of gratification through the same mechanism by which it benefits inhibitory control, since the ability to proactively keep in mind the promise of a greater reward and the reason for waiting could aid in the ability to wait for that reward, and additionally help children to monitor for internal cues that indicate the need to inhibit. In adults, ability to delay gratification predicts characteristics such as a body mass index (Bruce et. al., 2011;
Schlam et al., 2013), attentiveness and competence (Funder, Block, & Block, 1983). Broad measures of executive function have predicted delay of gratification in adults (Shamosh et al., 2008; Peters & Büchel, 2011) and children (Hongwanishkul et al., 2005; Carlson & Moses, 2001). Observed relationships between executive function and delay of gratification may be driven by proactive control, a component of EF. However, the relationship between delay of gratification and proactive control has not been directly investigated in children.

Although there are many established benefits of proactive control, the reactive-proactive transition may also confer costs. Specifically, children initially classified as proactive based on performance during a card sort task are worse at remembering information after a delay while distracted, as compared to reactive children (Blackwell & Munakata, 2013). Children viewed an image on a screen, and then experienced a brief delay, during which they were asked to tap on the table in front of them and count backwards (the distraction phase). Children who were proactive, as indexed by switching performance card sort task, chose the correct image more slowly than children who demonstrated a reactive profile. Two hypotheses have been put forth to explain this finding. One possibility is that proactive children have a longer general retrieval time than reactive children because reactive children practice retrieval more. A second possibility is that proactive children are slower overall because they first try to employ a proactive strategy, and then have to revert back to a reactive strategy when that strategy fails in the face of distraction. The present study will address this outstanding question by considering whether or not proactive children continue to show a memory retrieval deficit (relative to reactive children) in a memory task designed to equate for executive
strategies that could be used to aid encoding and recall.

As a final area of inquiry, we explore whether or not individual differences in cognitive control tendencies predict subclinical symptoms of Attention Deficit Hyperactivity Disorder (ADHD). Children with ADHD have a well-documented difficulty regulating their behavior in order to carry out goals (Biederman et al., 2004; Guderjahn et. al., 2013; Skogan et al., 2013), and perform worse on a variety of tasks that index inhibition and working memory (Schoemaker et. al., 2012; Berlin et. al., 2004; Skogan et. al., 2013; Roberts, Martel & Nigg, 2013). Some evidence suggests that children with ADHD may demonstrate more reactive control tendencies; however, these links have not been directly established. For example, adolescents with ADHD demonstrate errors typical of reactive children on the AX-CPT, a measure of proactive control (Iselin & Decoster, 2009). The present study builds upon these finding by investigating whether individuals with ADHD are less likely than neurotypical individuals to employ proactive control.

**Study Hypotheses**

The present study will consider whether the transition from reactive to proactive control confers both costs and benefits to other cognitive processes, building upon past findings by incorporating a robust measure of proactive control (the AX-CPT task). We hypothesize that proactive control will be linked to better performance on tasks assessing inhibition and delay of gratification, less efficient memory retrieval, and fewer subclinical ADHD symptoms.

**Methods**

**Participants.** Forty-three children ages 59-61 and 71-73 months (24 5-year-olds, 19 6-
year-olds; 21 males) were recruited for participation in this study from the Cognitive Development Center database. At time of recruitment, parents were informed that the study would be conducted over two visits, to be completed within a two-week interval. Five participants did not complete their second session, and were excluded from all subsequent analyses. One participant failed to comprehend the memory game task instructions, and was excluded from analyses of that task. Eight participants were excluded from analyses of the Delay of Gratification task because they chose the smaller reward immediately instead of waiting for a larger reward (3), they left the experiment room and asked the experimenter to stop the procedure (1), or because of experimenter/equipment error (4). Additionally, five participants were excluded from the CBCL analyses because their parents did not complete the questionnaire. Children received small prizes (e.g. stickers, bouncy balls) throughout the project, and parents received $5 as compensation for travel to the center.

**Design and Procedure.** Children were individually tested during two 75-minute sessions. Sessions were separated by a maximum of two weeks. During the first session all children completed the following tasks, in this order: AX-CPT, Card Sort (one dimension), Double-Go, Track-it, Foreperiod, and Offset Reaction Time, and parents completed the Behavioral Ratings Inventory of Executive Function (BRIEF) questionnaire. During the second session children completed Memory Retrieval, Stop Signal, Card Sort (three dimension), and Delay of Gratification, while parents completed the Child Behavior Checklist (CBCL) questionnaire. The present study focuses on analyses of one task administered in Session 1 (AX-CPT), three tasks administered
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during Session 2 (Memory Retrieval, Stop Signal, and Delay of Gratification), and one
parent questionnaire from Session 2 (the CBCL). Other tasks listed above were not
relevant for the research questions addressed in this thesis and are not discussed further.

**AX-CPT.** Children completed a touchscreen-based, child-adapted version of the
AX-CPT task, an assessment of cognitive control (Chatham et al., 2009; Figure 1). In the
child-adapted version, the “A” and “B” cues are replaced with pictures of the cartoon
characters Spongebob and Blue, and the “X” and “Y” probes are replaced with pictures
of a watermelon and a slinky. Children were taught to respond to sets of paired images
(i.e., a cue image followed by a probe image). The cue image was presented centrally on
the computer screen for 500 ms (either a Spongebob or Blue’s Clues character image).
After a delay of 120 ms, the probe, (a watermelon or a slinky) was presented for 6 s.
Children were instructed to respond to each cue-probe pair by pressing either a happy
face or a sad face, which was also visible on the screen. Children were told to press the
happy face whenever they saw the Spongebob-watermelon cue-probe pair, and the sad
face button whenever they saw B-X (Blue-Watermelon), B-Y (Blue-Slinky), or A-Y
(Spongebob-Slinky) cue-probe pairings. The game was programmed so that the A-X
(Spongebob-Watermelon) pair was used in 70% of trials and the A-Y, B-X, and B-Y
pairs were presented in equal proportions across the remaining 30% of trials.
Each child completed 4 blocks of 30 trials. During 2 blocks (the ‘distractor’ blocks)
visual distractors (landscape images) were introduced on the screen during the delay
period between the presentation of the cue and probe images. During the other 2 blocks
(the ‘no-distractor’ blocks), no images were introduced during the cue-probe interval.
Block order was counterbalanced across participants.

Indices of proactive control were derived from analyses of reaction times and error rates across the no-distractor blocks\(^1\). All responses made < 200 ms after the presentation of the probe were removed from the analysis, resulting in the exclusion of <1% of all trials. As in previous work (Chatham, Frank & Munakata, 2009), an RT based measure of proactive control was calculated using the median of trimmed RTs on AY and BX trials, which were entered into the formula \((AY-BX) / (AY+BX)\). Additionally, an accuracy-based measure of proactive control was calculated by subtracting accuracy on AY trials from accuracy on BX trials \((BX-AY)\)^2. These analyses were informed by patterns of slowing and error rates that have been observed in reactive and proactive children (e.g., Chatham, Frank & Munakata, 2009). Typically, proactive individuals demonstrate fast reaction times on BX trials relative to AY trials, and reactive individuals produce fast reaction times on AY relative to BX trials. Error rates follow a similar pattern: proactive individuals commit more errors on AY trials, where the prepared response creates interference, and fewer errors on BX trials, where a non-target response (frown face) is prepared before seeing the probe. Reactive children show an opposite pattern of errors: more errors are committed on BX trials, where the X probe can lead to false alarms (via retrieval-based interference), and fewer errors are committed on AY trials, since children have not prepared a response.

\(^1\) We focused on no-distractor blocks because the visual images used in the distractor blocks were designed to interfere with children's ability to maintain cue information across time.

\(^2\) Neither z-transforming nor normalization was necessary for the accuracy-based measure because accuracy is naturally bounded between 0 and 1.
Figure 1: AX-Continuous Performance Task. In this child-adapted version of this task, cartoon characters and objects replaced letter cues and probes. Children were taught to respond to cue-probe pairs by pressing either the happy face (after an A-X pairing; 70% of trials) or the frown face (after A-Y, B-X, and B-Y pairings; each 10% of trials).

Memory Retrieval Task. Children completed a touchscreen-based task assessing memory retrieval efficiency. The task began with a brief processing speed component. During the processing speed block, a grid of 10 black boxes was presented on the perimeter of the computer screen. Children started each trial by tapping a star in the middle of the screen with a pointer. Afterwards, one randomly-selected black box on the perimeter turned red. Children were instructed to move their pointer from the star, to the red box, and then back to the star. Each child completed 30 processing speed trials in this way. Reaction times on each trial were assessed by subtracting the time of stimulus onset (red box appearance) from the time children tapped the target box. Correct trial RTs were trimmed (removing trials > 3 standard deviations above that subject’s mean RT) and averaged to create a mean processing speed measure.

Following the processing speed block, children completed multiple memory retrieval blocks, where they had to recall where on the touchscreen photographic images of familiar objects (e.g., animals, household items) had previously been presented. Each memory retrieval block included an encoding phase and a retrieval phase. The task design attempted to equate for several executive strategies that children may have used to aid
encoding and retrieval. During the encoding phase, children saw each image presented from left to right, ensuring that children did not use different spatial strategies that may have helped them to encode image locations (e.g., by first looking at images ‘anchored’ in the corners of the screen, and then memorizing the location of other pictures in relation to them). Additionally, each image was presented individually, to ensure that children saw each image for the same period of time. The experimenter also stated a verbal label at the time each image was presented, ensuring that all children had access to verbal information about the stimuli which could help them to rehearse the order of images\(^3\).

Finally, test images were presented in random order to equate for potential executive strategies used during recall.

During the encoding phase, question-mark boxes appeared along the perimeter of the computer screen, indicating locations where pictures would subsequently appear. Then, individual target pictures appeared in sequential order from left to right, at the site of the corresponding question-mark box. Each image was presented for 2.5 s. Children were instructed to look at each target picture as the experimenter stated simple labels corresponding to each image (e.g., “dog”, “spoon”). After all of the pictures had been presented, a white screen appeared, along with a centrally-presented fixation point. Children were instructed to look at the fixation point and wait for a period of 8 seconds.

Following the encoding phase, children began the retrieval phase. During this phase, a single test image, corresponding to a target image from the encoding phase, appeared in the middle of the screen, and the child was instructed to point to the box where that target image was presented during the encoding phase. The number of target

\(^3\)The experimenter did not promote or discourage rehearsal during the interval between encoding and test phases; therefore, while all children had the opportunity to rehearse across the delay period, we did not equate for this strategy.
images presented in each memory retrieval block varied as a function of child accuracy on the preceding block. Each child completed two practice games with three target images each. Afterwards, children proceeded to two test games with four target images each. If children demonstrated 80% accuracy across the two 4-image games, they progressed to a set of five-image games. If they failed to achieve 80% accuracy across the two 5-image games, they played another 4-image game, in which they either achieved 80% accuracy and moved back up to five images, or did not and the game ended. Each child continued to play until they had played a maximum of four games at one level or identified the maximum number of images (20 images).

To index memory retrieval efficiency, we computed mean reaction times from correct trials on 5-image games. We chose to use to restrict RT analyses to 5-image games so as to only compare RTs across games with equivalent response options (since RTs could be expected to vary with the number of response options) at a level that almost all children completed with high accuracy, and to minimize confounding variance from motivation and concentration problems on the upper levels. Three children did not progress to level 5, and were therefore excluded from analyses of the memory retrieval task.

**Stop Signal.** Children also completed a behavioral motoric stopping task assessing inhibitory control (adapted from Chevalier, Chatham, & Munakata, 2014; Figure 2). During this task, children first completed a practice block of 24 “Go trials”, which aided in their learning of the task, established button-pressing as a prepotent response, and provided a mean reaction time estimate. During these trials children were
introduced to Mike the air controller and told that during the game they were going to help Mike land planes. Children used the keyboard to land planes by pressing the key (marked in yellow) on the same side as the plane when it appeared on the screen.

Following the practice trials, children moved on to the experimental phase, consisting of 3 blocks of 48 trials, where 75% of trials were “Go” trials and 25% of trials were “Stop” trials. Stop trials introduced the motoric stopping component of the task. Children were told that the planes could not land during a storm (depicted via a lightning bolt in the center of the plane), and therefore were not supposed to press any buttons if a lightning bolt appeared on the screen. The lightning bolt was presented after one of the following delays: 20%, 30%, 40% or 50% of each child’s mean reaction time. To combat slowing (a strategy children could adopt to improve accuracy on the task), allowable response limits on go-trials were set to 1.5 x each child’s mean RT. When children surpassed this limit, they received negative auditory feedback (a short two-part tone) and were not able to make the plane land, which encouraged them to speed their responses on future trials. Stop signal delays were titrated to achieve 50% accuracy for each child, and a stop-signal reaction time was calculated for each child.
Figure 2: Stop Signal Task. Children were taught to press buttons on the computer on the same side as the plane appeared on the screen during “Go” trials (75% of trials). Children were to refrain from pressing any keys during “Stop” trials where the lightning bolt appeared (25% of trials). The interval between the appearance of the plane and the appearance of the stop signal varied with child performance, such that accurate stop trials led to a slightly longer interval between the presentation of the plane and the stop signal (lightning bolt), and inaccurate trials led to a shorter interval between stimuli.

Delay of Gratification (DoG). Children completed a delay of gratification task, which reflects children’s willingness to forego a smaller, immediate reward in favor of a larger, future reward. During this task, children were given the option of taking a smaller reward immediately (18 M&Ms) or waiting for an unspecified period of time to receive a larger reward (36 M&Ms). At the beginning of the task, children were asked, “Would you rather have these M&Ms (shown smaller amount) or these M&Ms (shown larger amount)?” If the child showed an initial preference for the smaller reward, the experimenter gave the smaller reward to the child, and the child was excluded from subsequent delay of gratification analyses. If the child demonstrated an initial preference for the larger reward, the experimenter said, “Ok, I have to go do something in the other room, so I am going to leave these right here (placed smaller amount in front of child), and if you make sure to stay in your chair and not eat those M&Ms (pointed to smaller
reward), then you can have these M&Ms (pointed to larger reward) when I get back.” After the child agreed to this plan, the experimenter said, “If you feel like you really cannot wait for me to come back, then you can ring this bell (small bell placed beside child) and I will come back, but that means you can only eat these M&Ms (pointed to smaller reward) and not these M&Ms (pointed to larger reward).” Afterwards, the experimenter left the room and began timing the delay period. Parents were able to watch their children wait for the delayed reward (or consume the immediate reward) from a separate room via a webcam. To receive the larger reward, children had to wait 20 minutes without eating any part of smaller reward. The outcome measure for this task was the number of minutes children waited after the experimenter left the room before eating any part of the smaller reward.

**Child Behavior Checklist (CBCL).** The CBCL is a validated, 100-item questionnaire, which queries parents about their child’s behavior over the past two months (Achenbach, 1991). Parents give their child a score of 0, 1, or 2 for each statement on the questionnaire, with 0 signifying ‘not true’, 1 signifying ‘somewhat true’, and 2 signifying ‘very true’. The Attention Problems subscale of the survey can be used to screen for clinically-relevant ADHD traits, and demonstrates strong convergence with ADHD diagnosis (Chen et. al., 1994; Biederman et. al., 1993). The Attention Problems subscale includes the items: “Can’t concentrate, can’t pay attention for long”; “Can’t sit still, restless, or hyperactive”; “Poorly coordinated or clumsy”; “Quickly shifts from one activity to another”; and “Wanders away”. Standardized Attention Problem subscale percentile scores > 97 indicate that child behaviors are consistent with criteria used to establish a clinical ADHD diagnosis (Achenbach, 1991; Derks et. al., 2006).
Results

Preliminary Analyses

Before generating an index of proactive control, we analyzed within-participant median RTs and accuracy rates for each trial type (AY, AX, BY, and BX). Five participants responded incorrectly on all 6 B-X trials, and 11 participants demonstrated BX trial accuracy rates <= 50%. Therefore, we conducted all subsequent analyses using the accuracy-based measure of AX-CPT, which allowed us to retain the participants for whom we could not generate a reliable RT-based measure of proactive control. Performance on the accuracy-based measure of proactive control did not vary with age (p > .18). Therefore, we collapsed across the full age range for all analyses, and included age as a covariate.

Memory retrieval was generated using RTs from correct trials on level 5 (a 5-image level) of the memory game. Three participants failed to reach level 5, and were excluded from subsequent analyses.

For all analyses, outlying observations were identified (Cook’s D > 3 standard deviations above the mean) and removed. This resulted in the exclusion of no more than three cases from any analysis.

Proactive Control and Memory Retrieval Efficiency

Child memory retrieval, as indexed by reaction times on level 5, was not related to proactive control, controlling for mean processing speed RT ($F(1, 30) = 1.78; p > .19$). This finding persisted when we controlled for overall performance on the task, as indexed by each child’s final memory game level, and age (p’s > .17).
Figure 3: Memory game logged mean reaction time (RT) on level five predicted by proactive control. Proactive control did not predict memory retrieval reaction time on level five ($F(1, 30) = 1.78; p > .19$).

Proactive Control and Inhibitory Control

Child inhibitory control, as indexed by stop signal reaction time, did not relate to proactive control ($p > .7$; Figure 4). This finding persisted when we controlled for age ($p > .7$).

Figure 4: Stop signal reaction time as predicted by proactive control. Proactive control does not predict stop signal reaction time ($p > .7$).
Proactive Control and Delay of Gratification

Children with stronger proactive control demonstrated a greater ability to delay gratification, as indexed by total delay time on the M&M task \(F(1,22) = 5.56; p < .03\); Figure 5). This finding persisted when we controlled for age \(F(1,21) = 5.02; p < .04\).

![Figure 5](image)

**Figure 5**: Total delay time as predicted by proactive control. Proactive control significantly predicted total delay time on the delay of gratification task \(F(1,22) = 5.56; p < .03\).

Proactive control and ADHD Traits

We next considered whether or not children with more parent-reported attention problems characteristic of ADHD were less likely than children with fewer parent-reported attention problems to employ proactive control. As hypothesized, children with stronger proactive control had lower parent-reported scores on the Attention Problems subscale of the CBCL \(F(1, 29) = 5.24; p < .03\); Figure 6). This finding persisted when we independently controlled for gender and age (neither of which predicted CBCL attention problems scores).
Figure 6: CBCL Attention Problems standardized subscale score as predicted by proactive control. Children demonstrating better proactive control, as indexed by the AX-CPT, exhibited fewer parent-reported attention problems characteristic of ADHD ($F(1, 29) = 5.24; p < .03$).

**Discussion**

Our findings suggest that children who proactively prepare for and anticipate future events are more likely to delay gratification, and less likely to exhibit attention problems outside of the lab than children who tend to reactively respond to events in the moment. These findings represent the first demonstrations that child proactive control predicts delay of gratification and ADHD characteristics. We did not find evidence of a predicted relationship between proactive control and inhibitory control. Nor did we see evidence that proactive control benefits memory retrieval efficiency, in contrast to previous literature (Blackwell & Munakata, 2013).

Although our present findings are promising, they are based on partial data collection ($N = 43$ out of a planned $N$ of 80), and must therefore be interpreted with caution. Extending our sample may provide additional power to increase detection of
significant results in the case of null findings, or additional sample variance, which may change the overall pattern of results. For example, although we see a trending relationship between memory retrieval efficiency and proactive control in the expected direction, such that better proactive control predicts longer memory game response times, this relationship does not yet meet the criteria for significance (p < .2), and is difficult to interpret mid-data collection.

Our findings are also based upon a selective set of analyses, which may fail to reflect important behavioral differences. For example, we have restricted our memory retrieval efficiency measure to reaction times generated in a single level of the memory task. Although this analysis allows us to avoid confounds that prevent us from collapsing across task levels (e.g., children in higher levels have more response options to choose from, and therefore may generate slower RTs, on average, than children in lower levels), restricting our focus to RTs generated in one game level may ignore important differences in performance that could arise in later levels. Additionally, although we have attempted to control for overall accuracy in our memory game analyses by including the last level children successfully passed as a covariate, we are unable to fully account for speed-accuracy tradeoffs which may have influenced findings. Finally, our proactive control analyses were similarly restricted: to contend with missing data, we chose to use an accuracy-based measure, rather than an RT-based or composite measure of proactive control. As sample size increases, we may be able to consider more sophisticated analyses that will allow us to incorporate more task data.

An additional limitation, and planned future direction associated with this study relates to the specificity of observed effects. It is unclear whether the relationships
between proactive control and each outcome variable are driven entirely by proactive control. These linkages may instead be driven by general executive function abilities. To investigate this possibility, we plan to replicate the present analyses while also controlling for general EF ability. Our current test battery includes tasks which likely to tap domain general EF (such as three-dimension card sort, and the Behavioral Ratings Inventory of Executive Function). Inclusion of these control variables in our present analyses will allow us to determine whether or not proactive control independently predicts task performance, over and above general EF.

Another important future direction for this study is the incorporation of pupillometric data indexing children’s mental effort during the memory task. These data, which have been collected but not analyzed, will provide a robust within-task marker of cognitive control. Pupil diameter reflects mental effort, such that larger diameters indicate increased effort (e.g., Beatty, 1982; Poock, 1973). During the memory game, we captured pupil diameter during the interval between the encoding phase and the test phase. We expect that reactive and proactive children will demonstrate different pupillometric profiles, with proactive children showing higher mental effort across the interval relative to reactive children. We hope to use this index to more reliably characterize child behavior across the task, which may help augment our existing model of memory retrieval efficiency.

Finally, the present study is correlational, and therefore unable to establish the directionality of relationships between child proactive control and delay of gratification, or proactive control and parent-reported attention problems. To investigate these potential relationships, we could use a proactive control training paradigm, where children would
receive training meant to encourage proactive control. Pending replication of these findings in a sample of children meeting clinically-relevant diagnosis criteria for ADHD (another important direction for future work), we could investigate the effects of similar training on children with ADHD. Although current training programs designed for children with ADHD show little evidence that they are beneficial for improving the executive function deficits associated with ADHD (Rapport et. al., 2013), future work might consider whether training focused on more general aspects of cognitive control processes such as the temporal dynamics of control (e.g., a focus on proactive, rather than reactive control) would yield greater benefits than interventions that focus on specific executive functions.
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