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## Costs and benefits linked to developments in cognitive control

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### Abstract

Developing cognitive control over one's thoughts, emotions, and actions is a fundamental process that predicts important life outcomes. Such control begins in infancy, and shifts during development from a predominantly reactive form (e.g. retrieving task-relevant information when needed) to an increasingly proactive form (e.g. maintaining task-relevant information in anticipation of needing it). While such developments are generally viewed as adaptive, cognitive abilities can also involve tradeoffs, such that the benefits of developing increasingly proactive control may come with associated costs. In two experiments, we test for such cognitive trade-offs in children who are transitioning to proactive control. We find that proactive control predicts expected benefits in children's working memory, but is also associated with predicted costs in disproportionately slowing children under conditions of distraction. These findings highlight unique advantages and disadvantages of proactive and reactive control, and suggest caution in attempting to alter their balance during development.

### Introduction

Exerting control over one's thoughts, actions, and emotions is a fundamental process that predicts important life outcomes. Cognitive control allows us to suppress unwanted memories (Anderson & Green, 2001), control impulses (Logan, Schachar & Tannock, 1997), and reappraise negative emotions (Wager, Davidson, Hughes, Lindquist & Ochsner, 2008). Poor cognitive control is a hallmark of numerous disorders, including attention-deficit hyperactivity disorder (Barkley, 1997) and schizophrenia (Lesh, Niendam, Minzenberg & Carter, 2011). Childhood cognitive control, and the related construct of self-control, predict academic success, social functioning, and health, years later (Friedman, Haberstick, Willcutt, Miyake, Young, Corley & Hewitt, 2007; Moffitt, Arseneault, Belsky, Dickson, Hancox, Harrington, Houts, Poulton, Roberts, Ross, Sears, Thomson & Caspi, 2011). Small wonder, then, that there is growing interest in programs that improve children's cognitive control (Diamond, 2012).

Cognitive control develops from infancy, and undergoes critical transitions in early childhood (Bunge & Zelazo, 2006; Carlson, 2005; Deák, 2003; Munakata, Snyder &

Chatham, 2012). One key transition is from reactive control, or retrieving information and goals when they are needed (e.g. approaching an intersection and retrieving advice to look both ways before crossing, rather than darting across the street), to proactive control, or actively maintaining information in anticipation of using it (e.g. thinking to yourself to look both ways rather than darting across the street, before an intersection is even in sight). Preschoolers tend to be more reactive, while 8-year-olds are more proactive (Chatham, Frank & Munakata, 2009). The period of 5 to 6 years old seems particularly important for this transition, involving a shift from primarily reactive control to a mixture of proactive and reactive control depending on individual differences and task demands (Chatham, Provan & Munakata, 2013; Chevalier, Curran & Munakata, in preparation).

While such developments are viewed as adaptive, cognitive abilities can involve trade-offs (e.g. Doll, Hutchison & Frank, 2011; Friedman, Miyake, Robinson & Hewitt, 2011; Goschke, 2000), so developing cognitive control may confer both benefits and costs. For example, cognitive control supports task-switching (Munakata *et al.*, 2012), but may also interfere with learning and creativity by directing attention in an overly task-focused manner (Thompson-Schill, Ramscar & Chrysikou, 2009). Similarly, proactive control may support better preparedness than reactive control, but it is also more resource-demanding, relying on effortful maintenance of information in working memory (Braver, 2012; Cohen, Lewis-Peacock & Norman, 2012). Therefore, reactive control may be more adaptive when resources are limited, and children who have not transitioned to proactive control may fare better in these circumstances (Munakata, Snyder & Chatham, in press).

We tested potential benefits and costs of proactive control in two experiments with 6-year-old children, who are transitioning to proactive control. We assessed task-switching (from sorting cards by shape to sorting by color and then size) as an index of proactive control, given that developing cognitive control supports task-switching (Munakata *et al.*, 2012). Specifically, we used the 3-dimensional card sort measure of task-switching in children (Blackwell, Cepeda & Munakata, 2009; Deák, 2003), which likely taps proactive control to some degree, because multiple rules can interfere with one another and are each only presented once at the start of the relevant sorting block, making it difficult to retrieve the correct rule to solve the task reactively.<sup>1</sup> We expected variation in children's developmental levels at this transitional age, with some children showing a proactive profile on this task-switching measure and others showing a reactive profile. Experiment 1 tested whether children who had developed a proactive profile showed benefits in preparedness (faster reaction times on a delayed match-to-sample task). Experiment 2 tested whether children who had developed a proactive profile showed costs under distracting conditions, when sustaining proactive control is difficult. Both experiments also tested whether children who had developed a proactive profile showed evidence of proactive control in their visible strategies to remember information. We expected that developing proactive control would

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<sup>1</sup>Although task-switching is typically assessed on a trial-by-trial basis in adults (Monsell, 2003), blocked switching tasks are standard measures in young children (Deák, 2003; Zelazo, Frye & Rapus, 1996; Carlson, 2005). Simpler versions can be passed by 4-year-olds (Zelazo *et al.*, 1996), presumably because reactive control suffices when one of two rules is repeated before each trial. More sophisticated measures of proactive control in children (Chatham *et al.*, 2009) were not established when this research was conducted.

lead to more visible proactive strategy use, although children could also use non-visible strategies such as mental rehearsal.

## Experiment 1

We tested whether children who switch between tasks (relative to children who perseverate on prior tasks) show (a) better preparedness (i.e. faster response times) when remembering images over a delay, and (b) visible use of proactive strategies.

### Methods

**Participants**—Fifty-three 6-year-olds ( $M = 6.5$  years, range 6.1–7.0 years, 27 female) participated. Children were categorized by post-switch accuracy, as ‘switcher’ (75% to 100% correct,  $M = 93%$  color and 92% size trials correct) or ‘perseverator’ (0% to 25% correct,  $M = 4%$  color and 0% size trials correct). Thirty-seven children (70%, 18 female) were switchers, and 16 children (30%, nine female) were perseverators. As in similar task-switching studies (Blackwell *et al.*, 2009; Kharitonova, Chien, Colunga & Munakata, 2009; Kharitonova & Munakata, 2011), 14 additional participants were excluded for either insufficient (< 70%) pre-switch task-switching accuracy ( $n = 5$ ) or mixed switching (perseverating on one post-switch rule, switching on the other, making it difficult to group with either switchers or perseverators;  $n = 9$ ). Switchers were not significantly older than perseverators (6.6 years vs. 6.5 years,  $t < 1$ ).

**Procedures**—Participants completed computerized tasks in the order listed, in keeping with standard individual difference methods (e.g. Friedman, Miyake, Young, Defries, Corley & Hewitt, 2008) to minimize extraneous sources of variance for individual difference analyses.

### Processing speed

Children completed a 2-minute offset reaction time task (Cepeda, Blackwell & Munakata, 2013). Children placed one finger on a star in the lower right-hand corner of the touchscreen, and ‘popped’ blue circles that appeared at random locations. Time to remove the finger from the star (offset RT) was recorded across 10 trials.

### Working memory and proactive strategies

Children completed an 8–10-minute delayed match-to-sample task (DMS; adapted from Chelonis, Daniels-Shaw, Blake & Paule, 2000). One of seven images (square, circle, triangle, horizontal line, vertical line, cross, or X) appeared in the upper half of the computer touchscreen. Children were instructed to study the picture and press it to make it go away. After a delay of 1, 4, or 16 s, three pictures appeared on the lower half of the screen. Children were asked to select the picture that had just been presented. After two demonstrations, children completed 30 trials in random order, 10 at each delay. Observation time, accuracy, and RT were recorded upon children’s presses. Videos (available for 28 switchers and 11 perseverators<sup>2</sup>) were blind coded for proactive strategies.

## Task-switching/proactive control

Children completed a 6–8-minute 3-dimensional change card sort (3DCCS) with shape, color, and size blocks (Blackwell *et al.*, 2009; Deák, 2003; Figure 1). Instructions were given through pre-recorded video clips. For each block, children were asked to identify each target by the current dimension (e.g. ‘Can you press the cat?’), were informed of the current rules (e.g. ‘In the color game, when you see a red one, press the red one’), were asked three non-conflict questions (e.g. ‘In the size game, what do you press when you see a small one?’), and were presented with 12 individual stimuli, in pseudo-random order, that matched one target on each dimension (e.g. a large yellow bird). No feedback or additional instructions were provided.

**Data trimming and analysis**—Correct DMS RTs were trimmed as in Blackwell *et al.* (2009; building on Friedman & Miyake, 2004), to remove skew caused by the small number of trials contributing to each mean. At each delay, cases more than 3 *SDs* from the mean of the remaining participants were replaced with a value exactly 3 *SDs* from the new mean (5% of 1 s delay, 10% of 4 s delay, and 8% of 16 s delay values). Analyses of the effects of delay on different aspects of performance were conducted using one-way repeated measures ANOVA. Differences between switchers’ and perseverators’ DMS performance were analyzed using 2 (switch status)  $\times$  3 (delay) mixed-factor ANOVA. For accuracy and strategy analyses, age was covaried; for RT analysis, processing speed was also covaried, because switchers had faster offset RTs (455 ms) than perseverators (508 ms;  $t(51) = -2.3$ ,  $p < .05$ ). One perseverator was excluded from all RT analyses due to missing offset RT data.

## Results

### Delayed match-to-sample accuracy

Accuracy decreased with increasing delays (98%, 94%, and 92%, respectively;  $F(2, 104) = 7.7$ ,  $p = .001$ ,  $\eta^2 = .13$ ). Accuracy did not differ between switchers and perseverators ( $F < 1$ ). Accuracy can be achieved through either proactive control (actively remembering across the delay which shape was seen) or reactive control (considering the three alternatives presented at test and comparing to a retrieved memory), so we focus on reaction times.

### Delayed match-to-sample reaction times

As predicted, switchers responded faster on the DMS than perseverators ( $F(1, 48) = 4.1$ ,  $p < .05$ ,  $\eta^2 = .08$ ). In addition, longer delays led to increased RTs overall (1780 ms, 2237 ms, and 2585 ms, respectively;  $F(2, 104) = 44.5$ ,  $p < .01$ ,  $\eta^2 = .46$ ). Critically, switchers’ advantage was most evident at longer delays ( $F(2, 96) = 4.7$ ,  $p = .01$ ,  $\eta^2 = .09$ ) (Figure 2a), under the greatest demands on working memory, when proactive control has the biggest impact.<sup>3</sup> Switchers’ advantage cannot be explained by time spent studying pictures before

<sup>2</sup>Ten children (seven switchers) moved their hands out of view, and four children (two switchers) did not have videos due to parental preference or equipment malfunction.

<sup>3</sup>Although proactive control may be viewed as more susceptible to delay because it requires more resources during the delay, switchers’ fast RTs suggest that they successfully engaged proactive control across these delays; longer delays or more difficult tasks might be required to see proactive susceptibility to delay. Likewise, perseverators’ sensitivity to delay might indicate that shorter delays allowed more efficient reactive approaches because memory demands were minimal and traces had not decayed, facilitating retrieval; immature proactive control may also help perseverators during shorter delays.

the delay, as switchers did not study them longer than perseverators (switchers actually studied them for non-significantly less time: 2526 vs. 2763 ms;  $F < 1$ ), and controlling observation time did not alter the results.

### Delayed match-to-sample proactive strategies

During the delay, 16 children (30%) used visible strategies to maintain shape information, such as tracing shapes in the air, or forming shapes with their hands (e.g. putting thumbs and fingertips together to form a circle). Strategies were more common during longer delays (occurring on 3.8%, 5.1%, and 10.3% of trials, respectively;  $F(2, 76) = 5.5, p < .01, \eta^2 = .13$ ), consistent with increased memory demands. Switchers were marginally more likely to use strategies (50% of switchers) than perseverators (18% of perseverators;  $\chi^2(1,39) = 3.3, p < .07$ ), and used them marginally more often (7.5% of trials vs. 1.5%;  $F(1, 36) = 2.9, p < .10, \eta^2 = .07$ ). Strategy use did not improve accuracy or speed reaction times ( $F$ s  $< 1$ ), but this was not unexpected as children who did not show visible strategies may have used non-visible proactive strategies such as mental rehearsal.

**Discussion**—Switchers show faster RTs after remembering information over a delay, and use marginally more visible strategies to remember, relative to perseverators. These results are consistent with task-switching indexing proactive control and proactive control conferring benefits of preparedness.

## Experiment 2

To test whether proactive control confers a cost when proactive strategies are prevented, we added a distracted DMS, in which children tapped the table and counted backwards during the delay.

### Methods

**Participants**—Forty-three 6-year-olds ( $M = 6.5$  years, range 6.2–7.0 years; 22 female) participated.<sup>4</sup> Twenty-three children were switchers ( $M = 98\%$  color and 94% size correct; 10 female), and 20 were perseverators ( $M = 6\%$  color and 0% size correct; 12 female). Twelve additional participants were excluded: five did not have sufficient pre-switch accuracy, three had mixed switching, three did not achieve 80% correct after the 1 s undistracted DMS delay, and one did not complete the distracted DMS. Switchers were not older than perseverators (both  $M = 6.4$  years,  $t < 1$ ).

**Procedures**—Participants completed all tasks in the same order (again to minimize extraneous sources of variance as standard in individual difference methods): offset RT, distracted DMS, an inhibitory control measure lasting 2 minutes (not discussed further in this report), undistracted DMS, and 3DCCS. Offset RT and 3DCCS were identical to Experiment 1. The undistracted DMS was similar to Experiment 1, but the middle delay was increased from 4 s to 8 s to increase working memory demands. The distracted DMS used

<sup>4</sup>Fewer participants were run than in Experiment 1, because fewer children had mixed switching performance; initially 55 participants were planned and run for each study, but 12 additional participants were run in Experiment 1 to ensure sufficient numbers of switchers and perseverators.

seven different shapes for children to remember (heart, arch, diamond, rectangle, crescent, donut, and pentagon), chosen to be visually distinct from those in the undistracted DMS, and included instructions for children to tap on the table and count backwards (from 20 or 10<sup>5</sup>) during the delay. Videos were blind coded for distraction task performance (22 switchers, 18 perseverators), and proactive strategies (22 switchers, 16 perseverators<sup>6</sup>).

**Data trimming and analyses**—DMS RTs were trimmed as in Experiment 1 (undistracted DMS: 2% of 1 s, 2% of 8 s, and 12% of 16 s delay values; distracted DMS: 5% of 1 s, 2% of 8 s, and 5% of 16 s delay values). Analyses included the same one-way and 2 (switch status) × 3 (delay) mixed-factor ANOVAs as in Experiment 1. In addition, a 2 (DMS distraction) × 3 (delay) ANOVA assessed the overall costs of distraction, and a 2 (DMS distraction) × 2 (switch status) × 3 (delay) ANOVA assessed how distraction impacted switchers and perseverators. When performance was compared across experiments, only the two identical delays (1 s and 16 s) were included. Age was controlled when comparing children's accuracy and strategy use, and processing speed was also controlled when comparing RTs (though switchers did not have significantly faster offset RTs (463 ms) than perseverators (477 ms;  $t < 1$ )). One perseverator was excluded from RT analyses due to missing offset RT data.

## Results

**Distracted delayed match-to-sample**—Accuracy on the distracted DMS was lower (95%, 78%, and 76% at the respective delays) than on the undistracted DMS (97%, 87%, and 82%;  $F(1, 42) = 18.9, p < .001, \eta^2 = .31$ ), at all delays (interaction  $F < 2$ ). Switchers' and perseverators' accuracy was equally impaired by distraction ( $F < 1$ ).

RTs were longer on the distracted DMS than on the undistracted DMS ( $F(1, 42) = 61.7, p < .001, \eta^2 = .60$ ) particularly at the longer delays ( $F(2, 84) = 16.7, p < .001, \eta^2 = .29$ ). Critically, switchers were more impaired by distraction than perseverators: Switchers' RTs slowed from the undistracted to the distracted task by a larger margin than perseverators' ( $F(1, 38) = 4.6, p < .05, \eta^2 = .11$ ), consistent with switchers' preferred proactive approach being hurt more by distraction than perseverators' reactive approach. Switchers were actually slower than perseverators when distracted ( $F(1, 38) = 4.1, p = .05, \eta^2 = .10$ ) (Figure 2b). This switcher disadvantage represents a significant crossover from switchers' advantage in Experiment 1 ( $F(1, 88) = 11.2, p = .001, \eta^2 = .11$ ).

**Distractor task performance**—Switchers and perseverators performed similarly on the distraction task, such that differences in their distracted DMS performance do not seem to be explained by significant differences in how they performed the distraction task. Switchers and perseverators were equally likely to count from 20, were prompted by the experimenter to begin or continue counting with equal frequency, tapped at the same rates, and made the

<sup>5</sup>Children chose whether to start from 10 or 20; children who counted from 10 and 20 were equally accurate ( $F < 1$ ) and fast ( $F < 2$ ) at the primary DMS task. Children who started from 20 were slightly older ( $M = 6.5$  vs.  $6.4, t(38) = -2.5, p < .05$ ), but made mistakes while counting as frequently as children counting from 10 ( $F < 1.5$ ; 7%, 37%, and 44% of trials at each delay, across children). The children who started at 10 said marginally more numbers ( $F(1, 37) = 3.8, p = .06$ ) and tapped more rapidly ( $F(1, 37) = 11.0, p < .005$ ).

<sup>6</sup>Two perseverators were out of view of the camera; three children (two switchers) did not have videos due to parental preference or equipment malfunction.

same number of mistakes while counting ( $\chi^2$  and all  $F$ s < 1.5). The only hint of a potential difference was a trend for switchers to say fewer numbers while counting (controlling for processing speed;  $F(1, 35) = 2.7, p = .11$ ).

**Undistracted delayed match-to-sample**—Children's accuracy was lower (97%, 87%, and 82%) than in the undistracted DMS of Experiment 1 ( $F(1, 91) = 10.3, p < .005, \eta^2 = .10$ ), particularly at the longer delay ( $F(1, 91) = 9.3, p < .005, \eta^2 = .09$ ). As in Experiment 1, accuracy did not significantly differ between switchers and perseverators ( $F < 1$ ).

Interestingly, when the undistracted DMS followed a distracted DMS, switchers no longer had an RT advantage on the undistracted DMS ( $F < 1$ ): Switchers' RTs were 1851, 2414, and 2693 ms at the respective delays; perseverators' were 1912, 2378, and 2438 ms. This is likely due to children approaching the task differently, following a difficult DMS task and faced with a longer intermediate delay (8 s instead of 4 s). Consistent with this idea, switchers' and perseverators' RTs changed in opposite directions between experiments depending on delay ( $F(1, 88) = 6.9, p = .01, \eta^2 = .07$ ). Specifically, after the 16 s undistracted delay, perseverators' RTs decreased from Experiment 1 to Experiment 2 ( $F(1, 30) = 4.8, p < .05, \eta^2 = .14$ ), while switchers' RTs increased numerically from Experiment 1 to Experiment 2, although this difference did not reach significance ( $F(1, 56) = 2.0, p > .15$ ).

**Undistracted delayed match-to-sample proactive strategies**—Eighteen children (42%) were observed using visible or verbal proactive strategies. Consistent with the idea that children approached the undistracted DMS task differently in Experiment 2, switchers were not significantly more likely (50%) to use strategies than perseverators (44%;  $\chi^2 < 1$ ) and did not use strategies more frequently ( $F < 1$ ), and using a visible strategy marginally helped accuracy on longer delays ( $F(2, 66) = 2.7, p = .07, \eta^2 = .08$ ). As in Experiment 1, strategy use did not speed responses ( $F < 1$ ).

## Discussion

Switchers' RTs after remembering information over a delay are more slowed by distractions, relative to perseverators'. These results are consistent with proactive control conferring costs, when task demands interfere with resource-demanding proactive control. That is, distractions may influence switchers more than perseverators because switchers would otherwise be doing more than perseverators during the period that is now filled with distractions. Moreover, switchers did not simply fall to the level of the perseverators, as one might have expected. Instead, switchers were significantly slower than perseverators after remembering information over a delay with distraction. Why might this have happened?

One possibility is that switchers reverted to reactive control in the face of distractors and more complex shapes because proactive control was difficult or impossible, but they were less efficient at reactive control than perseverators because it is their less-favored, less-practiced approach. That is, the developmental transition to increased use of proactive control may have made switchers slower to reactively compare each of the test images to an item retrieved from memory. A slower, unpracticed reactive approach may explain why RTs were slowed by distraction even at the 1s delay, when reactive control may have been necessary because switchers' proactive control was disrupted by a shift in attention toward



(and in some cases, initiation of) the distraction task. In addition, if some switchers carried over this new reactive approach to the subsequent undistracted DMS, it would explain why switchers no longer have faster RTs than perseverators and show a trend toward slowing compared to switchers in the undistracted DMS of Experiment 1.

Alternatively, switchers may have attempted to proactively maintain the DMS information throughout the distraction task (treating it as a dual-task), but this approach was not particularly effective given the distractors and more complex shapes. When presented with the test images to select among, switchers may have first tried a proactive approach, looking for the image that they had tried to maintain across the delay. If this proactive approach failed, they may have then reverted to a reactive approach of retrieving the item from memory. According to this account, switchers were slower than perseverators because their proactive approach was less efficient than perseverators' reactive approach, or because it delayed the initiation of a reactive approach (that may have been just as efficient as perseverators'). Such dual-tasking between proactive maintenance and distraction for switchers only may explain the trend for them to say fewer numbers than perseverators in the distraction task; however, this was only a trend and switchers and perseverators performed remarkably similarly on the distraction task overall. Inefficient reactive control and dual-tasking are not mutually exclusive; in the face of distraction, some switchers may have reverted to less-efficient reactive control while others dual-tasked ineffectively, and a given child may have tried each approach across different trials or even within a trial.

Surprisingly, on the final, undistracted DMS, perseverators were just as likely as switchers to show evidence of proactive strategies, and had equally fast RTs. The increased working memory demands (intermediate delay of 4 s in Experiment 1 vs. 8 s in Experiment 2) may have encouraged proactive control (as observed in Chevalier *et al.*, in preparation), particularly for perseverators, who had more room to improve. In addition, perseverators using reactive control may have been speeded by practice from the distracted DMS, while some switchers may have been slowed by carry-over effects, such as retaining a less-efficient reactive approach. While these possibilities are difficult to distinguish because this undistracted DMS followed a distracted DMS, the pattern of results across the two experiments indicates that switchers perform worse than perseverators on the DMS only under conditions of distraction.

## General discussion

Children who switch between rules can show better preparedness on a working memory task than children who perseverate on prior rules (in Experiment 1 only), but this pattern reverses in the face of distractions (in Experiment 2). We interpret this pattern in terms of benefits and costs of developments in cognitive control, specifically, developing proactive control. As children begin proactively maintaining information in anticipation of needing it, they can be better prepared when the time comes to use it, relative to children who encode the information and reactively retrieve it when prompted. However, children who have transitioned to proactive control are disproportionately impaired when proactive maintenance becomes difficult or impossible, when resources are limited. Under such circumstances, children who have transitioned to proactive control may perform more

poorly than children who rely more heavily on reactive control because proactive control is less efficient than reactive control, or the developmental transition to proactive control leads to less effective use of reactive control, or both.

Our findings help to validate a 3-dimensional change card sort task (Blackwell *et al.*, 2009; Deák, 2003) as an index of proactive control in children: The predicted costs and benefits of proactive control were observable with 3DCCS as the index of proactive control. In addition, switchers on the 3DCCS task showed marginally more visible proactive strategies on the working memory task in Experiment 1. However, switchers and perseverators showed similar use of visible proactive strategies in the more demanding working memory task of Experiment 2, which may indicate the importance of considering how proactive and reactive control are influenced by task demands as well as individual differences. More targeted measures of proactive control in children continue to be developed (Chatham *et al.*, 2009; Chevalier *et al.*, in preparation; Fisher, Thiessen, Godwin, Kloos & Dickerson, 2013), and should prove informative in future investigations.

These findings suggest caution in attempting to improve children's cognitive control. Such programs may benefit struggling children, given the important outcomes predicted by childhood cognitive control (Friedman *et al.*, 2007). However, speeding the transition to proactive control may have costs, such as shifting children to approaches that are less effective under certain circumstances, or prematurely reducing the efficacy of reactive control, and potentially impacting cognition more generally. For example, reactive control engages a prefrontal-hippocampal network (Braver, Gray & Burgess, 2007) and may shape the development of these regions (Chatham *et al.*, 2009), such that speeding the transition from reactive control could disrupt typical neural developments and associated processes.

Such potential trade-offs are relevant, because children do not simply grow out of reactive control; even adults will engage reactive control under some circumstances (e.g. Locke & Braver, 2008). Additional work should investigate how children and adults learn to coordinate different modes of cognitive control (Braver, Paxton, Locke & Barch, 2009), why the development of proactive control might lead to worse performance under demanding conditions (e.g. contrasting the inefficient-reactive-control and dual-tasking accounts considered here), and whether the trade-off observed here is specific to this transitional period or generalizes beyond it (e.g. with reactive processes showing continued decline as proactive control develops further). Such work should inform both theory and intervention developments.

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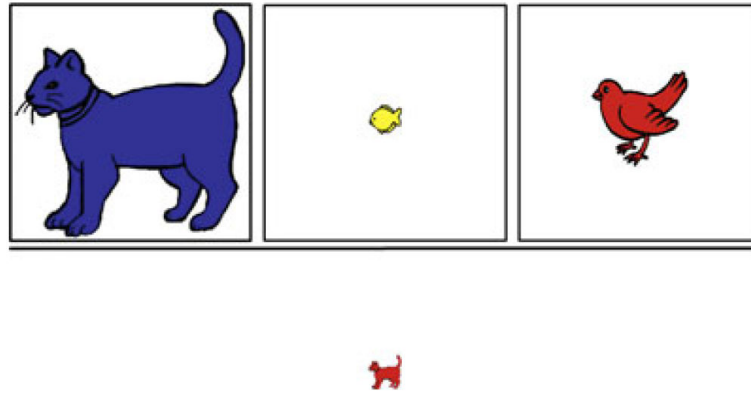
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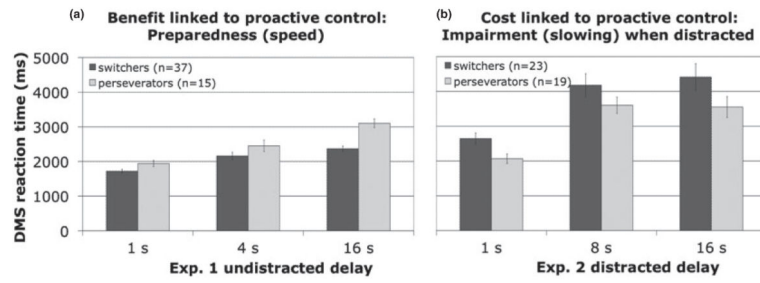
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### Research highlights

- The development of cognitive control predicts important life outcomes.
- We show that the developmental transition from predominantly reactive to increasingly proactive control is associated with benefits in preparedness.
- However, this transition is also associated with costs in reacting to demanding situations.
- Such trade-offs suggest that attempts to speed developments in cognitive control may have unanticipated consequences.



**Figure 1.** 3-dimensional card sort (from Blackwell et al., 2009). As a measure of flexible switching and an index of proactive control, children were instructed to sort stimuli that matched each target on one dimension, first by shape, then by color, then by size.



**Figure 2.**

(a) Benefits associated with proactive control (Experiment 1): Flexible task-switchers were faster than perseverators on a working memory task, particularly as working memory demands increased with delay. (b) Costs associated with proactive control (Experiment 2): Flexible task-switchers were slower than perseverators on a working memory task, when a distractor task made it challenging to actively maintain information during the delay.