The opposites task: Using general rules to test cognitive flexibility in preschoolers

Baker, S, Friedman, O and Leslie, A

http://dx.doi.org/10.1080/15248371003699944

RUNNING HEAD: INHIBITORY PROCESSING IN PRESCHOOLERS

In Press, Journal of Cognition and Development

The Opposites task: Using general rules to test cognitive flexibility in preschoolers

Sara T. Baker

University of Bristol

Ori Friedman

University of Waterloo

Alan M. Leslie

Rutgers University

July 7, 2009

Abstract

Executive functions play an important role in cognitive development and, during the preschool years especially, children's performance is limited in tasks that demand flexibility in their behavior. We asked whether preschoolers would exhibit limitations when they are required to apply a general rule in the context of novel stimuli on every trial (the "opposites" task). Two types of inhibitory processing were measured: response interference (resistance to interference from a competing response) and proactive interference (resistance to interference from a previously relevant rule). Group data show three-year-olds have difficulty inhibiting prepotent tendencies under these conditions, whereas five-year-olds' accuracy is near ceiling in the task.

Keywords: Executive functions, inhibition, preschool

The Opposites task: Using general rules to test cognitive flexibility in preschoolers

During the early years, children become increasingly able to control their actions in a context appropriate fashion (Diamond, 1988; Diamond & Doar, 1989; Diamond & Gilbert, 1989). This increased control depends on the development of executive functions and is accompanied by changes in the anatomical and functional structure of the brain (Amso & Casey, 2006). Executive processes are thought to underlie children's performance on laboratory tests in various cognitive domains, including *naïve physics* (e.g., Hood, Wilson & Dyson, 2006), *naïve mathematics* (e.g., Bull, Espy & Wiebe, 2008), and *naïve psychology* (e.g., Leslie, German & Polizzi, 2005). Moreover, cognitive flexibility, and behavioral regulation more generally, likely serves as a scaffold for appropriate behavior in school settings (Diamond, Barnett, Thomas & Munro, 2007; Mischel, Shoda & Rodriguez, 1989; Duckworth & Seligman, 2005; Blair & Razza, 2007; McClelland et al., 2007).

Executive functions are commonly viewed as a set of distinct abilities, and there is an emerging consensus that central components include working memory, set shifting, and inhibition (Huizinga, Dolan, & Van der Molen, 2006; Davidson, Amso, Anderson, & Diamond, 2006; Carlson, 2005; Casey, Giedd, & Thomas, 2000; Lehto, Juujarvi, Koositra & Pulkkinen, 2003). Nonetheless, the theoretical landscape presents some grey areas, particularly concerning inhibition (see for a discussion MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). Current measures of inhibitory processing are classified on a variety of orthogonal dimensions: There are conflict vs. delay tasks (Carlson & Moses, 2001), hot vs. cold tasks (Hongwanishkul, Happaney, Lee & Zelazo, 2005), response interference vs. proactive interference tasks (Friedman & Miyake, 2004), response given vs. open tasks (Simpson & Riggs, 2005), effortful vs. automatic inhibition tasks (Nigg, 2000), and so on. The relation amongst these different classification systems remains unclear, and researchers differ in how they fit specific tasks to the dimensions.

Several studies have used sophisticated statistical methods (e.g., confirmatory factor analysis) to evaluate the relationship between different measures of executive functions, including inhibitory resources. Huizinga et al. (2006) tested 7- to 21-year-olds with a battery of tasks, including three aimed at measuring inhibition of motor responses. Inter-correlations among the tasks were small and mostly non-significant, suggesting little coherence amongst various aspects of the inhibition construct. In a similar investigation of executive functioning in 9- to 12-year-olds, Van der Sluis, de Jong & van der Luij (2007) did not find a distinct inhibitory factor in their confirmatory factor analysis.[1] In contrast, Miyake et al. (2000) found weak, but significant, correlations amongst adults' scores on their inhibitory tasks. This discrepancy could be explained by methodological divergences (e.g., Huizinga et al. and Van der Sluis et al. controlled for non-executive factors while Miyake et al. did not) or differential organization of executive processes as a function of brain maturation. Given the elusive nature of inhibitory processes within the broader context of executive functions, it is desirable to have a battery of tasks that recruit a variety of capacities while minimizing noise due to variable task demands. The aim of the present study is to develop a measure of open response conflict inhibition targeting both response interference and proactive interference. This novel combination of features is explained below.

Measures of preschoolers' inhibitory processing typically require children to respond to a small set of stimuli, by following rules that specify the exact response required. For example, in the day/night task, children are instructed to say "night" when shown cards depicting daytime and to say "day" to cards depicting nighttime (Diamond, Kirkham & Amso, 2002; Gerstadt, Hong, & Diamond, 1994). Three-year-olds often fail to follow these instructions, and often err by saying "day" for day cards and night for "night" cards.[2]

To consider a second example, the dimensional change card sort (DCCS) requires children to sort cards into two piles first using one rule (e.g., put blue things here, put red things there) and then using a second rule (e.g., put cars here, put flowers there). Three-year-olds easily sort according to the first rule, but often have difficulty in switching to the second rule (Frye, Zelazo, & Palfai, 1995; Zelazo, Müller, Frye, & Marcovitch, 2003; Zelazo, Frye & Rapus, 1996).[3] As in the day/night task, the task rules specify the desired stimulus-response mappings, and so the same responses remain correct for the duration of each sorting rule. The main point for current purposes is that success in both the day/night and DCCS tasks can be achieved using rules that concretely link a small set of stimuli to specific desired responses. The instructions children receive specify which response should be produced in the presence of each stimulus and are therefore classified as "response-given" tasks.

In everyday life, however, children are often required to apply rules that do not specify a concrete response. Consider a girl who has been asked to follow the request or rule: "Put your toys away right now!" Following this rule will likely require inhibition, because the girl must overcome her natural tendency to play with each toy, and to instead select the conflicting response of putting each where it belongs. Unlike the rules in most inhibitory tasks, the rule "Put your toys away right now!" does not specify a particular input (e.g., day card) because the rule can be applied to any of the girl's toys. And the rule does not identify an exact response (e.g., say "night") because the various toys belong in different places. We refer to such rules as "general" rules.

In putting away her toys, the girl follows a rule that is more open or general than the rules typically used in response-given inhibitory tasks. One task that appears to use general rules is the Whisper task (Kochanska et al., 1996). In this task, children are asked to whisper the names of different familiar cartoon characters. Three-year-olds find this difficult because their first tendency is to shout out the names. The Whisper task requires applying a general rule to the varying pictures, yet the part of the response program (whisper, don't shout) that poses difficulty remains the same from trial-to-trial. The rule resolves the conflict by explicitly stating "whisper". Thus, the rule constrains the response to such a degree that the task does not require much generalization across trials.

The present experiment introduces the opposites task, a measure of inhibitory control that requires preschoolers to apply a general rules across varying stimuli, while also requiring varying responses on every trial. Most existing inhibition tasks for preschoolers either require children to overcome proactive interference from a previously relevant rule (e.g, the DCCS) or to overcome the pull of a competing response (e.g, the day/night task). However, the opposites task assesses both response interference and proactive interference, while equating for task demands. On each of several trials, children were shown two pictures which semantically opposed (or contrasted) each other, and the experimenter named one of them. In a first testing block, children learned either a congruent or an incongruent rule. For example, children learning the congruent rule had to point to a picture of an open door upon hearing the word "open"; those learning the incongruent rule had to point to the picture of a closed door when they heard the word "open". Comparing performance across these two rules gives a measure of *response interference*. Response interference should arise when children are asked to go against a prepotent tendency, in this case the tendency to point to the picture of the word they hear. [4] In a second testing block, children either continued using the same rule or switched rules. To successfully switch rules, children needed to overcome *proactive interference* from the previously relevant rule. For example, if children first learn the congruent rule, then they need to switch rules in the second block and follow the incongruent rule.

There were therefore four conditions, varying in which rule was used in the first block, and in whether or not there was a rule switch in the second block. The conditions were expected to differ in levels of inhibitory effort required for success. We expected that learning the incongruent rule in the first block would introduce difficulty (due to response interference) relative to learning the congruent rule on the first block. Similarly, requiring a rule switch in the second block would be more difficult (due to proactive interference) than allowing the child to continue using the same rule. We expected that the congruent-congruent condition would yield the highest performance overall because the rule did not require inhibition and there was no rule switch. We predicted that the most difficult block would be the second block of the "congruent-incongruent" condition because it would combine both response interference and proactive interference. We expected to observe age-related improvements in first block incongruent performance and in second block switch performance. Specifically, three-year-olds should show more errors than five-year-olds in the incongruent first block. Three-year-olds should also show more errors than five-year-olds in the second block after switching rules.

Experiment

Method

Participants. The experiment was completed by 244 children (115 boys, 129 girls) who were randomly assigned to one of the four conditions: congruent-congruent, congruent-incongruent, incongruent- incongruent, incongruent-congruent. There were 67 three-year-olds (M = 43 months, SD = 3.0 months), 100 four-year-olds (M = 54 months, SD = 3.2 months), and 77 five-year-olds (M = 64 months, SD = 4.0 months). Eight additional children were excluded from the analysis. Five children were excluded because they were not following the basic turn-taking structure of our task, two were excluded due to experimenter error, and one was excluded due to distracting circumstances during the test session.

Materials. The experiment used an 8x11 inch binder, containing 14 laminated pages. Each page showed two pictures side by side, separated by a line. The pictures were approximately four inches in diameter. Some pages displayed semantically opposed pairs of pictures (e.g., open and closed doors), while others displayed variations along a relevant dimension (e.g., swimming and flying ducks; see Appendix). For 191 children the experimenter went through the book from front to back and for 53 children the experimenter went through the book from back to front (14 three-year-olds, of whom seven learned the incongruent rule first, 20 four-year-olds of whom ten learned the incongruent rule first, and 19 five-year-olds of whom nine learned the incongruent rule first).

Procedure. The same female experimenter administered every individual session during school hours in a quiet area of the child's preschool. The task consisted of two blocks of trials. Each block began with the experimenter giving the instructions. At the start of congruent blocks, children were told: "We are going to play a game. In this game, I am going to say a word. Then, on your turn, you just point to the picture I said. Ready?". At the start of incongruent blocks, children were told: "We are going to play a silly game. I'm going to say a word. Then you point to a picture on my page. But guess what? Don't point to the one I say. You point to the other picture. OK? Whatever you do, don't point to the picture I say, you have to show me the other one! Ready?").

In each trial a different pair of pictures was displayed; the experimenter reminded children of the rule (e.g., "pointing to the *other* picture, *not* the one I say….") and then said the target word. The first trial of each block was a training trial. Children who passed this trial were told that they had done a great job and were ready to play the game "for real". Children who pointed to the wrong picture in the first training trial were reminded of the rule, heard the target word once again, and were then given a second chance to point. Those who pointed to the wrong picture on this second training trial were shown the correct response, were reminded of the rule again, and were told that they would start the game for real. The remaining six trials in each block were test trials. The child received a sticker at the end of the session, which lasted approximately 10 minutes.

For training trials, we counted the number of attempts children required. Children who passed on the first training trial received a score of 1, children who passed on the second training trial received a score of 2, and children who failed both training trials received a score of three. For test trials, the first picture pointed to was scored, even if a second response was made. Children were given 1 for each correct answer in each block, so scores ranged from zero to six.

Results

We first examined whether gender was a factor in our pointing task. A 2 x 2 ANOVA (gender x block) showed that gender did not significantly affect preschoolers' performance in any of the training or in any of the test blocks (block one training: $F(1, 240) = 2.778$, $p = .097$; block one test: $F(1, 240) = .125$, $p = .724$; block two training: $F(1, 240) = .901$, $p = .343$; block two test: $F(1, 240) = .031$, $p = .861$). Gender was not considered as a factor in subsequent analyses.

Next, data were entered into 2 x 2 (order x block) ANOVA to test whether the order of presentation of our pages affected children's training or test performance. There was a significant effect of order on block one training ($F(1, 240) = 5.004$, $p = .026$). Children who saw the pages in reverse order needed less training (M = 1.19, SD = .483) than children who saw the book in the original order (M = 1.40, SD = .673). However, the means for both groups remained under two, showing that on average all children were able to correctly learn the rules during training. Furthermore, because there was no effect of order on the number of correct answers during the test phases, we collapsed the two orders for subsequent analyses.

We then entered children's scores into a 3 x 2 x 2 ANOVA (age x first block rule x rule switch). There was a main effect of age on training scores and on test scores in both blocks (block one training, $F(1,232) = 5.943$, $p = .003$; $\eta^2 = .049$; block one test, $F(1,232) = 7.082$, $p = .001$, $\eta^2 = .058$; block two training, $F(1,232) = 13.284$, $p < .001$,

$\eta^2 = .103$; block two test, $F(1,232) = 14.134, p < .001; \eta^2 = .109$). Children got better at the task as they got older.

We found a main effect of rule on training in the first block ($F(1,232) = 20.018, p < .001, \eta^2 = .079$). We also found a main effect of rule on performance on the test items in the first block ($F(1,232) = 61.778, p < .001, \eta^2 = .210$). During training it was easier to learn the congruent rule (mean training trials = 1.18, SD = .464) than the incongruent rule (mean training trials = 1.53, SD = .741). Likewise the congruent rule was easier to apply during test than the incongruent rule (see table for means).

INSERT TABLE ABOUT HERE

In the second block there were main effects of rule switching on training scores ($F(1,232) = 14.531, p < .001, \eta^2 = .059$) and on test scores ($F(1,232) = 19.899, p < .001, \eta^2 = .079$). Children required more trials to learn a new rule in the second block (M = 1.5 trials for training, SD = .79) than to demonstrate their understanding of a rule they had used before (M = 1.2 trials for training, SD = .53). Children who switched rules in the second block performed worse, irrespective of the rule they were required to apply (M = 4.17, SD = 2.167), than children who continued to use the same rule in the second block (M = 5.08, SD = 1.783).

Switch costs depended on the direction of the switch. An interaction between first block rule and rule switching revealed higher switch costs when children had to switch from using the congruent rule to using the incongruent rule: training scores in second block: (F(2,232) = 15.558, $p < .001$, $\eta^2 = .063$) and test scores in second block: (F(2,232) = 66.372, $p < .001$, $\eta^2 = .222$; see table for means).

There was also a significant three-way interaction between first block rule, rule switching and age on training scores (F(2,232) = 5.067, $p < .007$; $\eta^2 = .042$) and test scores (F(2,232) = 6.946, $p = .001$; $\eta^2 = .056$) in the second block. The difference in switching to a congruent versus an incongruent rule was thus somewhat accentuated for the younger children compared to the older children. Given that the two-way first block rule x rule switching interaction was of moderate effect size (~22% variance accounted for) while the three-way interaction showed a small effect size (~6% variance accounted for), we think it unlikely that the two-way effect was subsumed under the three-way effect.

Discussion

This opposites task allows resistance to both response interference and proactive interference to be measured in the context of an open response conflict inhibition task. Children were required to apply a general congruent or incongruent rule across varying stimuli, and then to switch rules or continue use of the original rule. The incongruent rule was harder than the congruent rule, especially for the three-year-olds. This finding is consistent with findings from the day/night task, where three-year-olds typically match their verbal response to the stimulus card rather than following the incongruent rule (saying "day" to night cards and vice versa; Gerstadt, Hong & Diamond, 1994).

Children had more trouble switching rules than continuing to use the same rule. Children had the most difficulty when they had to switch rules in the second block and to apply the difficult, incongruent rule. This suggests children's difficulty was compounded when they had to overcome response interference from a prepotent tendency while resisting proactive interference from a previous rule. These findings are similar to three-year-olds' behavior in the classic dimensional change card sort, where young preschoolers perseverate in sorting cards according to the first rule they use, even though they understand a new rule has been introduced (Zelazo, Frye & Rapus, 1996).

Our findings contrast with findings from other rule switching tasks. Using the same/silly card sorting task, Brooks and colleagues found that three-year-olds successfully switched from a block of congruent trials to a block of incongruent trials, or vice versa, as long as there was no irrelevant information on the cards (Brooks, Hanauer, Padowska & Rosman, 2003). Likewise, three-year-olds succeeded in Perner & Lang's (2002) reversal shift task, which also used two blocks of trials and included a second block incongruent rule after a rule switch.

Poorer performance in the opposites task might have resulted because this task requires children to apply a general rule across novel stimuli on every trial. Seeing new pictures and hearing new words in each trial increases the amount of information children need to process, perhaps increasing difficulty for young children whose inhibitory resources are weak. Future investigations can target the ways in which preschoolers' cognitive load affects their cognitive flexibility.

The general nature of the rules in the opposites task elicits behavior which has theoretical implications for two dominant theories of cognitive flexibility: the attentional inertia account (Kirkham, Cruess & Diamond, 2003; Diamond & Kirkham, 2005) and the cognitive control and complexity theory (Zelazo, Müller, Frye & Marcovitch, 2003). Neither of these accounts alone predicts that the most difficult condition in our task is the second block of trials after a rule switch when children must apply the incongruent rule to varying stimuli. The attentional inertia account offers an explanation for children's difficulty shifting attention from one perceptual dimension to another (e.g., color to shape). This account cannot explain children's difficulty with the incongruent rule in our task. Children do not need to overcome a tendency to fixate on a single perceptual dimension in order to successfully apply our general rule. The cognitive control and complexity theory focuses on children's ability to embed complex rule structures in the service of their actions, and offers an explanation for why rule-switching is difficult for young children. But as far as we can tell, success on the opposites task does not require representing an embedded rule structure.

Where does three-year-olds' difficulty come from in our task? Accounts of preschoolers' executive functions must include some role for a cognitive mechanism whereby children can manipulate their own conceptual representations above and beyond any learned stimulus-response pairings. Where such a capacity is limited we may then observe conceptual inertia—difficulty switching away from using a general rule (i.e. one not specifying fixed stimulus-response pairings). Conceptual inertia is similar to the notion of cognitive inhibition put forth by Nigg (2000).

We believe older children did better than younger children in our task because older children have greater inhibitory resources, allowing them to overcome conceptual inertia more readily than younger children. Alternatively, older children might be better at applying the incongruent rule because their underlying impulse to match the auditory stimulus is weaker than younger children's (Simpson & Riggs, 2005). In other words, performance improvements might reflect decreases in the strength of interfering responses, rather than increases in the capacity to resist interference. To support our account over this competing explanation, we decided to test whether the natural impulse to match the auditory stimulus is as strong for older children as it is for younger children. We presented 50 new three- to five-year-olds with the visual and auditory stimuli used in the main experiment. This time we did not give them a rule to follow. Instead we told them that they could point "wherever they wanted". We recorded the number of times these children pointed to the incongruent picture. Children showed a significant matching bias, which did not vary with age. These findings suggest that even five-year-olds have a natural tendency to produce congruent actions, implying that age-related improvements in the incongruent condition of the opposites task result from increasing inhibitory capacity.

It is noteworthy that switching to the congruent rule was easier than switching to the incongruent rule. Two other developmental studies of rule-switching found higher costs for switching to the congruent rule, as compared to the incongruent rule (Davidson, Amso, Anderson, & Diamond, 2006; Crone, Bunge, Van der Molen, & Ridderinkhof, 2006). The disparity in the findings may result from differences in the ages of the children in question, or from differences in procedures. Our opposites task presented one block of six post-switch trials using the same rule, while Davidson et al. and Crone et al. used tasks with mixed blocks, where children were required to switch rules several times back and forth. Thus, on their congruent switch trials, children's responses might have been subject to a phenomenon similar to inhibition of return. Inhibition of return occurs when attention to a stimulus is suppressed, making it more difficult to attend to the same stimulus on subsequent trials (for a review see Klein, 2000). Perhaps in Davidson et al.

and Crone et al.'s studies, children suppressed the congruent rule when switching to the incongruent rule and then had trouble returning to it. The fact that the congruent rule is more natural, as shown by our baseline measure described above, implies that stronger inhibitory effort might be required to suppress it when switching away. Hence inhibition of return would be more apparent for congruent trials in mixed blocks, compared to incongruent trials. There was no opportunity for such a mechanism to take hold in our task because there was only one rule switch.

The opposites task offers three attractive features. First, we have a baseline measure of children's tendency to match the word they hear and the picture they point to in the absence of any instructions. This measure of the prepotent response is crucial in any discussion of inhibition. Indeed it is difficult to talk about inhibition without describing what is being inhibited. The whisper task does not have such a baseline (Kochanska et al., 1996). A control condition for the day/night task associates stimuli with semantically unrelated words (Diamond, Kirkham & Amso, 2002). Although this control measures performance in a context presumed to require less inhibitory effort, it does not measure prepotent behaviours. The dimensional change card sort has a condition with a congruent rule, but no baseline condition to measure pre-potent behaviors (Zelazo, Müller & Marcovitch, 2003). The baseline condition of our opposites task allows us to quantify the urge we are asking the children to go against during the more difficult incongruent trials.

The second feature is that the opposites task contains two measures of inhibition, one requiring resistance to response interference (comparable to the inhibitory effort in the day/night and whisper tasks) and one requiring resistance to proactive interference from a previously relevant rule (such as in the post-switch block of the dimensional change card sort and other set-shifting tasks). Being able to assess two types of inhibitory effort within one task allows us to compare these two types of inhibition while reducing potential for noise due to varying performance factors. Finally, our task uses an open response format, in which a general rule is applied across various stimulus-response pairings.

Our task presents a high degree of ecological validity compared to other laboratory tasks. Indeed context-appropriate behavior depends crucially on creating novel pairings between stimulus and response rather than perseverating in inappropriate ways. To achieve this level of cognitive flexibility children must be able to apply general rules across varying contexts that do not share particular stimulus-response pairings. For example, a child must learn to take turns and wait until the opportune moment rather than acting impulsively whether in school with peers, at home with siblings or in a novel context with strangers. Our opposites task, with its unique combination of features, provides a way of measuring this set of capacities, which are relevant both in principle and in practice.

References

Amso, D., & Casey, B.J. (2006). Beyond what develops when: Neuroimaging may inform how cognition changes with development. *Current Directions in Psychological Science*, *15*, 24-29.

Blair, C., & Razza, R.P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647-663.

Brooks, P.J., Hanauer, J.B, Padowska, B., & Rosman, H. (2003). The Role of selective attention in preschoolers' rule use in a novel dimensional card sort. *Cognitive Development*, *18*, 195-215.

Bull, R., Espy, K.A., & Wiebe, S.A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*, 205-228.

Carlson, S.M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*, 595-616.

Carlson, S.M., & Moses, L.J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*, 1032-1053.

Casey, B.J., Giedd, J.N., & Thomas, K.T. (2000). Structural and functional brain development and its relation to cognitive development. *Biological Psychology*, *54*, 241-257.

Crone, E.A., Bunge, S.A., Van der Molen, M.W., & Ridderinkhof, K.R. (2006). Switching between tasks and responses: A Developmental study. *Developmental Science*, *9*, 278-287.

Davidson, M.C., Amso, D., Anderson, L.C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*, 2037-2078.

Denckla, M.B., & Reader, M.J. (1993). Education and psychosocial interventions: Executive dysfunction and its consequences. In R. Kurlan (Ed.), Handbook of Tourette's Syndrome and Related Tic and Behavioral Disorders. New York: Marcel Dekker, 431-451.

Diamond, A. (1988). Differences between adult and infant cognition: Is the crucial variable presence or absence of language? In L. Weiskrantz (Ed.), *Thought without language*, (pp. 335–370). Oxford: Oxford Science Publications.

Diamond, A., Barnett, W., S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*, 1387-1388.

Diamond, A., & Kirkham, N. (2005). Not quite as grown-up as we like to think: Parallels between cognition in childhood and adulthood. *Psychological Science*, *16*, 291-297.

Diamond, A., & Doar, B. (1989). The performance of human infants on a measure of frontal cortex function, the delayed response task. *Developmental Psychobiology*, *22*, 271–94.

Diamond, A., & Gilbert, J. (1989). Development as progressive inhibitory control of action: Retrieval of a contiguous object. *Cognitive Development*, *4*, 223–249.

Diamond, A., Kirkham, N.Z., & Amso, D. (2002). Conditions under which young children can hold two rules in mind and inhibit a prepotent response. *Developmental Psychology*, **38**, 352-362.

Duckworth, A.L., & Seligman, M.E.P. (2005). Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychological* Science, *16*, 939-944.

Friedman, N.P., & Miyake, A. (2004). The Relations among inhibition and interference control functions: A Latent-variable analysis. *Journal of Experimental Psychology: General.* 101-135.

Frye, D., Zelazo, P.D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development*, *10*, 483-527.

Gerstadt, C., Hong, Y., & Diamond, A. (1994). The relationship between cognition and action: Performance of 3 ½ -7 year old children on a Stroop-like day/night test. *Cognition*, *53*, 129-153.

Hongwanishkul, D., Happaney, K.R., Lee, W.S.C, & Zelazo, P.D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*, 617-644.

Hood, B.M., Wilson, A., & Dyson, S. (2006). The Effect of divided attention on inhibiting the gravity error. *Developmental Science*, 303-308.

Huizinga, M., Dolan, C.V., & Van der Molen, M.W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, *44*, 2017-2036.

Kirkham, N., Cruess, L., & Diamond, A. (2003). Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science*, *6*, 449-476.

Klein, R. (2000). Inhibition of return. *Trends in Cognitive Sciences*, *4*, 138-147.

Kochanska, G., Murray, K., Jacques, T.Y., Koenig, A.L., & Vandegeest, K.A. (1996). Inhibitory control in young children and its role in emerging internalization. *Child Development*, *67*, 490-507.

Lehto, J. E., Juujärvi, P., Kooistra, L., Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, *21*, 59-80.

Leslie, A.M., German, T., & Polizzi, P. (2005). Belief-desire reasoning as a process of selection. *Cognitive Psychology*, *50*, 45-85.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation*, Vol. 43 (pp. 163-214). San Diego, CA: Academic Press.

Mahone, E.M., Koth, C.W., Cutting, L., Singer, H.S., & Denckla, M.B. (2001). Executive function in fluency and recall measures among children with Tourette syndrome or ADHD. *Journal of the International Neuropsychological Society*, *7*, 102-111.

McClelland, M.M., Cameron, C.E., Connor, C.M., Farris, C.L., Jewkes, A.M., & Morrison, F.J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*, 947-959.

Meltzer, L., Katzir-Cohen, T., Miller, L., & Roditi, B. (2001). The Impact of effort and strategy use on academic performance: Student and teacher perceptions. *Learning Disability Quarterly*, 85-98.

Mischell, W., Shoda, Y., & Rodriguez, M.L. (1989). Delay of gratification in children. *Science*, *244*, 933-938.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., & Howerter, A. (2000). The Unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A Latent variable analysis. *Cognitive Psychology*, *41*, 49-100.

Müller, U., Dick, A.S., Gela, K., Overton, W.F., & Zelazo, P.D. (2006). The Role of negative priming in preschoolers' flexible rule use on the dimensional change card sort task. *Child Development*, *77*, 395-412.

Nigg, J.T. (2000). On Inhibition/ disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, *126*, 220-246.

Perner, J., & Lang, B. (2002). What causes 3-year-olds' difficulty on the dimensional change card sorting task? *Infant and Child Development*, *11*, 93-105.

Simpson, A., & Riggs, K.J. (2005). Factors responsible for performance on the day/night task: Response set or semantics? *Developmental Science*, *8*, 360-371.

Van der Sluis, S., de Jong, P.F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence*, *35*, 427-449.

Wiebe, S.A., Espy, K.A., & Charak, D. (2008) Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, *44*, 575-587.

Zelazo, P.D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development*, *11*, 37-63.

Zelazo, P.D., Müller, U., Frye, D., & Marcovitch, S. (2003). The Development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*.

Appendix

List of items used in the opposites game.

Tied	Untied
Boy	Girl
Flying	Swimming
Healthy	Sick
Hot	Cold
Rainy	Sunny
Closed	Open
Up	Down
Sleeping	Awake
Empty	Full
Angry	Friendly
Big	Small
Winter	Summer
Old	Baby

Acknowledgments

The authors gratefully acknowledge the children, parents and schools who gave their time for this work. Research assistants in the Rutgers Cognitive Development Lab contributed administrative support to the project. The National Science Foundation partially funded our work through grant BCS-0725169 to AML. We are indebted to Bruce Hood, Ulrich Müller, Douglas Frye and Patricia Bauer as well as two anonymous reviewers for their helpful comments on earlier drafts.

Address correspondence to: Sara Baker, Department of Experimental Psychology, University of Bristol, 12a Priory Road, Bristol, BS8 1TU, England; Phone: +44(117)954 6613; s.baker@bristol.ac.uk

Footnotes

[1] This may have been because the variance unique to inhibition was captured in a measure of response latency and contributed to the Naming factor (see p. 444 of their discussion).

[2] In another version of the task, children are required to "say the opposite" when they see a card. Still, the correct response ("day" for night card and "night" for day card) is specified by the experimenter in the training phase and this stimulus-response mapping does not change.

[3] Some authors have suggested that inhibitory capacity is not solely responsible for children's performance in the card sorting task. Activation of previously suppressed information and hierarchical rule representation may also play a role (Zelazo, Müller, Frye & Marcovitch, 2003; Müller, Dick, Gela, Overton & Zelazo, 2006).

[4] Response interference does not arise solely from a conditioned tendency for children to match what they hear. In modified versions of the day/night task, children were required to say "day" to abstract designs, or to say "dog" to a picture of the sun (Gerstadt et al. [1994] and Diamond et al. [2002]). These conditions elicited better performance from four-year-olds than the classic rule "say 'day' to moon cards and 'night' to sun cards". Thus it is more difficult for four-year-olds to produce an incongruent response when it is semantically opposed to the stimulus than when there is no semantic relation to the stimulus. Response interference arises not only when children must complete an action going against previous actions, but specifically if there is a concurrent, competing action in the response set that is relevant, and prepotent. Interference from a previously relevant action is reflected in the notion of proactive interference. It is worth noting that response interference and proactive interference are not mutually exclusive. Some contexts may call up both types of interference simultaneously.

Table 1.
Mean Percentage Correct in Second Block by Age, Rule and Switch. Average Raw Score out of Six, Standard Deviation in Parentheses.

	Congruent			Incongruent		
	First block	Second block		First block	Second block	
		No switch	Switch		No switch	Switch
Three-year-olds	91.33 (5.48, .712)	91.67 (5.50, .86)	80.5 (4.83, 1.54)	52.5 *n.s.* (3.15, 2.36)	56.33 *n.s.* (3.38, 2.50)	22.17 (1.33, 1.80)
Four-year-olds	96.33 (5.78, .545)	97 (5.82, .48)	85.33 (5.12, 1.37)	70 (4.20, 2.46)	75 (4.50, 2.30)	48.5 *n.s.* (2.91, 2.33)
Five-year-olds	98.33 (5.90, .307)	99 (5.94, .24)	88 (5.28, 1.64)	80.33 (4.82, 1.78)	82.5 (4.95, 1.91)	80.17 (4.81, 1.60)

All means are significantly different from chance at $p < .01$ except those indicated by *n.s.*