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Sustained selective attention predicts flexible switching in preschoolers

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ABSTRACT

Stability and flexibility are fundamental to an intelligent cognitive system. Here, we examined the relationship between stability in selective attention and explicit control of flexible attention. Preschoolers were tested on the Dimension Preference (DP) task, which measures the stability of selective attention to an implicitly primed dimension, and the Dimension Change Card Sort (DCCS) task, which measures flexible attention switching between dimensions. Children who successfully switched on the DCCS task were more likely than those who perseverated to sustain attention to the primed dimension on the DP task across trials. We propose that perseverators have less stable attention and distribute their attention between dimensions, whereas switchers can successfully stabilize attention to individual dimensions and, thus, show more enduring priming effects. Flexible attention may emerge, in part, from implicit processes that stabilize attention even in tasks not requiring switching.

Introduction

An intelligent cognitive system depends on both stability and flexibility. Stability is relevant because similar contexts and tasks benefit from similar solutions. Adaptive intelligence, however, also

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requires dropping old solutions when some shift in task and context demands a change. Basic properties of the cognitive system seem to ensure both stability and flexibility. On the side of stability, the processing of immediate input emerges within the current state of the system such that there is a pull toward the just immediate past, a pull evident in phenomena such as priming (Gershkoff-Stowe, Connell, & Smith, 2006; Huttenlocher, Vasilyeva, & Shimpi, 2004; Naito, 1990; Thothathiri & Snedeker, 2008) and perseveration (Cragg & Chevalier, 2012; Deák, 2003; Smith & Samuelson, 1997; Smith, Thelen, Titzer, & McLin, 1999). On the side of flexibility, processes of habituation, the attraction of the unexpected, and internal control processes work to shift attention and thoughts in new directions (Addyman & Mareschal, 2013; Horst, Samuelson, Kucker, & McMurray, 2011; Kidd, Piantadosi, & Aslin, 2012; Miyake et al., 2000). Attention can be sustained selectively through implicit processes that stabilize attention, and it can be flexibly shifted through explicit control processes to fit new task goals (Cepeda, Kramer, & Gonzalez de Sather, 2001; Rueda, Posner, & Rothbart, 2005; Zukier & Hagen, 1978). The ability to both stabilize attention and flexibly shift attention in the service of a goal is a significant achievement in human cognition and one with a long and protracted developmental course that spans from infancy to adolescence (Best & Miller, 2010; Garon, Bryson, & Smith, 2008).

During the late preschool period, young children begin to show increasingly robust abilities in flexibly shifting their attention. One widely used task to measure flexible attention is the Dimension Change Card Sort (DCCS) task (Frye, Zelazo, & Palfai, 1995). On the DCCS task, children are asked to sort cards varying on two dimensions (usually shape and color; see Fig. 1). On the first phase of the task children are asked to sort the cards by one dimension, and on the second phase they are asked to switch and sort the same cards by the other dimension. Younger and older preschoolers sort by the first rule without error. However, when the rule changes, only older preschoolers adjust their behavior to the new rule. A recent meta-analysis found that only 41% of children switch successfully at 3 years of age on the post-switch phase of the DCCS task, whereas 88% of children do so at 5 years of age (Doebel & Zelazo, 2015). These findings suggest that older preschoolers can flexibly switch their attention to previously irrelevant information according to an explicit task rule.

At the same time that children's attention is becoming more flexible, allowing children to switch attention between dimensions, an older literature points to a similar progression in the ability to stabilize attention to individual dimensions. To examine attentional stability, this older literature measures children's ability to sort or classify stimuli by a single dimension, property, or attribute in the face of irrelevant or distracting information. For example, when asked to sort cards by one dimension, young preschoolers are more affected than adults by variation along the irrelevant dimension even though the relevant property is always explicitly stated in the instructions (Smith & Kemler, 1978). Younger children also appear to flit inconsistently from one property to the next or distribute attention unsystematically across dimensions, whereas older children seem to more consistently track a single property or dimension (Cook & Odom, 1992; Gelman, 1969; Lane & Pearson, 1982; Smith & Kemler, 1978; Strutt, Anderson, & Well, 1975; Thompson & Markson, 1998). This increased ability to focus on comparisons of objects along a single dimension has also been shown in tasks where children were not explicitly instructed about which attribute to selectively attend to (Smith, 1989; Thompson, 1994; Ward, 1980; see also Hanania & Smith, 2010). That is, even in uninstructed sorting tasks, older children selectively attend to a single dimension better than younger children, suggesting that the ability to stabilize selective attention during sorting or classification does not necessarily require explicit task demands. One idea is that for older perceivers, sustained selective attention to a single dimension is driven by implicit default processes (Garner, 1974). This idea finds support in studies showing that priming (an implicit process where repetition aids in maintaining attention to a stimulus, attribute, or dimension over time) is positively associated with the ability to filter out distractions during classification. For example, the repetition of a target stimulus has been found to facilitate classification of that stimulus in the presence of distracting information (Day & Stone, 1980; Enns & Cameron, 1987). Together, these findings suggest improvements during the preschool years in children's ability to stabilize attention selectively to relevant individual properties and that this ability may rely on developmental changes in implicit attentional processes.

How are developmental advances in stable selective attention and in flexible attention related? One possibility is that these abilities develop independently, with processes such as priming attention through repetition emerging before the ability to explicitly switch attention in response to changing

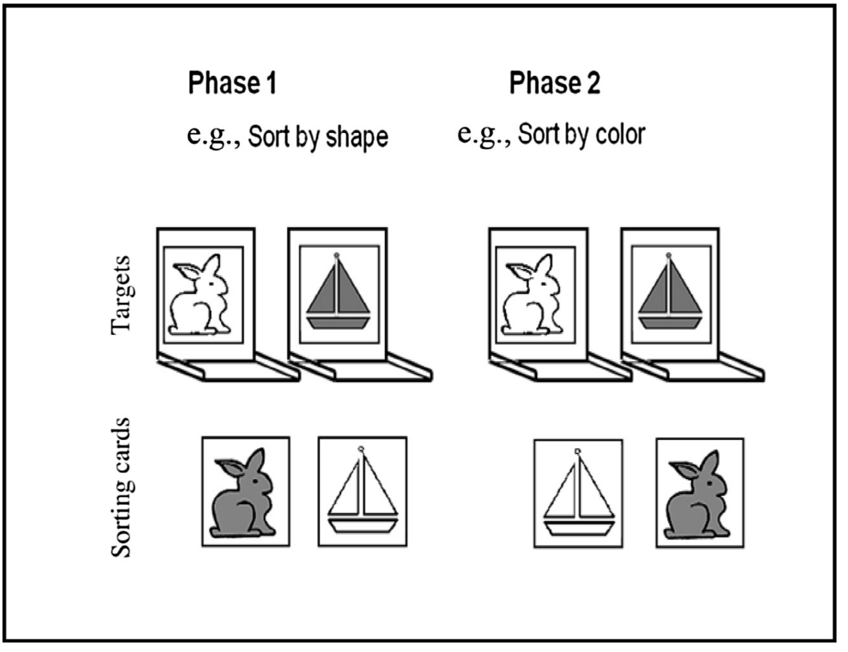

Fig. 1. The two phases of the Dimension Change Card Sort (DCCS) task. Children are provided with *sorting* cards that vary on two dimensions: color and shape. In each phase, children are asked to place the sorting cards into two boxes marked by *target* cards, each of which matches the sorting cards on exactly one dimension. In Phase 1, children are asked to sort by one dimension (e.g., shape). In Phase 2, children are asked to switch to sorting the same cards by a different dimension (e.g., color). Children's ability to sort correctly in Phase 2 (the post-switch phase) is taken as a measure of their ability to switch between relevant dimensions.

task demands. However, these two processes could compete such that children who have just achieved the ability to stick to one source of information could initially have trouble shifting attention. This hypothesis fits the current understanding of performance on the post-switch phase of the DCCS task: Not all children can switch away from the previously relevant, but now irrelevant, dimension (Diamond, Kirkham, & Amso, 2002; Kirkham, Cruess, & Diamond, 2003; Kloo & Perner, 2005; Müller, Dick, Gela, Overton, & Zelazo, 2006; Zelazo, Müller, Frye, & Marcovitch, 2003).

Another way in which stability and flexibility may be related is that stable attention processes may actually lead to and support the ability to flexibly switch between dimensions. Several studies have reported positive correlations between implicitly sustained selective attention over time (as measured by priming tasks) and preschool children's ability to inhibit attention to distractions in an explicit attention task (Burden & Mitchell, 2005; Day & Stone, 1980; Enns & Cameron, 1987; see also Kharitonova & Munakata, 2011). Arguably, the ability to switch to a new rule on the DCCS task would seem to benefit from a system that can easily identify and sustain attention ("stick") to that new dimension selectively so as to avoid reverting to the old dimension and sorting incorrectly. Furthermore, the processes that enable children to "stick" to the new dimension after the explicit instructions to switch could be supported by implicit attentional processes.

The study reported in this article was designed to test these possibilities. We compared preschool children's performance in two tasks: the DCCS task and an implicit Dimension Preference (DP) task (Medin, 1973). The DP task presents children with a triad of figures that vary on two dimensions (see Fig. 2). In the test trials, the target matches one choice figure in color and the other choice figure in shape. Children are asked to choose the figure "most like" the target. Similar to the DCCS task, the DP task measures children's ability to judge stimuli based on a single dimension. Unlike the DCCS task, however, there are no rules and no mention of the dimensions or attributes. Instead, the task measures

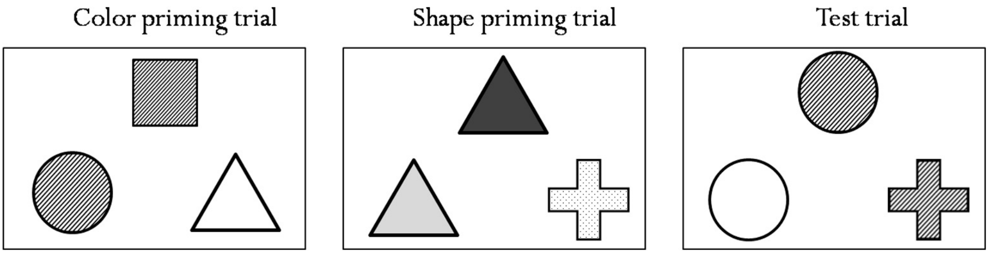

Fig. 2. Sample triads for the Dimension Preference (DP) task. Each triad is composed of the target object (top item), and two choices (bottom items), from which children were instructed to choose the item that was "most like" the target object. In the priming trials, only one choice matches the target object along a single dimension (color or shape). In the preference test trials, each choice object matches the target object along one dimension; for example, the target object, a red circle (dark), matches one choice object, a red cross (dark), in color and the other choice object, a blue circle (light), in shape. Children were presented with 2 priming trials that primed the same dimension (either two color priming trials or two shape priming trials) and then were presented with 10 test trials. The relevant measure of interest is children's choice during the test trials when primed with either color or shape.

momentary preferences for comparing the figures along one dimension. Medin (1973) showed that when exposed to a few beginning trials in which only one choice figure matched the target figure on one dimension (see Fig. 2), children often continued to choose that same dimension on the competing dimension test trials. This suggests that even in the absence of explicit instruction, children can be primed to sustain their attention to a single dimension across trials. Therefore, in contrast to other measures of sustained selective attention (e.g., Fisher, Thiessen, Godwin, Kloos, & Dickerson, 2013), the DP task measures children's ability to sustain attention to a single dimension through implicit processes (i.e., priming). By examining individual children's performance across the DCCS and DP tasks, we can ask whether sustained selective attention, driven by implicit processes, is related to flexible switching. We compared children across a wide age range, representative of the time period within which children's abilities to switch on the post-switch phase of the DCCS task improve. If sustained selective attention and flexible switching develop independently, then performance on one task should not be related to performance on the other task. If sustained attention to a single dimension is negatively related to the ability to switch between dimensions, then children who stabilize attention on the primed dimension on the DP task should be those who fail to switch on the DCCS task. Alternatively, if the ability to stabilize and sustain attention to individual properties or features is positively related to flexible attention, then those children who stabilize attention on the primed dimension on the DP task should be those who also successfully switch on the DCCS task.

Method

Participants

A total of 64 children were recruited in Bloomington, Indiana, in the midwestern United States and were tested in their day-care facility; parental consent was obtained for all participants. Each child participated in the DCCS task and the DP task on different days (between 2 and 7 days apart), with order of tasks randomized across children. Eight children were excluded for failing to pass the first phase of the DCCS ($n = 1$), for not completing the DP task ($n = 1$), or for failing to get at least one trial correct on the initial priming trials on the DP task ($n = 6$). The final sample was 56 children ($M_{age} = 4.1$ years, $SD = 0.69$, range = 3.0–5.4; 25 boys), a sample size that is similar to those in previous studies examining the relation between performance on the DCCS and other tasks (e.g., Kharitonova & Munakata, 2011; van Bers, Visser, & Raijmakers, 2014). The age range of children reflected the age range between which past research has documented the developmental progression of success on the DCCS task (see Fig. 3 for a histogram of ages; Doebel & Zelazo, 2015). This age range, therefore, included children likely to pass and likely to fail the DCCS task.

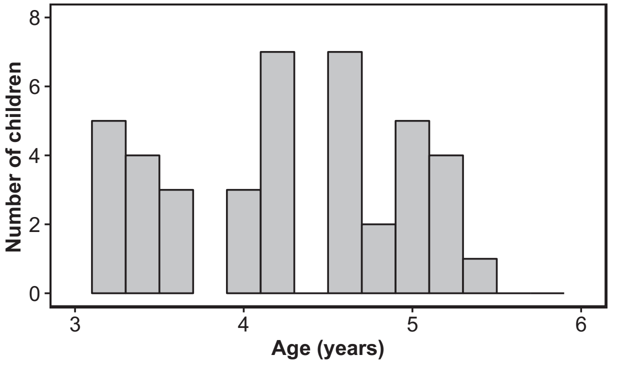

Fig. 3. Histogram of ages of the final sample of children included in the study.

Stimuli and procedure

Dimension Change Card sort task

Children were randomly assigned to sort one of two sets of picture cards into trays (red rabbits and blue boats or green flowers and yellow cars). On the pre-switch phase, children were asked to sort 6 cards (e.g., 3 red rabbits and 3 blue boats) by one dimension; on the post-switch phase, children were asked to switch and sort the same 6 cards by the other dimension (see Fig. 1). The first sorting rule (color or shape) was randomized across children.

The instructions on pre-switch trials followed this form: "In this game, we're going to sort these cards by shape. So in this game, all the rabbits go in this box with this rabbit, and all the boats go in this box with this boat." On the post-switch phase, the need to switch was made explicit following this form: "Now we're going to change the game; we're not going to sort by shape anymore. Now we're going to sort the cards by color. So in this game, all the red ones go in this box with this red one and all the blue ones go in this box with this blue one." Every trial throughout the task began with an explicit statement of the sorting rule (e.g., "All the red ones go in here with this red one, and all the blue ones go in here with this blue one"), and when a sorting card was presented to children, both dimensions were labeled (e.g., "Here's a red rabbit. Where does it go?"). The cards were placed face down in the tray as they were sorted. The order of sorting cards was randomized with the constraint that the same card did not appear more than twice in succession. Corrective feedback was given only on the pre-switch phase.

Dimension Preference task

A total of 12 triads of geometric figures varying in color and shape were presented on letter-size laminated paper. Each triad consisted of one figure at the top of the page (the target) and two figures at the bottom (the choices) (see Fig. 2). Participants were asked to choose which of the two choice figures looked most like the target figure. The figure shapes were triangles, squares, crosses, and circles; the colors were red, blue, green, and yellow. The first 2 trials were priming trials in which the target matched one of the choices on exactly one dimension (the same dimension on both trials) and did not match the other choice on either dimension (see Fig. 2, priming trials). Children were randomly assigned to the color priming or shape priming condition. The 10 remaining trials were preference test trials in which the target matched one choice on one dimension (e.g., color) and the other choice on the other dimension (e.g., shape). The two choice figures always differed from each other on both dimensions.

On the priming trials, the experimenter pointed to the two choice figures and then the target figure, saying, "Neither of these two looks exactly like this one, but which one looks most like this one?" (as in Medin, 1973). On the test trials, the experimenter asked, "Which of these [choices] looks most like this one [target]?" The experimenter never mentioned the color or shape of the items. The same randomized order of test triads was presented in both the color priming and shape priming conditions, arranged such that no figure (color and shape combination) appeared on consecutive trials. The spatial position of the color and shape matches was counterbalanced across the randomly ordered trials. No feedback was given in either priming or preference test trials.

Results

Before looking at the relationship between children's ability to sustain attention to a single dimension on the DP task and the ability to flexibly switch on the DCCS task, we describe children's performance in each task.

Dimension Change Card sort task

Performance was measured by the number of correctly sorted cards on each phase of the DCCS task. As in previous studies (e.g., Hanania, 2010; Kirkham et al., 2003; Yerys & Munakata, 2006), children tended to sort either all of the cards correctly or none of the cards correctly on both sorting phases (89.3% of both phase scores were 0 or 6). Because scores were bimodally distributed, children were categorized as passing or failing each phase. Children were categorized as passing a phase if at least 5 of the 6 cards were sorted correctly; otherwise, children failed that sorting phase. The majority of children, *perseverators* (36 children, 64.3%), failed to sort correctly on the post-switch phase, perseverating instead on the first sorting rule. The remaining children, *switchers* (20 children), sorted correctly on both phases. Age was a significant predictor of success on the post-switch phase of the DCCS task (see Table 1), with perseverators (M_{age} = 4.04 years, SD = 0.71) being significantly younger than switchers (M_{age} = 4.45 years, SD = 0.69), $t(55)$ = 2.40, p = .02.

Dimension Preference task

The question for the DP task is whether children would continue to attend to a single dimension when responses could be made on the basis of either dimension equally well on the 10 preference test trials. The 2 first trials of the DP task were priming trials that offered a match to the target figure on only one dimension (the primed dimension). These priming trials could guide children's attention to that dimension without instruction or explicit reference to that dimension. To measure the tendency to stick with the primed dimension during the test trials, two scores were calculated for each child. The first score, *prime matches,* is a measure of the overall tendency to choose an item that matches the target on the primed dimension; this was scored by counting the number of trials across the 10 preference test trials on which children chose the item matching the target on the primed dimension. The second measure, *prime run*, is a measure of how long children stuck with the primed dimension in their choices following the priming trials; this was scored by counting the number of consecutive test trials immediately following the priming trials on which children chose the item that matched the target on the primed dimension. As an additional measure of sustained selective attention, we also examined children's tendency to stick to a single dimension by calculating the longest run of consecutive trials for which children matched based on the same dimension regardless of whether this run immediately followed the priming trials or whether the dimension was the primed dimension. It is

Table 1
Results for logistic (DCCS task) and linear (DP task) regression analyses examining the relation between age and task performance.

Predictor	DCCS task			DP task								
				Prime match			Prime run			Longest run		
	Beta	*SE*	*p*	*Beta*	*SE*	*p*	*Beta*	*SE*	*p*	*Beta*	*SE*	*p*
Age	1.04	0.45	.02*	0.73	0.60	.22	0.89	0.85	.30	0.83	0.61	.18

* Significant value.

important to note, however, that for the majority of children the longest-run was actually a run in which children made matches according to the primed dimension (43 children, 77% of the sample).

Children selected the primed dimension on 1.7 of the 2 priming trials (*SD* = 0.46). Thus, although overall children chose the correct match on most priming trials, not all children chose the correct match on both priming trials. We take this into consideration when assessing group differences below.

Means and standard deviations for the prime match, prime run, and longest run measures are shown in Table 2. In contrast to the DCCS task, age was not a significant predictor of any of the measures on the DP task (see Table 1).

Group differences

We examined the link between performance on the DCCS task and the DP task two ways. First, we conducted sub-group analyses where we examined the two groups of children, switchers and perseverators, and compared their performance on the DP task. This provides a first test of the three hypotheses: Are stable and flexible attention processes (a) independent abilities, (b) competing abilities such that sticking to the primed dimension on the DP task is associated with perseveration on the DCCS task, or (c) supportive abilities such that sticking with the primed dimension on the DP task is associated with switching on the DCCS task? Second, because switchers were older than perseverators, this comparison does not rule out the possibility that age may be a mediating factor in the observed relation between the DCCS task and the DP task (note, however, that age was not a significant predictor of the DP task). Accordingly, we conducted logistic regression models to examine whether performance on the DP task significantly predicted whether children would succeed at switching on the DCCS task by taking age into account. Finally, in addition to assessing the full sample in both types of analyses, we also considered just those children who got both priming trials right on the DP task (23 perseverators and 16 switchers). These children (*strongest primed group*) can be considered as the most strongly primed children because they chose the primed dimension on both priming trials and had higher scores for all DP measures than the full sample (strongest primed group: prime match, *M* = 8.10, *SD* = 2.75; prime run, *M* = 6.41, *SD* = 4.16; longest run, *M* = 7.69, *SD* = 2.95). If there is a link between performance on the DCCS and DP tasks, then it should definitely be present in the strongest primed group.

Sub-group analyses

If the processes that stabilize attention to one dimension on the DP task are the same as those that compete with successful switching on the DCCS task, then perseverators on the DCCS task would be expected to have strong perseveration on one dimension on the DP task. If, however, the processes that stabilize attention on the DP task support switching by stabilizing attention on the new post-switch dimension, then the switchers on the DCCS task would be expected to show a better ability to stick to a single dimension on the DP task than the perseverators.

Because the scores for the DCCS task and the DP task were not uniformly distributed, we assessed differences between the two groups of children (switchers and perseverators) using bootstrapping, where we resampled the data for each score (samples = 10,000) to create a sampling distribution of the difference of means. Then, *p* values were calculated from the overall mean of differences in the sampling distribution. For each comparison, we also report *t* values, effect sizes (Cohen's *d*), and 95% confidence intervals (CIs). To assess the strength of all effects we report, we refer the reader to

Table 2
Means and standard deviations for the three measures of the DP task

Measure	*M*	*SD*
Prime match	7.11	3.04
Prime run	4.91	4.34
Longest run	6.75	3.12

a recent meta-analysis of different versions of the DCCS task (Doebel & Zelazo, 2015) and studies examining its correlation with other tasks (Kharitonova & Munakata, 2011; van Bers et al., 2014).

For the full sample of children, the results showed that the differences between perseverators and switchers were most robust on the two run measures that assess how long children stuck with a dimension. The prime run scores were higher for those who switched successfully on the DCCS task ($M = 6.50$, $SD = 4.48$) than for those who perseverated ($M = 4.03$, $SD = 4.48$), $t(55) = 2.09$, $p = .04$, $d = 0.59$, 95% CI [0.08, 4.06]). Overall prime matches were also higher for switchers, although only marginally (switchers: $M = 8.00$, $SD = 2.97$; perseverators: $M = 6.61$, $SD = 3.00$), $t(55) = 1.71$, $p = .09$, $d = 0.46$, 95% CI [−0.28, 3.70]). These results indicate that perseverators on the DCCS task did not stick with the primed dimension for as long as switchers on the DCCS task. In addition, perseverators did not stick as long with a dimension as switchers, as measured by the longest run of trials matched by either dimension (switchers: $M = 7.90$, $SD = 2.97$; perseverators: $M = 6.11$, $SD = 3.06$), $t(55) = 2.11$, $p = .04$, $d = 0.60$, 95% CI [0.11, 4.10]). Children who perseverated on the DCCS task were less likely to stick with either the primed dimension or unprimed dimension on the DP task than children who switched successfully on the DCCS task. This provides the main evidence for the hypothesis that attentional processes tapped in the DP task overlap with those that support switching to a new rule on the DCCS task.

When we considered just the strongest primed group, we found the same pattern of results as above for all measures (prime match: perseverators, $M = 7.74$, $SD = 2.65$; switchers, $M = 8.63$, $SD = 2.9$; $t(38) = 1.00$, $p = .30$, $d = 0.32$, 95% CI [−0.98, 2.96]; prime run: perseverators, $M = 5.35$, $SD = 4.16$; switchers, $M = 7.94$, $SD = 3.77$; $t(38) = 2.02$, $p = .05$, $d = 0.65$, 95% CI [0.003, 4.02]; longest run: perseverators, $M = 6.83$, $SD = 3.08$; switchers, $M = 8.94$, $SD = 2.37$; $t(38) = 2.33$, $p = .02$, $d = 0.76$, 95% CI [0.33, 4.39]). Fig. 4 displays, for each trial, the proportion of children for the full sample who responded in accordance with the primed dimension up to (and including) that trial. Children who switched successfully on the DCCS task were more likely to continue responding by the primed dimension than children who perseverated. In addition, the number of children who stuck with the primed dimension on all 10 free-choice trials differed for the DCCS switchers and perseverators (switchers: 12 of 20, 60%; perseverators: 8 of 36, 22.2%), $\chi^2(1, N = 56) = 4.33$, $p = .04$, $\phi = 0.32$.

Logistic regression analyses

Our sub-group analyses showed that children who successfully switched on the DCCS task also stuck longer with a single dimension on the DP task. However, children who successfully switched on the DCCS task were also older. Thus, it is possible that, in general, children who are older are also more likely to stick with the primed dimension on the DP task. The first evidence against this notion is that age was not a significant predictor of any of the measures of the DP task (see Table 1). However, a stronger test of the link between performance on the DP task and performance on the DCCS task is one

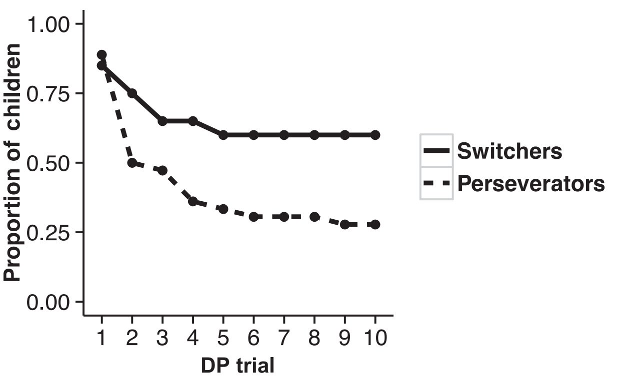

Fig. 4. Trial-by-trial analysis of the proportion of children (for the full sample) who chose the prime match on the DP task grouped by children who successfully switched or perseverated on the DCCS task.

Table 3
Results for three logistic regression models examining how age and performance on the DP task predict switching on the DCCS task for the full sample and for just those children who got both DP priming trials correct

Predictor	DCCS task (full sample)			DCCS task (strongest primed group)		
	Beta	*SE*	*p*	*Beta*	*SE*	*p*
Age	0.96	0.46	.04*	1.31	0.59	.03*
Prime match	0.14	0.11	.20	0.12	0.14	.38
Age	0.98	0.46	.03*	1.46	0.63	.02*
Prime run	0.13	0.07	.08	0.19	0.10	.05*
Age	0.95	0.46	.04*	1.34	0.62	.03*
Longest run	0.17	0.10	.09	0.29	0.14	.04*

* Significant value.

that takes age into account. In a final analysis, we examined if the DP measures predicted whether children would pass or fail the post-switch phase of the DCCS task over and above age. This is the strongest test of a link between the two tasks given that age is a significant predictor of switching on the DCCS task. We conducted separate logistic regressions for each DP measure that assessed the role of that measure and age in performance on the DCCS task (either passing [1] or failing [0]). We conducted these regression models separately for the full sample and for the strongest primed group. Age was a significant predictor of the DCCS task in all models (see Table 3). When considering the full sample of children, the effects of the prime run and longest run scores were marginally predictive of switching on the DCCS task; when considering the strongest primed group, these same factors significantly predicted switching on the DCCS task. These results mirror the findings in the subgroup analyses and demonstrate that sticking with a single dimension on the DP task contributes (independent of age) in predicting DCCS performance.

Discussion

The results presented here are contrary to the hypothesis that children perseverate in the DCCS task because they have a general tendency to stick to one dimension or that strong selective attention processes compete with successful switching. Instead, *sticking* to one dimension on the DP task and *switching* on the DCCS task are linked. Our sub-group analyses demonstrated that switchers stuck longer with the primed dimension than perseverators. In addition, more switchers than perseverators stuck with the primed dimension for the entire set of DP test trials (Fig. 4). The relationship between sticking with the primed dimension and switching on the DCCS task was still present when age was taken into account. How long children stuck with the primed dimension marginally predicted switching ability on the DCCS task over and above age for the full sample. The effect was strongest for those children who were correct on both priming trials of the DP task. For this strongest primed group, both the prime run and longest run scores significantly predicted switching on the DCCS task over and above age. These results show that sticking with the primed dimension on the DP task is related to flexibly switching between dimensions on the DCCS task. These findings are consistent with the idea that sustained selective attention, driven by implicit processes, supports flexible switching (Burden & Mitchell, 2005; Enns & Cameron, 1987). Interestingly, as demonstrated by the longest run measure, switchers were also more likely to stick with a single dimension throughout the DP task. Although the longest run scores for the majority of children reflected sticking with the primed dimension (77% of children), it also included children who stuck with the dimension that was not primed. One possibility is that sticking to the nonprimed dimension is a priming effect; if children — for whatever reason, including inattention to the choices on the priming trials — chose to match by the nonprimed dimension, then they could (through the same implicit processes) sustain attention to that dimension for the long run.

Individual children differed markedly on the DP task: For some children, just 2 priming trials that forced attention to one dimension were sufficient to elicit stable attention to that dimension across a series of trials. For other children, the effects of the 2 priming trials did not last as long, and these children drifted to matching the objects randomly by either dimension. Relevant to our starting hypotheses, these differences are associated with performance differences in the second phase of the DCCS task. For some children, the new verbal instructions in the switch phase of the DCCS task are sufficient to elicit a switch in attention to the instructed dimension, allowing children to then maintain attention on this new dimension across a series of switch trials. For other children, the verbal instructions were not sufficient to enable attention to "lock onto" that new dimension. Is "sticking" on the DP task and "locking onto" the verbally instructed dimension supported, perhaps in part, by the same attentional processes? Previous research on the DCCS task tells us that perseverators often can repeat the instructions and seem to understand what they are supposed to do, but they cannot sustain that knowledge in action (Zelazo, Frye, & Rapus, 1996; but see Munakata & Yerys, 2001, for an alternative explanation). By hypothesis, weaker or immature processes of sustaining attention, also evident on the DP task, may contribute to their difficulties in turning verbal instructions into a rule whose execution can be maintained. We have proposed that these overlapping attentional processes are implicit, not under control of the explicit decision processes that decide to shift attention. However, it is also possible that children who were strongly primed on the DP task may have inferred a rule by which to choose matches, and those children are also the children who are more likely to strongly represent the correct rule on the DCCS task, which has been found to predict successful switching (Blackwell, Cepeda, & Munakata, 2009; Chevalier & Blaye, 2008; Morton & Munakata, 2002; Zelazo et al., 2003). The current findings cannot resolve these two interpretations.

Either way, our working hypothesis is that the ability to stabilize attention to a single dimension across trials — as measured by the DP task — also supports stable attention in *both phases* of the DCCS task (Hanania & Smith, 2010). Our hypothesis, and the idea that the relevant sustaining processes might be implicit, builds on an older empirical literature and mathematical models of children's emerging abilities to stabilize attention to a single dimension. That literature indicates that (a) attending selectively to individual dimensions when comparing and remembering objects improves with age (Lane & Pearson, 1982; Smith, 1989; Strutt et al., 1975; Thompson, 1994; Ward, 1980) and (b) stable attention to one dimension is not all or none but rather a matter of degree (Smith, 1989). As a result, young children (moderated by task and stimuli) become incrementally better at sustaining attention to a single dimension such that young preschoolers' attentional performance may fit a model in which the attentional weighting of task relevant and irrelevant dimensions is a 50:50 ratio, slightly older children's performances may fit a weighing ratio of 60:40, and by the time children are 5 years old they may fit a 90:10 ratio reflecting strong selective attention. In addition to these findings, we propose that the attention weights at time t_n prime those at time t_{n+1} such that (with other task factors remaining unchanged) if the attentional weight for one dimension *is sufficiently high*, the likelihood of attending selectively to that dimension *increases* over time, sustaining attention to that dimension (see also Buss & Spencer, 2014). This sustaining component, however, does not mean an inability to shift attention given explicit instructions to do so, and the current results suggest that this sustaining component may support implementation of the switch once that goal has been decided.

We illustrate this proposal in Fig. 5A for performance on the DP task for two groups of children: those who failed to switch on the DCCS task (perseverators) and those who succeeded in switching (switchers). By hypothesis, children enter the DP task equally likely to attend to both dimensions ("0" in Fig. 5A). The priming trials (P1 and P2 in Fig. 5A) increase the attentional weight of, or likelihood of attending to, the primed dimension (Dimension 1) above 50% attention (the response threshold) for both groups of children, but the weighting is higher for the switchers. Because attention at time t_{n+1} builds on the attentional weights at time t_n, there is stronger and more enduring attention to the primed dimension (Dimension 1) and, reciprocally, less attention to the unprimed dimension (Dimension 2). For the perseverators, the priming of the relevant dimension is weak; therefore, their attention wavers between both dimensions.

We propose that the same processes operate in the DCCS task. Different from the DP task, the DCCS task gives explicit instructions and continual reminders of the task rules, which may also strengthen attentional weights (Vales & Smith, 2015). In the pre-switch phase (Fig. 5B), these verbal instructions have a sufficiently strong effect for all children's weighting of the relevant dimension (Dimension 1), and as a result virtually all children sort by the correct rule in the pre-switch phase. Notice, however,

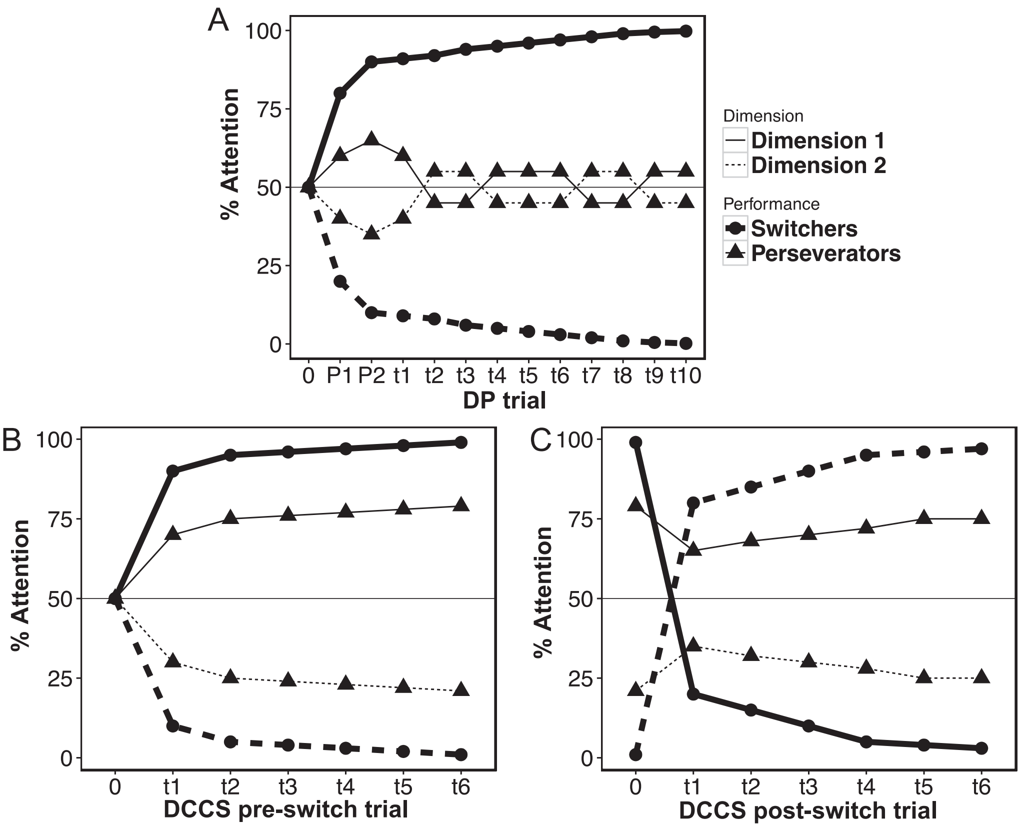

Fig. 5. Depiction of our theoretical account. For all panels, percentage attention to Dimension 1 (solid lines) and Dimension 2 (dashed lines) are displayed for children who succeeded at the DCCS task (switchers, circles) and those who failed at the DCCS task (perseverators, triangles). Attention above threshold (50% attention) indicates that children respond according to that dimension. (A) Distribution of attention for the DP task. Attention before the task is indicated by "0", the priming trials are indicated by "P1" and "P2", and "t1" to "t10" represent the 10 test trials on the DP task. (B) Distribution of attention for the pre-switch phase on the DCCS task. Time "0" is before the task, and "t1" to "t6" are 6 pre-switch trials on the DCCS task. (C) Distribution of attention for the post-switch phase on the DCCS task. Trial "0" indicates attention before the switching instructions are given, and "t1" to "t6" are 6 post-switch trials on the DCCS task.

that even though both groups of children sort correctly in the pre-switch phase, our account suggests that activation for the pre-switch dimension is weaker in the perseverators because they are continuing to distribute their attention, probabilistically, to both dimensions. Although this proposal might seem to be at odds with the fact that children tend to perform in an all-or-none fashion on the DCCS task (i.e., sorting either correctly or incorrectly on most trials), it is plausible that the underlying process and the associated attentional weights are not all-or-none (see Hanania & Smith, 2010; van Bers et al., 2014).

The differences in sustained attention to individual dimensions between the two groups of children become more clear when the task instructions require children to switch to the other dimension (Dimension 2, Fig. 5C). The switchers are strongly primed by the instructions to attend to the new dimension while reducing attention to the now irrelevant dimension and, as in the pre-switch phase, do so quite selectively. This early high and selective activation helps the switchers to implement and sustain attention and not succumb to the previously attended dimension. We assume that the new instructions also activate attention to the new dimension for the perseverators, but that activation is not highly selective and so the formerly relevant (but now irrelevant) dimension is also activated. The greater sustaining component for the switchers relative to the perseverators may help the switchers to maintain the selective set induced by the instructions and, thus, to implement them. By hypothesis, the formerly relevant dimension wins out for the perseverators because this sustaining component to the new instructions is not sufficient to counter the activation built up in the pre-switch phase even though that built-up sustaining activation may be — as the current results suggest — weaker for perseverators than for switchers.

We have phrased our explanation in terms of how the "sustaining component" plays a role in selective attention and, by our hypothesis, in switching as well. Both sustaining attention selectively and switching require inhibition; thus, the current "sustaining component" may reflect inhibitory processes. Many tasks that have been used to measure inhibition and executive control (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; De Luca et al., 2003) tap into sustained attention to one dimension by requiring rapid decisions about one dimension in the face of variations on other dimensions. Strong activation to the relevant dimension — by priming, by decision, by instructions — may concurrently generate and/or depend on strong inhibition to the irrelevant dimension (Buss & Spencer, 2014; Morton & Munakata, 2002). Similarly, in both cases (switching when the new rule is presented and sustaining attention with a high degree of selectivity), the strength of the activation matters both in memory representations (Blackwell et al., 2009) and in the weighting of different cues (endogenous vs. exogenous; van Bers et al., 2014). This component of our hypothesis fits well with proposals that language (Doebel & Zelazo, 2013), maintaining rules and representations (Blackwell et al., 2009; Chevalier & Blaye, 2008; Morton & Munakata, 2002; Zelazo et al., 2003), and the ability to consciously control attention (Diamond et al., 2002; van Bers et al., 2014; Zelazo, 2004) support activation of relevant information on the DCCS task. Similarly, a number of studies have demonstrated that highlighting the relevant dimension (through labeling or by increasing the salience of the dimension) predicts switching (see Doebel & Zelazo, 2015, for a review), suggesting that factors that seem likely to increase sustained selective attention to the relevant dimension do also support attentional flexibility. Indeed, these processes (inhibition, memory activation, cue weighting, and language) have a long history as key explanations of selective attention; for, instance, language has been proposed to facilitate attending to a single dimension in tasks demanding selectivity (Gentner & Rattermann, 1991; Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005; Smith, Gasser, & Sandhofer, 1997). In addition, our proposal is consistent with previous proposals examining perseveration in younger children, suggesting that these factors may have implications for attentional stability and flexibility across development (e.g., Munakata, 1998). Understanding how all of these processes fit together and develop across age is critical to a complete understanding of attentional control.

The current results offer new insights into a more integrated explanation of these processes by showing that stability and flexibility are related in individuals, at least in the manifestations tested on the DP and DCCS tasks. These results are novel, and our interpretation of them is in need of further empirical test. But they remind us that attentional development likely has multiple inter-related components and that the development of the self-control of attention builds on multiple skills, including those in operation during nonexplicitly instructed tasks. Flexible behavior may emerge, in part, from the same processes that underlie stability—including processes that narrow attention to a single source of information and processes that sustain attention on a single source of information.

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