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Bottom-up and top-down dynamics in young children's executive function: Labels aid 3-year-olds' performance on the Dimensional Change Card Sort

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Abstract

Executive function (EF) improves between the ages of 3 and 5 and has been assessed reliably using the Dimensional Change Card Sort (DCCS), a task in which children first sort bivalent cards by one dimension (e.g., shape) and then are instructed to sort by a different dimension (e.g., color). Three-year-olds typically perseverate on the pre-switch dimension, whereas 5-year-olds switch flexibly. Labeling task stimuli can facilitate EF performance (Jacques & Zelazo, 2005; Kirkham, Cruess, & Diamond, 2003), but the nature of this effect is unclear. In 3 experiments we examined 2 hypotheses deriving from different theoretical perspectives: first, that labels facilitate performance in a more bottom-up fashion, by biasing attention to relevant task rules (Kirkham et al., 2003); and second, that labels aid performance in a more top-down fashion by prompting reflection and an understanding of the hierarchical nature of the task (Zelazo, 2004). Children performed better on the DCCS when labels referred to the relevant sorting dimension (Experiment 1). This was a function of the content of the labels rather than the change in auditory signal across phases (Experiment 2). Furthermore, labeling the opposite dimension only did not have a symmetrically negative effect on performance (Experiment 3). Together, these results suggest external, verbal labels bias children to attend to task-relevant information, likely through interaction with emerging top-down, endogenous control.

Keywords

Executive function; Cognitive control; Dimensional Change Card Sort; Task-switching; Language and thought; Cognitive development

1. Introduction

An important aspect of adaptive functioning is the ability to inhibit and override automatic behaviors when they are not appropriate. A person walking down a familiar path may be inclined to follow it to an oft-frequented destination; but if their intention is to go some place new, the tendency to act according to an established habit must be suppressed and a new plan of action must be enacted and followed. The ability to use thought flexibly to

guide action, termed executive function (EF), develops early in childhood with particularly marked changes occurring between 3 and 5 years of age. This change has been assessed reliably using the Dimensional Change Card Sort task (DCCS; Zelazo, 2006). In this task, children first sort bivalent test cards (e.g., red rabbits and blue boats) according to one dimension (e.g., color) for several trials, and then are instructed to switch to sorting the same cards according to a new set of rules (e.g., shape). Three-year-olds typically perseverate; that is, they continue to sort the cards according to the initial rule. Moreover, they do so even though they are informed of the new rules before every trial and even though they can demonstrate knowledge of the new rules (Zelazo et al., 2003; Zelazo, Frye, & Rapus, 1996). By contrast, most 4- and 5-year-olds perform the task without difficulty.

Several theoretical accounts have been put forth to explain developmental change in EF as indexed by this task, each postulating distinct underlying cognitive changes. These include the development of an inhibition mechanism (Kirkham, Cruess, & Diamond, 2003), expanded working memory (Morton & Munakata, 2002), and the ability to construct higher-order rules (Zelazo & Frye, 1997; Zelazo et al., 2003). Kirkham et al. (2003) argued that children who perseverate on the pre-switch rules lack an inhibitory mechanism that they can use to get “unstuck” from thinking about the stimuli in a way that is no longer correct. Morton and Munakata (2002) proposed that perseveration is a function of the relative absence of active memory traces in prefrontal cortex that support the maintenance of information that can override latent traces formed through repeated experience. The Cognitive Complexity and Control – Revised theory (Zelazo et al., 2003) suggests that prefrontal cortical development underlies an age-related increase in the capacity for reflection, which in turn allows children to recognize, and articulate in internal speech, the inherent incompatibility of the pre- and post-switch rules and construct a higher-order rule that resolves the conflict (e.g., “There are two ways to play this game. If we’re playing the shape game, then the rabbits/boats go here; but if we’re playing the color game, then the red/blue ones go there”).

Although these accounts have different emphases, they all posit a role for language in the development of EF. On Diamond’s view, for example, language in the form of private speech aids cognitive control in children by supporting working memory and inhibitory control (Diamond, personal communication, October 31, 2011; Diamond, Barnett, Thomas, & Munro, 2007). Similarly, Zelazo and colleagues suggest that language is required for the formulation of higher-order rules. Research suggests that language is indeed related to EF in early childhood (see Cragg & Nation, 2010, for a review). In a study by Karbach and Kray (2007), children were instructed to verbalize their thoughts as they completed a switching task; whereas younger children tended to label their perceptual experience (e.g., saying “apple” if the target was an apple), older children were more likely to verbalize words associated with the required response (where the item was to go), and those who did so tended to respond faster than those who did not. Research including children and older adults indicates that the cost of task-switching relative to performing a single task is reduced when both younger and older participants are instructed to verbalize task-relevant words. Articulatory suppression manipulations (designed to interrupt inner speech) exacerbate age-related differences in task performance, leading to disproportionate decrements in

performance in children and older adults relative to intermediate age groups (Kray, Eber, & Karbach, 2008).

Although such research suggests a relation between labeling and the development of EF, precisely how the two are related remains to be explored. One possibility is that labeling may improve performance measures of EF in a relatively “bottom-up” fashion, by biasing children to attend to relevant aspects of a task. For example, Müller, Zelazo, Hood, Leone, and Rohrer, 2004 examined the effects of labeling on performance on a Stroop-like task and found that having 3-year-olds label or point to the relevant stimulus enhanced their performance.

An alternative possibility is that labels elicit top-down processes, by encouraging children to reflect on their representations. Labeling a child’s interpretation of a stimulus may help make that interpretation an explicit object of consideration (e.g., highlighting the fact that one’s current construal of the stimulus is, in fact, a construal). It may help children to step back and consider alternative ways of thinking about the stimulus (Carlson & Beck, 2009; Carlson & Zelazo, 2008; Jacques & Zelazo, 2005).

Several experiments have examined the effects of labeling on children’s performance on the standard DCCS (Kirkham et al., 2003; Müller, Zelazo, Lurye, & Liebermann, 2008; Towse, Redbond, Houston-Price, & Cook, 2000; Yerys & Munakata, 2006). Kirkham et al. (2003) modified the standard DCCS procedure (in which the experimenter labels the relevant dimension on the test card), and instead prompted children themselves to label the relevant dimension on the test cards. That is, on each trial, children were asked, “What color [shape] is this one?” instead of being told, “Here’s a red one [rabbit]”. Children were more likely to perform correctly on the post-switch phase of the DCCS when they labeled the relevant dimension themselves versus having the experimenter do so. Similarly, Towse et al. (2000) found that some children who initially failed the DCCS were able to sort correctly after being prompted to identify a test card by the relevant dimension. Kirkham et al. suggested that a labeling procedure where the relevant dimension is highlighted helps to guide performance through the (re)focusing of attention; thus having children generate the label themselves ought to encourage more pronounced attentional shifting, helping them override the tendency to get “stuck” on the first dimension (Diamond & Kirkham, 2005; Kirkham et al., 2003). Although this evidence that labeling facilitates DCCS performance is suggestive, subsequent attempts to replicate these findings have not been successful. Across three experiments, despite close replication of procedures, Müller et al. (2008) found no evidence of better performance on the DCCS by children who labeled the cards versus those for whom the labels were provided by an experimenter.

Preliminary findings from a recent meta-analysis of studies using the DCCS suggests, however, that even when the experimenter labels the test cards, the way in which the cards are labeled makes a difference. In the meta-analysis, the labeling procedure varied across studies using the standard task. Children performed better on versions where only the relevant dimension was labeled than they did on those in which both dimensions were labeled (Doebel & Zelazo, 2011). A limitation of this meta-analytic finding is that other factors may explain the difference rather than the labeling procedure per se, given the lack

of experimental control. No single study has yet compared these conditions experimentally. A similar pattern was found, however, by Munakata and Yerys (2001), using a version of the DCCS in which children were asked to respond verbally by indicating in which box each test card should go. Children performed less well when both dimensions were labeled (e.g., “A red truck”) than when only the relevant dimension was labeled (Munakata & Yerys, 2001). Although suggestive, it is unclear whether a similar pattern of performance would hold when a behavioral response is required.

The aim of the present study was to explore further the effect of external, verbal labeling on DCCS performance in order to gain insight into how labeling may facilitate EF in young children. In our first experiment, children completed three versions of the DCCS that differed only in terms of the test card labeling procedure: Cards were labeled by the relevant dimension, both dimensions, or neither dimension. If labels improve performance by biasing attention in a bottom-up fashion to the relevant aspect of the stimuli, as suggested by Müller and colleagues (2004), performance on the relevant label condition should be superior to both of the other conditions, which should not differ. In contrast, if labels are facilitative in a top-down fashion, because they prompt reflection, it should not matter whether reference is made to one or both dimensions, and both labeling conditions should produce better performance than the condition in which neither dimension is referenced. Determining whether labels support performance in a bottom-up fashion and/or a top-down fashion will provide new insight into how labels interact with emergent EF in early childhood.

2. Experiment 1

2.1. Method

2.1.1. Participants—Thirty-seven 3-year-olds ($M = 41.02$ months, range = 37–44 months; $SD = 1.57$ months; 19 males) participated. Children were recruited from a university database of families living in a Midwestern city who previously indicated that they were willing to be contacted about opportunities to participate in research. Parents received a small gift and \$5 to cover travel costs. Eight additional children were recruited but excluded from further analyses because they failed the pre-switch phase of one or more of the three card sorts ($n = 3$), parental interference or uncooperativeness on the part of the child ($n = 4$), or experimenter error ($n = 1$).

2.1.2. Design and procedure—Participants completed three card sorts (in a counterbalanced order across participants), which differed only in the card-labeling procedure. A within-subjects design was selected for two reasons. First, this design permitted us to examine individual patterns across versions. We were particularly interested in the possibility that individual children might do better on one version than the others. Second, given that previous studies have noted the absence of practice effects from repeated administrations of the DCCS (Zelazo et al., 2003), a within-subjects design reduces error variance associated with individual differences. Further care was taken to reduce any possibility of practice effects by using new shapes and colors for each sort as well as including a brief pause between card sorts.

First we describe the procedure common to all versions and then features specific to each version. The procedure for the DCCS closely followed that described by Zelazo (2006). The experimenter sat across from the child at a small table, on which there were two black boxes with slits cut into the top for sorting cards. On the front of the boxes were two target cards (e.g., a blue rabbit and red boat). The task stimuli consisted of 14 test cards, each of which matched the targets on one dimension only (e.g., 7 red rabbits and 7 blue boats). When introducing the task, the experimenter identified the target cards by both dimensions (e.g., “Here’s a blue rabbit and here’s a red boat”), and provided the child with the sorting rules (e.g., “We’re going to play the shape game. In the shape game, the rabbits go here and the boats go here”). The experimenter demonstrated the rules of the game by sorting one test card and then gave the child the opportunity to sort a second test card with feedback. The pre-switch test phase immediately followed. On each trial, the experimenter reminded the child of the rules of the game, presented and labeled a test card (according to each condition), and then asked children, “Where does it go?” Test cards were presented in a quasi-random order, with the restriction that the same test card not be presented more than two times consecutively. No feedback was provided during pre-switch test trials. Once 6 test cards were sorted, the experimenter announced that the rules had changed and that they were going to play a new game and presented the child with the new sorting rules. The child was then given the opportunity to sort 6 more test cards. Again, on each trial, the new sorting rules were repeated, a test card was presented and labeled, and children were asked, “Where does it go?” No feedback on the child’s performance was provided.

The experimental manipulation consisted of systematic variation in the card labeling procedure across the three card sorts administered to each child. In the Relevant Label condition, the experimenter labeled the card by the dimension that matched the current rules of the game (e.g., “Here’s a *rabbit*. Where does it go?”). In the Both Label condition, the experimenter labeled the card by both dimensions depicted on the card (e.g., “Here’s a *red rabbit*”). In the Non-Descript Label condition, the experimenter provided a general label that did not refer to either dimension (e.g., “Here’s *one*”).

The first dimension that children sorted by (e.g., shape or color) was counterbalanced such that half of the children sorted by each dimension on their first sort. Dimension order was alternated across the three sorts. Importantly, three distinct sets of cards with unique pairs of bi-dimensional test stimuli were used in order to minimize carry-over effects from one card sort to the next. In addition to the red and blue rabbits and boats, stimuli were gray and brown frogs and trucks, and yellow and green horses and planes. The order in which these three card sets were administered was also counterbalanced.

2.2. Results

All children included in the final sample sorted all cards correctly during the pre-switch phase. In the post-switch phase, most children consistently sorted all cards either correctly or incorrectly (% of children doing so by condition: Non-Descript Label, 73%; Both Label, 89%; Relevant Label, 78%). For this reason, it was appropriate to conduct our primary analyses using success/failure as our dependent measure. Children were classified as

“passing” the post-switch phase for a particular condition if they sorted 5 or 6 of the 6 post-switch cards correctly. Otherwise, they were classified as failing.

Preliminary analyses revealed no effects of gender, dimension order (shape versus color first), or experimental condition order, so these variables were not included in further analyses. As expected, there were no practice effects, and if anything, performance declined across sorts (presumably due to fatigue); performance on the third sort (24%) was poorer than on the first (46%), $X^2(df = 1, N = 36) = 4.923, p = .022$, but not the second (35%), nor was performance on the second sort worse than that on the third sort, ps ns.

Nineteen children (of 37) passed in the Relevant Label condition (51%); 9 passed in the Both Label condition (24%), and 10 passed in the Non-Descript Label condition (27%). Fig. 1 illustrates individual performance by condition. To test whether post-switch performance differed across these three conditions, we conducted pairwise comparisons using the McNemar Test, and found that children were significantly more likely to pass in the Relevant Label condition than in the Non-Descript Label condition or in the Both Label condition, $X^2(df = 1, N = 36) = 8.1, p = .002$, and $X^2(df = 1, N = 36) = 4.923, p = .022$, respectively. Performance in the Non-Descript and Both Label conditions did not differ.

We examined individual patterns of performance in an effort to further explore the relative difficulty of the different conditions. Most children failed in all three conditions ($n = 16$) or passed in all three ($n = 6$). Of the 10 children who passed in only one condition, 8 (80%) passed in the Relevant Label condition. Of the 5 who passed in two conditions, all passed in the Relevant Label condition while also passing in either the Both ($n = 3$) or Non-Descript Label conditions ($n = 2$).

2.3. Discussion

We found that children performed better when the experimenter labeled test cards by the stimulus attribute corresponding to the relevant dimension only than they did when she referred to attributes corresponding to both dimensions or provided a non-descript label. Performance in the latter two conditions did not differ. The rates at which children passed the task are typical for this age. Three-year-olds tend to pass the standard version at a rate of 40.5% when the relevant dimension is labeled, and 22.5% when both dimensions are labeled (Doebel & Zelazo, 2011). This pattern is consistent with the suggestion that labels orient children’s attention to the current rules through the activation of the relevant concept (e.g., activation of the concept *rabbit* when playing the shape game). In the case of the DCCS, therefore, language may support 3-year-olds’ EF in a bottom-up fashion, such that the label may help children focus attention on the relevant rules. This is consistent with Müller et al.’s (2004) finding that having 3-year-olds label response-relevant features of task stimuli helps children choose the correct response in the face of interfering information, suggesting that labeling aids EF by biasing attention toward relevant rule sets and away from irrelevant ones.

An alternative possibility, however, is that children perform better in the Relevant Label condition simply because in this condition, the dimension of the stimuli that is labeled changes from the pre- to the post-switch phase, whereas in the other two conditions, the

stimuli are labeled in the same way on pre- and post-switch trials. A change in the way in which stimuli are labeled may capture children's attention, and this, in turn, may prompt reflection on the situation, including the changing rules. This interpretation would, of course, be consistent with the reflection account, insofar as such detection of conflict and a degree of uncertainty may trigger the reflective reprocessing of information about the problem children face. To examine this possibility, we conducted another experiment that compared the Relevant Label condition, in which the test cards are labeled by the relevant dimension in both the pre-switch and post-switch phases (hitherto referred to as the Relevant-to-Relevant condition) to two conditions that controlled for the fact that labels change in the Relevant-to-Relevant condition. In the Non-descript-to-Both-Label condition, test cards were labeled differently on pre- and post-switch phases, but neither way was expected to facilitate performance: non-descript labeling of the test cards in pre-switch phase and labeling of both dimensions in the post-switch phase. A second control condition was the Non-descript-to-Relevant condition, in which test cards were given a non-descript label in the pre-switch phase, followed by a relevant label in the post-switch phase. Bottom-up accounts of the effect of labeling would predict that children should perform better in the two conditions that involve a relevant label on the crucial post-switch phase (i.e., Relevant-to-Relevant and Non-descript-to-Relevant) than the condition involving a mere switch of labels (Non-descript-to-Both-Label), because in these conditions the relevant labels would cue children to attend the stimuli that were relevant to the post-switch rules. Alternatively, if the change in the way the test cards are labeled is the sole reason for the beneficial effect of relevant labels in Experiment 1, perhaps because it prompts children to reflect on the task, then the Non-descript-to-Both-Label condition should also show evidence of facilitation.

3. Experiment 2

3.1. Method

3.1.1. Participants—Thirty-six 3-year-olds ($M = 43.61$ months, range = 39.69–48.69 months; $SD = 2.39$ months; 18 males) participated. Children were recruited in the same manner as in Experiment 1. Nine additional children were recruited but excluded from further analyses because they failed the pre-switch phase of one or more of the three card sorts ($n = 3$), parental interference or uncooperativeness on the part of the child ($n = 4$), or experimenter error ($n = 3$).

3.1.2. Design and procedure—The within-subjects design and procedure were identical to that of Experiment 1 except for the specific ways in which test cards were labeled, according to condition: Relevant-to-Relevant Label, Non-descript-to-Relevant Label, and Non-descript-to-Both Label conditions.

3.2. Results

Twenty-four children (of 36) passed in the Relevant-to-Relevant Label condition (67%); 25 passed in the Non-descript-to-Relevant Label condition (69%), and 14 passed in the Non-descript-to-Both Label condition (39%). Children performed significantly worse in the Non-Descript-to-Both label condition than the Relevant-to-Relevant Label and the Non-Descript-to-Relevant Label condition, $X^2(df = 1, N = 36) = 5.79, p = .0162$, and $X^2(df = 1, N = 36) =$

8.6, $p = .003$, respectively, and performance in the Relevant-to-Relevant Label and the Non-Descript-to-Relevant Label conditions did not differ, $X^2(df = 1, N = 36) = .0, p = ns$. Individual performance across conditions is illustrated in Fig. 1.

3.3. Discussion

The Experiment 2 results further support the bottom-up account of the influence of labeling on EF, such that relevant stimulus labels appear to bias attention to the current sorting rules. We did not find evidence that merely changing the way in which stimuli are labeled from pre- to post-switch facilitates performance (perhaps by triggering reflection); performance was poorest in a condition that controlled for a change in labels (from “Here’s one” to “Here’s a red rabbit”). Rather, our findings are consistent with the interpretation that 3-year-olds’ performance on this task is facilitated in a more bottom-up fashion by labels that cue children to attend preferentially to those aspects of the stimuli that are relevant to the post-switch rules.

Although the pattern of findings is consistent with a bottom-up account, it is certainly possible that bottom-up processes interact dynamically with top-down, deliberate processes. For example, relevant labels may bias children to attend to the relevant aspects of the stimuli, but this in turn may facilitate children’s efforts to understand the structure of the task and keep the relevant rules in mind. If this were the case, one would predict that relevant labels have more of an influence on performance than irrelevant labels. Irrelevant labels may cue children to attend to the irrelevant aspects of the stimuli, which would be expected to impair performance. But if bottom-up influences interact synergistically with top-down processes, the magnitude of the effect should be asymmetrical—that is, greater facilitation by relevant labels than interference by irrelevant labels. To address this question we conducted a third experiment in which, in addition to conditions in which there was bottom-up support (i.e., relevant labels) and no support (i.e., both dimensions labeled), children experienced an Opposite Label condition, in which the experimenter supplied labels that only corresponded to the opposing sorting dimension. For example, if a child was playing the shape game, the experimenter presented the test card and said, “Here’s a red one,” and gave it to the child to sort. If the interaction between labels and EF is primarily a bottom-up phenomenon, performance should be at its worst in the Opposite Label condition, better in the Both Label condition, and best in the Relevant Label condition. If, in contrast, the influence of labeling is best understood as an interaction between bottom-up and top-down signals, performance should be similar in the Opposite Label and the Both Label conditions, with both conditions yielding inferior performance to that in the Relevant Label condition. Finally, this experiment provides an additional test of whether changing labels from pre- to post-switch may, simply by virtue of the change, prompt reflection and lead to better performance. If this were the case, then the Opposite Label condition may be expected, paradoxically, to facilitate children’s performance.

4. Experiment 3

4.1. Method

4.1.1. Participants—Thirty-eight 3-year-olds ($M = 43.81$ months, range = 37.95–46.92 months; $SD = 10.6$ months; 19 males) participated. Children were recruited in the same manner as in Experiments 1 and 2. Nine additional children were recruited but excluded from further analyses because they failed the pre-switch phase of one or more of the three card sorts ($n = 3$), parental interference or uncooperativeness on the part of the child ($n = 4$), or experimenter error ($n = 2$).

4.1.2. Design and procedure—The design and procedure were identical to that of Experiment 1 with the exception that the Opposite Label condition was introduced in place of the Non-descript Label condition.

4.2. Results

All children included in the final sample sorted all cards correctly during the pre-switch phase. In the post-switch phase, most children consistently sorted all cards either correctly or incorrectly (by condition, Relevant Label: 92%; Both Label: 97%; Opposite Label: 89%). Thus, as in the previous two experiments, proportion of children passing the task (i.e., sorting 5 of 6 post-switch test cards correctly) was the dependent variable.

Preliminary analyses revealed no effects of gender, dimension order (shape versus color first), or experimental condition order, on performance across experimental conditions, so these variables were not included in further analyses. In the Relevant Label condition, 18 (of 38) children passed (47%); 11 passed in the Both Label condition (29%); and 11 passed in the Opposite Label condition (29%). To test whether post-switch performance differed across conditions, we conducted pairwise comparisons using the McNemar Test, and found that children were significantly more likely to pass in the Relevant Label condition than the Opposite Label condition or the Both Label condition, $X^2(df = 1, N = 38) = 5.818, p = .0159$, and $X^2(df = 1, N = 38) = 7.111, p = .004$, respectively. Performance in the Opposite and Both Label conditions did not differ, $X^2(df = 1, N = 38) = .167, p = ns$.

Individual performance patterns indicated that most children either failed all three conditions ($n = 17, 45\%$) or passed all three ($n = 8, 21\%$). Seven (18%) passed only the Relevant Label condition, and 3 (8%) failed only the Opposite Label condition. Fig. 1 illustrates how individual children performed across conditions as well as performance patterns across the three experiments.

4.3. Discussion

In contrast to the boost in performance found in the Relevant Label condition, children's performance in the Opposite Label condition was not diminished relative to the Both Label condition. Nor was it facilitated. This finding is similar to that found by Jordan and Morton (2008), in experiments in which the DCCS was modified by adding congruent flankers during the post-switch phase (e.g., colored bars when the post-switch sorting dimension was color and shape silhouettes when it was shape) or incongruent flankers (e.g., shape

silhouettes when the post-switch sorting dimension was color). Congruent flankers facilitated performance relative to a control group who sorted cards with neutral flankers, yet performance was not comparably worsened by the presence of incongruent flankers. This is not to suggest that under no circumstances would performance be degraded through some manipulation increasing the activation of the pre-switch rules relative to the post-switch rules (as may be the case in Negative Priming versions of the DCCS; Müller, Dick, Gela, Overton, & Zelazo, 2006); but it does not appear to be the case that labeling the potentially misleading aspects of the test cards is sufficient to degrade performance compared to a condition in which labels refer to both dimensions. Hence it should not bias attention toward or away from the features of the test cards that are relevant to the post-switch rules.

5. General discussion

The aim of this study was to investigate the effect of labeling on young children's EF performance by manipulating how stimuli are labeled in the DCCS. The results across three experiments suggest that labels can aid EF and that this influence occurs through a dynamic interaction between bottom-up and top-down processes.

We found a specific facilitative effect of relevant labels on children's switching performance; performance when relevant labels were provided was superior to performance in all other conditions across experiments. The relevant labels appeared to exert influence on performance particularly when used in the post-switch phase, as evidenced by comparable performance between the Relevant-to-Relevant and Non-descript-to-Relevant conditions. The pattern of findings across Experiments 1 and 2 indicate that relevant labels facilitate performance in a bottom-up fashion. Contrary to what would be predicted by the reflection account, specific labels referring to both dimensions did not aid switching (Experiment 1) nor did merely changing labels across phases (Experiment 2). Experiment 3 provided evidence that, although labels facilitate EF in a more bottom-up fashion, bottom-up processes are not sufficient for labels to exert influence on switching performance. Interfering labels were not as powerful as one might expect if the bottom-up influence of the Opposite Label condition were the only process operating.

The pattern of results obtained across the three experiments is broadly consistent with the results of experiments involving the DCCS that have demonstrated how biasing children to attend to the relevant aspects of the stimuli can facilitate performance (Diamond, Carlson, & Beck, 2005; Fisher, 2011; Jordan & Morton, 2008, 2012; Kirkham et al., 2003; Kloo & Perner, 2005). Jordan and Morton's (2008) studies discussed above are one example indicating how increasing the salience of the post-switch dimension can aid performance. An example of how performance can be worsened by increasing the relative salience of the pre-switch dimension is an experiment by Kirkham et al. (2003), in which the DCCS was modified such that children sorted the test cards in the pre-switch phase face up rather than the standard face-down procedure. Children in this condition performed more poorly than children in a control condition who completed the standard task.

The evidence that in the DCCS labeling appears to influence 3-year-olds' behavior in a bottom-up fashion in no way implies that language does not also serve a top-down regulatory function, as theorized by Vygotsky and Luria, even in the context of this task. Indeed, a plausible interpretation is that the bottom-up support of labeling works in concert with emerging top-down influences on behavior to produce improvement in performance. For example, it may be that relevant labels help children focus attention in the absence of a mature inhibitory control (Diamond et al., 2007; Kirkham et al., 2003). Alternatively, labeling the relevant dimension may scaffold the selection of the post-switch rules in contrast to the pre-switch rules even in the absence of a robust representation of a higher-order rule (Zelazo et al., 2003).

Indeed, the results of Experiment 3 provide preliminary support for the idea that children's performance is not simply being directed by the different labels, but that the labeling cues interact with an emergent top-down mechanism of control. Interfering labels were not as powerful as one might expect if the bottom-up influence of labeling and the top-down influence of relevant rule representations were merely additive. Rather, labels appear to exert their influence synergistically with emerging top-down processes. For example, children whose performance was helped by the relevant labels may have had a fragile representation of the hierarchical nature of the task ("If we're playing the shape game, rabbits go here and boats go there, but if we're playing the color game the red ones go here and the blue ones go there") and without bottom-up support would have defaulted to using the lower-order rules which were more strongly represented due to previous experience ("Red ones go here and blue ones go there").

Importantly, across our experiments, most children failed all versions of the task, and children who passed a version of the task that did not provide supportive labels (e.g., the Both Label condition) almost always passed in the Relevant Label condition and also tended to pass the more difficult version with interfering labels. This pattern further suggests that children who will most benefit from relevant labels are those for whom the ability to regulate attention endogenously, perhaps due to a relatively fragile representation of the relevant rules, is emergent. Those with a very weak or absent representation of the relevant rules may be unable to utilize supportive labels. On the other hand, those who have a robust representation of the relevant rules will likely find the relevant labels superfluous. This is not to suggest that there is a point in early childhood in which the development of top-down control is complete and labels or other environmental supports are no longer relevant, but that the patterns of interaction between bottom-up and top-down influences on EF dynamically change over the course of development and probably vary in different contexts and given different task demands. In a similar vein, it is possible that as children develop, top-down processes may progressively assume more of the burden of self-regulation, although clearly much cognitive processing even in adulthood is automatic and under environmental control (Bargh & Chartrand, 1999). Future research is needed to investigate and gain further insight into how bottom-up and top-down processes interact in the development and functioning of EF and how labeling mediates these processes. For example, research is needed to address whether the provision of external labels actually aids the development of top-down EF mediated by internal labels, or whether the benefit of

external labels is limited to supporting the momentary exercise of cognitive flexibility in children who are unable to guide action adaptively using endogenous control.

In conclusion, the three experiments reported here provide new insight regarding the role of external labels in young children's emerging ability to exercise EF. They also add to the growing literature on diverse bottom-up influences on EF in early childhood. Finally, these studies shed light on the interaction between bottom-up and top-down influences on EF and suggest new avenues for further exploration of how this dynamic changes over the course of development.

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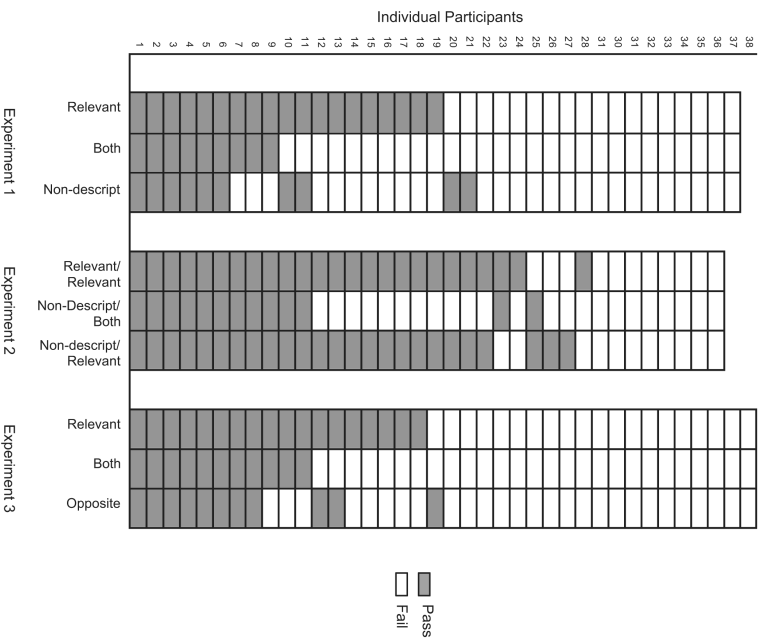


Fig. 1. Individual performance patterns by experiment and condition. Different children participated in each experiment.