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Perseveration and the status of 3-year-olds' knowledge in a card-sorting task: Evidence from studies involving congruent flankers

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ABSTRACT

Infants and young children often perseverate despite apparent knowledge of the correct response. Two Experiments addressed questions concerning the status of such knowledge in the context of a card-sorting task. In Experiment 1, three groups of 3-year-olds sorted bivalent cards one way and then were instructed to switch and sort the same cards using new rules under varying conditions of support offered by congruent flankers. Although formal aspects of the task such as higher-order rule use, stimulus redescription, and dimensional shifting remained constant across all conditions, use of the new rules increased with parametric increases in environmental support for the use of the new rules. In Experiment 2, 3-year-olds were more likely to switch and use new rules when test stimuli were flanked by congruent flankers rather than neutral flankers, even though both conditions made equivalent demands on attentional inhibition. Thus, in both experiments, children's knowledge of the new rules proved to be adequate under less demanding conditions but inadequate under more demanding conditions. These findings are consistent with the idea that children's knowledge is graded in strength rather than present or absent.

Introduction

Infants (e.g., Aguiar & Baillargeon, 2003; Marcovitch & Zelazo, 1999; Noland, 2007) and young children (e.g., Kirkham, Cruess, & Diamond, 2003; Kloo & Perner, 2005; Zelazo, Müller, Frye, & Marcovitch,

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2003) often perseverate by acting incorrectly on the basis of habit. In the Dimensional Change Card Sort (DCCS) task (Zelazo, Frye, & Rapus, 1996), for example, children are asked to first sort a series of bivalent cards (e.g., blue trucks and red rabbits) by one set of rules (e.g., color rules: "blue ones go here and red ones go there") and then switch and sort the same cards by another set of rules (e.g., shape rules: "trucks go here and rabbits go there"). When instructed to switch, most 3-year-olds persist in sorting test cards by the first set of rules regardless of which set of rules was used first (e.g., Zelazo et al., 1996). Remarkably, children err despite apparent knowledge of the new rules (Zelazo et al., 1996). For example, when asked where various cards go in the new game, children point to the correct sorting locations but revert to using the old rules when asked to sort the cards by the new set of rules.

Perseverative inflexibility of this kind may reflect qualitative constraints in children's understanding of the new rules. For example, 3-year-olds may know the new rules, but may be unable to reflect on this knowledge due to age-related constraints in the representation and use of higher-order rules (CCC-R theory; Zelazo et al., 2003). In the absence of a higher-order rule, children do not recognize the contradistinctive relation between old and new rules and, therefore, have difficulty in selecting the correct pair of rules in postswitch trials (Zelazo & Frye, 1997; Zelazo et al., 2003). Another possibility is that 3-year-olds do not fully understand that objects can be redescribed as being of a different kind. Put simply, children of this age do not understand that an object described earlier as a truck, for example, can be redescribed as something yellow. Consequently, when instructed to switch from sorting cards one way to sorting them in a new way, 3-year-olds fail to treat test cards as entities under a new description and, therefore, perseverate on their first description (Kloo & Perner, 2005). Still another possibility is that 3-year-olds fail to recognize that the postswitch instructions signal a new problem. Although children of this age can accurately infer the meaning of novel words from predicate cues such as "looks like a ___," "is made of a ___," and "has a ___," they have difficulty in flexibly inferring new word meanings in the face of changing predicate cues (Deák, 2000). This may have implications for children's performance in tasks such as the DCCS in which children need to recognize and respond to subtle changes in predicate cues across pre- and postswitch instructions. Whatever the underlying specifics, perseverative inflexibility in the DCCS may suggest that children lack knowledge that is critical for correct postswitch performance.

It is possible, however, that children possess the requisite knowledge for succeeding, but the expression of this knowledge in overt behavior is conditional on some other factor. Children, for example, may fully understand the new rules but fail to act on the basis of this knowledge because they have difficulty in inhibiting attention to stimulus features that were relevant in preswitch trials (Kirkham et al., 2003). Consistent with this idea, manipulations that increase the salience of stimulus features that are relevant in postswitch trials and that make it easier for children to inhibit attention to previously relevant stimulus features increase the likelihood that 3-year-olds correctly switch in postswitch trials (Kirkham et al., 2003; cf. Müller, Zelazo, Lurye, & Liebermann, 2008). Alternatively, children may have knowledge of the new rules but knowledge that is only weakly maintained (Chevalier & Blaye, 2008; Morton & Munakata, 2002). Weak representations may support correct responses given adequate environmental support (for discussion, see Munakata, 2001) but may be inadequate for supporting correct responses under more challenging conditions involving distraction or conflict. The active–latent (A–L) model (Morton & Munakata, 2002), for example, is a neural network model that simulates age-related changes in performance in the DCCS. According to this account, even very young children have knowledge of all the relevant sorting rules, but their ability to use each rule is dependent on the difference in the strength of latent representations of competing rules. Specifically, the strength of latent representations changes with experience according to a Hebbian learning algorithm (Munakata & McClelland, 2003). Successful use of a rule in preswitch trials strengthens the latent representation of that rule and creates an imbalance in the strength of underlying latent rule representations that favors previously relevant rules. On this account, knowledge of the relevant rules is graded, and switching becomes easier under environmental conditions that support the use of weak representations and more difficult under conditions that support the ongoing use of strong, previously relevant representations (for further discussion, see Yerys & Munakata, 2006). Indeed, 3-year-olds' knowledge of the postswitch rules in the DCCS appears to be intact when tested by means of standard knowledge questions that refer only to the relevant feature of the test cards (e.g., "where do *trucks* go in the shape game?") but deficient when tested with conflict questions that refer to both color and shape features (e.g., "where do the *yellow trucks* go in the shape game?") (Munakata & Yerys, 2001). On this account, it should be possible to systematically increase the likelihood that a 3-year-old will pass the DCCS through parametric variations in the amount of environmental support for the use of postswitch sorting rules.

We tested this prediction in the current study through the use of congruent flankers. Flankers are incidental stimuli that are presented adjacent to a target stimulus and that provide environmental (or bottom-up) support for responses to the target. In the Eriksen flanker task (Eriksen & Eriksen, 1974), for example, participants indicate as quickly and accurately as possible whether a centrally presented arrow (e.g., >) is pointing left or right. Responses are faster and more accurate when the target is flanked by congruent flankers (e.g., >>>>>) rather than by neutral flankers (e.g., ∗∗>∗∗). Congruent flankers also facilitate 3-year-olds' performance in the DCCS (Jordan & Morton, 2008). In one study, 3-year-olds were randomly assigned to either a neutral or congruent condition. In preswitch trials, children in both conditions were presented with bivalent test cards (e.g., blue trucks) flanked by small black bars (i.e., neutral flankers) and were instructed to sort the cards using a pair of rules (e.g., by shape). In postswitch trials, the flankers changed and children were instructed to switch and sort the same cards using new rules (i.e., by color). In the neutral condition, the spatial orientation of the flankers changed but their identity (i.e., color) remained the same, whereas in the congruent condition, the identity of the flankers changed (so that the flankers became congruent in color with the test card) but their spatial orientation remained the same. Consistent with the idea that children's knowledge of the postswitch rules is weak, 3-year-olds were significantly more likely to switch and use the new rules given environmental support from congruent flankers than they were in the neutral condition that offered no such support. These effects were not attributable to children matching the flankers to the target location (Jordan & Morton, 2008, Experiment 2) and were observed even though demands on higher-order rule use, stimulus redescription, and dimensional shifting were equivalent across conditions.

To test whether the likelihood that 3-year-olds switch sorting rules during the postswitch phase of the DCCS varies with *the amount* of environmental support for the use of the new rules, we parametrically varied the horizontal displacement of congruent flankers in postswitch trials. According to spotlight (Posner, 1980) and zoom lens (Eriksen & St. James, 1986) models of selective attention, attention to unattended stimuli (i.e., flankers) decreases as these stimuli are increasingly spatially displaced from a target. Thus, the facilitative effect of congruent flankers decreases with parametric increases in their horizontal displacement (Miller, 1991). We used this well-documented effect in the current experiment and predicted that parametric increases in the horizontal displacement of congruent flankers should be associated with parametric decreases in the number of correct postswitch trials in the DCCS. Increases in the horizontal displacement of the flankers should lead to parametric decreases in the amount of environmental support for the use of the new rules and, therefore, should decrease the likelihood that a weak representation of the postswitch rule would be reflected in overt sorting behavior.

Experiment 1

Method

Participants

The participants were 65 3-year-olds (36 boys and 29 girls, mean age = 41.80 months, *SD* = 3.22, range = 36–47) from Caucasian middle-class families. An additional 11 children were dropped from the analyses because they failed the preswitch phase of the task (defined as 7 or fewer correct sorts out of 10 preswitch trials) ($n = 8$), refused to complete the task ($n = 1$), had not yet learned to label the colors used in the task ($n = 1$), or demonstrated a response bias (i.e., always selected the same target) ($n = 1$).

Design and procedure

Children completed a computerized DCCS task administered with a touch-screen monitor (Elo Touch Systems) using E-Prime software (Psychology Software Tools). Parental consent and child assent were obtained prior to administration of the task. Children were tested individually. Their seat was adjusted so that their eyes were level with the center of the monitor and they were within reaching distance of the monitor (∼40 cm). Testing took approximately 15 min.

The task consisted of 10 preswitch trials and 8 postswitch trials (see Fig. 1). Two 11.5 × 8.9-cm target images (a blue rabbit and a red truck) were displayed in the lower left and right quadrants of the screen, respectively, throughout the task. On each trial, a 3.2 × 2.5-cm test stimulus (either a red rabbit or a blue truck) appeared in the center of the screen. In preswitch trials, test cards were flanked on the left and right by two neutral flankers, 2.5 × 4.4-cm black bars presented in a vertical orientation. In postswitch trials, test stimuli were flanked by images that were congruent with the relevant postswitch sorting rules. When color was relevant, the red rabbits and blue trucks were flanked by red and blue vertical bars (2.5 × 4.4 cm), respectively. When shape was relevant, the red rabbits and blue trucks were flanked by rabbit and truck silhouettes (3.2 × 2.5 cm), respectively (see Fig. 1).

During the preswitch phase, children were instructed to sort the cards one way (e.g., color: "In the color game, red ones go here and blue ones go there"). Next, during the postswitch phase, they were instructed to switch and sort the cards in a new way (e.g., shape: "In the shape game, rabbits go here and trucks go there"). Knowledge of the new rules was tested prior to the first postswitch trial by means of a standard knowledge question (e.g., "In the shape game, where do the trucks go?"). Children indicated their responses by pointing to one of the two target locations. The relevant rules were then repeated prior to each trial, and the relevant dimension was labeled for children (e.g., "Here is a truck; where does it go?"). Children received no feedback regarding their performance.

Children were randomly assigned to one of three conditions—Near, Middle, or Far—that differed only in terms of the horizontal displacement of the flankers in postswitch trials (i.e., the distance between the test stimulus and the flankers). Flankers were horizontally displaced 3, 6, and 10 cm from the center of the test stimulus in the Near, Middle, and Far conditions, respectively. The order of

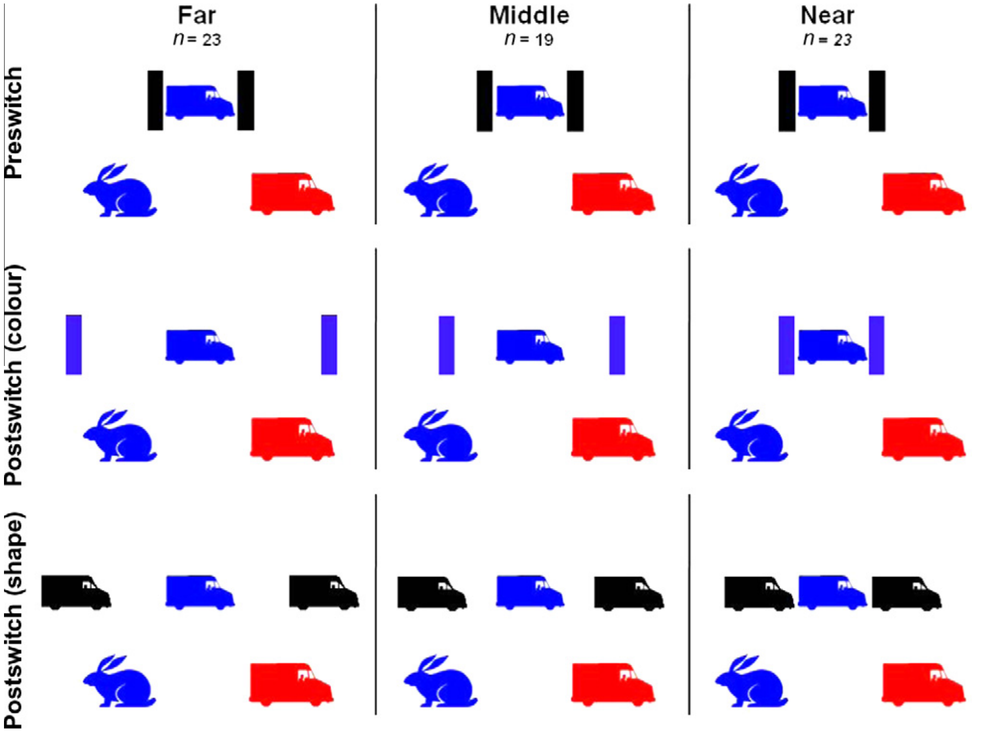

Fig. 1. Preswitch and postswitch stimuli used in Experiment 1. Postswitch stimuli differed as a function of experimental condition. The figure is not to scale.

relevant sorting dimensions was counterbalanced across children. Both preswitch and postswitch trials consisted of an equal number of each of the two possible test stimuli presented in a random order unique to each participant.

Results

Altogether, 23, 19, and 23 children completed the Near, Middle, and Far conditions, respectively. The preswitch dimension was counterbalanced within each of these conditions. The numbers of children switching from color to shape rules were 16, 12, and 12 for the Near, Middle, and Far conditions, respectively. Consistent with previous research (e.g., Müller et al., 2008; Zelazo et al., 1996, 2003), children's postswitch performance was not affected by the order of rule presentation in any of the conditions. The average numbers of correct postswitch trials were 5.09 (SD = 4.04) and 5.33 (SD = 3.31) when children were asked to sort by color and shape, respectively, in the Near condition, $t(21) = 0.16$, *ns*. Similarly, the numbers of correct postswitch trials did not differ based on the relevant postswitch dimension for either the Middle condition (color: M = 4.89, SD = 3.26; shape: M = 3.90, SD = 2.81), $t(17) = -0.71$, *ns*, or the Far condition (color: M = 2.75, SD = 2.77; shape: M = 1.91, SD = 2.84), $t(21) = -0.72$, *ns*. Therefore, data were collapsed along this dimension within each condition for subsequent analyses.

There were no differences between the groups in terms of male/female ratio (Near: 13/10; Middle: 11/8; Far: 12/11) or age in months (Near: M = 42.48, SD = 3.44; Middle: M = 42.00, SD = 2.77; Far: M = 40.96, SD = 3.31), $F(2, 62) = 1.34$, *ns*. In addition, all children in all conditions correctly answered the questions concerning the postswitch rules prior to postswitch sorting. Group differences in postswitch performance, therefore, cannot be attributed to differences in sex, age, or understanding of the postswitch rules. Furthermore, all children in the three conditions passed the preswitch phase given that this was a criterion for inclusion in the analysis. Any differences in postswitch performance, therefore, were not attributable to differences in preswitch performance.

Of primary interest was whether the average number of correct postswitch sorts parametrically decreased with increases in the horizontal displacement of the flankers. Results are shown in Fig. 2. Consistent with our predictions, there was a significant negative linear association between postswitch

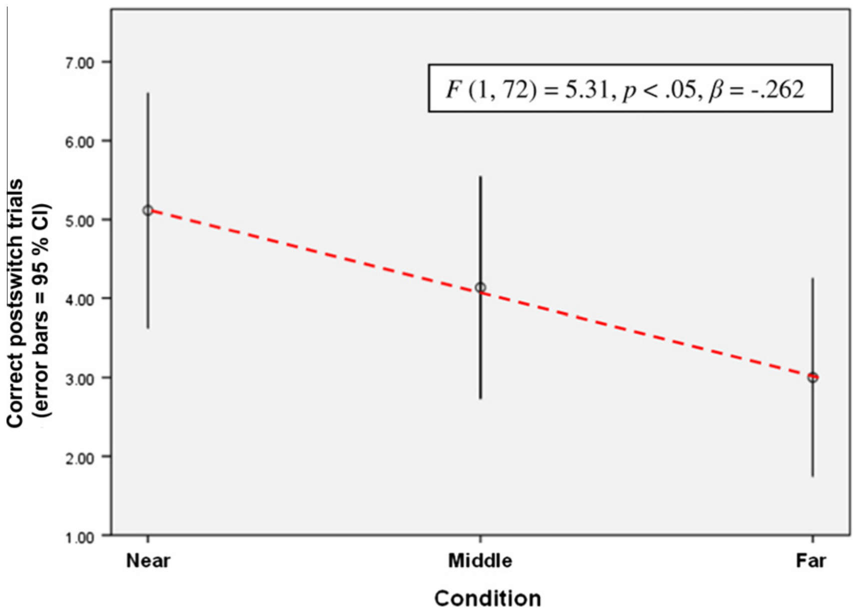

Fig. 2. Mean postswitch scores as a function of condition (i.e., flanker displacement).

performance and increased flanker displacement, $F(1, 72) = 5.31$, $p < .05$, $\beta = -.262$, with 67%, 42%, and 21% of children passing in the Near, Middle, and Far conditions respectively.

Discussion

Three groups of 3-year-olds were instructed to switch and use a new pair of rules to sort bivalent test cards under various conditions of environmental support offered by congruent flankers. Although children in all conditions accurately answered simple questions about the new rules, correct use of the new rules varied across the three conditions, with the number of correct postswitch sorts decreasing with increases in the horizontal displacement of congruent flankers. The results extend previous findings that congruent flankers facilitate switching in postswitch trials of the DCCS by showing that postswitch performance can be made to parametrically vary with the amount of environmental support for the use of the new rules offered by congruent flankers. The findings raise important questions concerning the status of children's knowledge of the new sorting rules.

Perseverative inflexibility in postswitch trials of the DCCS may reflect qualitative constraints in children's understanding of the new rules, including constraints in the representation and use of higher-order rules, the understanding that objects described one way can be redescribed in a new way, or the recognition that subtle changes in predicate cues across preswitch and postswitch instructions specify different problems. In short, children might persist in using the old rules because they lack the requisite knowledge for succeeding. The challenge, however, would be to explain why parametric variation in environmental support led to parametric variation in how likely children were to use the new rules. In all conditions, children were required to switch between pairs of contradistinctive rules, redescribe test stimuli in a new way, and recognize that the postswitch instructions specified a new problem. However, performance varied across the three conditions as a function of flanker proximity. At a minimum, these findings suggest that qualitative constraints in higher-order knowledge alone cannot account for children's postswitch sorting in the DCCS; something else influences children's performance.

One possibility, specified in CCC-R (Zelazo et al., 2003), is that pairs of lower-order rules (i.e., shape rules and color rules) vary continuously in their level of activation. Use of shape rules in preswitch trials, for example, may lead to an increase in the activation of shape rules and a corresponding decrease in the activation of color rules. Thus, in the absence of environmental support, a switch to color rules is difficult because the now relevant color rules are less active than the now irrelevant shape rules. By this account, congruent color flankers facilitate postswitch performance by increasing activation of color rules. Under such circumstances, color rules can be selected directly without needing to represent and use higher order rules. Congruent flankers may also highlight subtle changes in predicate cues across preswitch and postswitch trials (e.g., "Now we are playing the *color* game") or help children to recognize that stimuli that had been described one way can be redescribed in a new way. In short, the current findings may be consistent with the idea that 3-year-olds lack the requisite knowledge for flexible rule switching in the DCCS if one assumes that congruent flankers either obviate the need for such knowledge or facilitate an understanding of the task that is normally beyond the grasp of 3-year-olds.

Such speculations, however, are not beyond dispute. Although it is possible, for example, that congruent flankers highlight relevant predicate cues in the task instructions or facilitate stimulus redescription, the mechanisms by which these effects might occur are not well spelled out in the respective theories. In addition, to claim that congruent flankers allow the appropriate lower-order rules to be selected directly, and so obviate the need for representing a higher-order rule, is akin to claiming that the flankers eliminate conflict from postswitch trials altogether. Such claims, however, are hard to reconcile with the fact that although postswitch performance was better in some conditions than in others, in no condition was postswitch performance at ceiling. Even when congruent flankers were presented in close proximity to the test stimuli, the test stimuli contained conflicting color and shape features and the task continued to be difficult for children. What is unclear from this account, then, is why small amounts of conflict can be managed without higher-order rules, whereas greater amounts of conflict cannot.

As such, it may be more parsimonious to assume not that children so much lack the requisite knowledge for switching but rather that the expression of this knowledge is contingent on some other factor. One possibility is that children's representation of the new rules is weak and, therefore, is contingent on environmental support for the use of this knowledge. On this account, sorting cards one way in preswitch trials creates a bias for those features (by means of Hebbian learning); in short, connections between relevant features (e.g., shape) and responses become stronger, whereas connections between irrelevant features (e.g., color) and responses become weaker. Therefore, switching sorting criteria leads to conflict because postswitch instructions mandate the use of new features (i.e., color), but the bias from preswitch trials is to continue using the old features. Congruent flankers presented in close proximity to the test stimulus partially attenuate this conflict by facilitating the processing of features that were ignored in preswitch trials but that are now relevant in postswitch trials. Children are more likely to switch under these conditions because their weak representation of the postswitch instructions is adequate for overcoming partially attenuated conflict. However, as the displacement of congruent flankers parametrically increases, the conflict between task instructions and prior bias also increases and children become less likely to switch correctly. Thus, the current findings are readily accommodated by a graded representations view that young children form a weak active representation of the new rules whose adequacy varies with the amount of environmental support for the use of this knowledge (Morton & Munakata, 2002; Munakata, 2001).

It is possible, however, that children's knowledge of the new rules is perfectly intact, as reflected by the fact that they correctly answer basic questions about the new rules, but that the expression of this knowledge in overt behavior is contingent on children's ability to inhibit attention to previously relevant stimulus features (Kirkham et al., 2003). On this account, congruent flankers increase the salience of the relevant postswitch features and make it easier for children to inhibit attention to the previously relevant features. Performance varied across the conditions because incrementally increasing the horizontal displacement of the congruent flankers incrementally increased the demands on attentional inhibition.

To distinguish the graded representations and attentional inertia accounts, we conducted a second experiment in which we compared 3-year-olds' performance in two versions of the card-sorting task that were indistinguishable in terms of their demands on attentional inhibition but that varied in terms of the degree of environmental support for the use of postswitch rules offered by congruent flankers. Two groups of children were administered a negative priming version of the card-sorting task that is designed to clarify what aspect of preswitch experience carries forward and interferes with postswitch performance (Müller, Dick, Gela, Overton, & Zelazo, 2006). One possibility is that features that were relevant in preswitch trials (e.g., color) remain "activated," making it difficult for children to shift their attention away from these features in postswitch trials. A second possibility is that features that were irrelevant (i.e., ignored) in preswitch trials remain "suppressed" or negatively primed, making it difficult for children to switch their attention to these features in postswitch trials (Müller et al., 2006). In the task, children are asked to ignore shape, for example, and to sort red trucks and blue rabbits by color in preswitch trials. To test whether trucks and rabbits remain suppressed in postswitch trials and to avoid any effects of persistent activation of previously relevant color features, children are then asked to sort cards featuring the old shapes in new colors (e.g., green rabbits and orange trucks). Even though the task makes no demands on attentional inhibition, because the features that were relevant in preswitch trials have been removed in post-switch trials, most 3-year-olds children perseverate in this version of the task.

In the second experiment, we used the negative priming version of the card-sorting task to test whether the facilitative effect of congruent flankers could be observed under conditions in which demands on attentional inhibition were minimal. Two groups of 3-year-olds were administered the negative priming version of the card-sorting task. One group received environmental support for the use of the new rules by means of congruent flankers, and the other group received no such support (i.e., children were presented with neutral flankers). For both groups, demands on attentional inhibition were kept constant because features that were relevant during the preswitch phase were replaced during the postswitch phase and, therefore, it was not possible for children's attention to get stuck on those features in postswitch trials. Therefore, any facilitative effect of congruent flankers on postswitch performance could not be attributed to diminished demands on attentional inhibition.

Experiment 2

Method

Participants

The participants were 50 3-year-olds (29 boys and 21 girls, mean age = 41.0 months, *SD* = 2.0, range = 36–47) from Caucasian middle-class families. An additional 10 children were dropped from analyses because they failed the preswitch phase of the task (defined as 7 or fewer correct sorts on preswitch trials) ($n = 4$), because they refused to complete the task ($n = 2$), or because of equipment failure ($n = 4$).

Design and procedure

Children completed a computerized Negative Priming (NP) version of the DCCS task in which stimulus features that are relevant in preswitch trials are replaced with novel features in postswitch trials. Children were randomly assigned to either a neutral or congruent condition. In both conditions, the task was administered with a touch-screen monitor (Elo Touch Systems) using E-Prime software (Psychology Software Tools). Parental consent and child assent were obtained prior to administration of the task. All children were tested individually. Testing took approximately 15 min.

In both conditions, the task consisted of 10 preswitch and 8 postswitch trials (see Fig. 3). In preswitch trials, children sorted red rabbits and blue trucks by either color or shape. Children who had sorted by color in preswitch were instructed in postswitch to sort orange rabbits and green trucks by shape. Children who had sorted by shape in preswitch were instructed in postswitch to sort red shirts and blue boats by color. Children sorted each card into one of two sorting locations that were located in the bottom corners of the screen and that were marked with 11.5×8.9-cm target images. The target images matched each of the test stimuli along one dimension but mismatched along the other dimension. During the preswitch phase, targets were a blue rabbit (presented in the lower left quadrant) and a red truck (presented in the lower right quadrant). For children sorting orange rabbits and blue trucks by shape during the postswitch phase, the targets depicted a green rabbit (presented

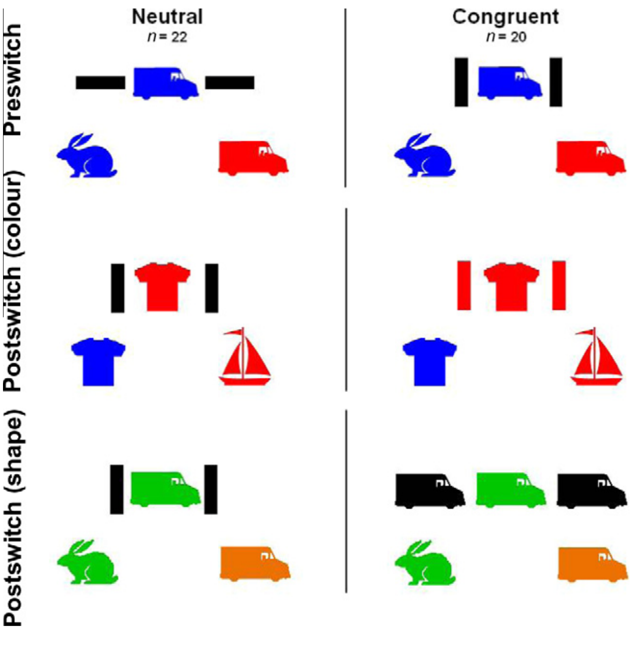

Fig. 3. Preswitch and postswitch stimuli used in Experiment 2. Postswitch stimuli differed as a function of experimental condition. The figure is not to scale.

in the lower left quadrant) and an orange truck (presented in the lower right quadrant). For children sorting red shirts and blue boats by color during the postswitch phase, the targets were a blue shirt (presented in the lower left quadrant) and a red boat (presented in the lower right quadrant). On each trial, a 3.2×2.5-cm test stimulus appeared in the center of the top half of the screen.

During the preswitch phase, children in both conditions were provided with a set of rules for sorting the test stimuli by one dimension (e.g., color: "In the color game, the red ones go here and the blue ones go there"). During the postswitch phase, all children were instructed to switch and were given a new set of rules for sorting by the other dimension (e.g., shape: "In the shape game, the rabbits go here and the trucks go there"). The relevant rules were repeated prior to each trial, and the relevant dimension was labeled for children (e.g., "Here is a red one; where does it go?"). Children were not provided with feedback regarding their performance.

In preswitch trials of both conditions, test cards were flanked on the left and right by two 2.5×4.4-cm black bars. In the neutral and congruent conditions, neutral flankers were presented in a horizontal and vertical orientation, respectively. These flankers were considered as neutral because neither their color nor their shape related to the preswitch sorting rules. In postswitch trials of both conditions, the flankers changed. In the neutral condition, the flankers changed in their spatial orientation but remained neutral (i.e., unrelated to the relevant sorting feature), whereas in the congruent condition, they changed in their identity so that they became congruent with the feature that was relevant in postswitch trials. When postswitch rules specified color as relevant, the red shirts and blue boats were flanked by red and blue vertical bars (2.5×4.4 cm), respectively. When postswitch rules specified shape as relevant, the orange rabbits and green trucks were flanked by rabbit and truck silhouettes (3.2×2.5 cm), respectively.

In both conditions, the order of the relevant sorting dimensions was counterbalanced across children and both preswitch and postswitch trials consisted of an equal number of each of the two possible test stimuli presented in a random order unique to each participant.

Results

In total, 25 children (15 boys and 10 girls) completed the neutral condition and 25 children (14 boys and 11 girls) completed the congruent condition. In each condition, the preswitch dimension was counterbalanced. The number of children switching from color to shape was 12 in the neutral condition and 13 in the congruent condition. The average numbers of correct postswitch trials in the congruent condition were 5.25 ($SD = 3.36$) and 6.08 ($SD = 3.04$) when children were asked to switch to sorting by color and shape, respectively, $t(23) = -0.65$, *ns*. In the neutral condition, children sorted correctly on an average of 5.31 postswitch trials ($SD = 3.45$) when asked to switch from shape to color and 2.50 trials ($SD = 3.34$) when asked to switch from color to shape. The difference in performance across shape-to-color and color-to-shape switches approached but did not reach conventional levels of statistical significance, $t(23) = 2.06$, $p = .051$. Given this and the fact that we had no reason (either from the DCCS literature or from our theory) to expect differences across switch types, we collapsed across switch type.

The mean age of the children in the two groups (neutral: $M = 40.6$ months, $SD = 2.43$; congruent: $M = 41.0$ months, $SD = 2.99$) did not differ, $t(48) = -0.52$, *ns*. All children in both conditions passed the preswitch phase given that this was a criterion for inclusion in the analysis. Any differences in postswitch performance, therefore, were not attributable to differences in preswitch performance.

The primary measure of interest was the number of correct postswitch trials. Because most children sorted either correctly or incorrectly on all postswitch trials, children were classified as either passing or failing the postswitch. Consistent with earlier investigations of the effect of congruent flankers on preschoolers' card sorting (Jordan & Morton, 2008), 6, 7, or 8 correct postswitch trials was used as the criterion for passing, where the probability of achieving a score in this range by chance was .14. On the basis of prior evidence that congruent flankers facilitate postswitch performance (Jordan & Morton, 2008, Experiment 1), a one-tailed nonparametric statistic based on a binomial approximation of the normal distribution was used to test for group differences (Evans, Hastings, & Peacock, 2000). A significantly greater proportion of children passed the postswitch phase in the congruent condition (18/25 or .72) than in the neutral condition (12/25 or .48) ($Z = 1.73$, $p < .05$, one-tailed).

The group effect remained unchanged when a more stringent criterion of 7 or 8 correct postswitch trials was used as the pass/fail criterion.

Discussion

Attentional inertia and graded representations accounts make very similar predictions about the effect of various manipulations on children's performance in the DCCS. Congruent flankers, for example, facilitate children's use of postswitch rules in the DCCS (Jordan & Morton, 2008), and the magnitude of this effect varies with the angle of horizontal displacement of the flankers (Experiment 1). Both of these effects can be readily accommodated by the attentional inertia and graded representations accounts. Therefore, in the current experiment, two groups of 3-year-olds were instructed to switch and use a new pair of rules in a negative priming version of the DCCS, a version of the task that eliminates demands on attentional inhibition by replacing features that were relevant in preswitch trials with new features in postswitch trials. In one condition, children received environmental support for the use of the new rules by means of congruent flankers; in the second condition, children received no such support. Although demands on attentional inhibition were equivalent across conditions (i.e., effectively eliminated), children were more likely to use the new rules when target images were flanked by congruent flankers than when they were flanked by neutral flankers. The results are consistent with the idea that congruent flankers facilitate postswitch performance in the DCCS by providing environmental support for the use of the new rules. On this account, switching sorting criteria in postswitch trials leads to conflict because new rules mandate the use of features that were ignored in preswitch trials and, therefore, were not readily processed in postswitch trials (Müller et al., 2006). Congruent flankers presented in close proximity to the test stimulus partially attenuate this conflict by facilitating the processing of these features. Children are more likely to switch under these conditions because their weak representation of the postswitch instructions is adequate for overcoming weaker (i.e., partially attenuated) conflicts but not stronger conflicts.

General discussion

At 3 years of age, children frequently perseverate in simple card-sorting tasks by persistently using old rules that are no longer appropriate despite apparent knowledge of the new rules. By some accounts, children's inflexibility is tied to qualitative constraints in higher-order knowledge, including the representation and use of higher-order rules (Zelazo & Frye, 1997; Zelazo et al., 2003), the understanding that single objects can afford multiple descriptions (Kloo & Perner, 2005), and the recognition that pre- and postswitch trials constitute different problems (Deák, 2000). By other accounts, children's inflexibility stems from quantitative constraints in their knowledge of the new rules; specifically, children perseverate because they only weakly maintain the new rules. By still other accounts, children's knowledge is perfectly intact and they perseverate because of constraints in attentional inhibition. In Experiment 1, 3-year-olds showed parametric improvement in their use of new rules as the horizontal displacement of congruent flankers was parametrically decreased. In Experiment 2, congruent flankers facilitated children's performance in a negative priming version of the DCCS in which demands on attentional inhibition remained constant across conditions. The findings are important because they clarify the status of children's knowledge of the postswitch rules and, therefore, help to arbitrate between alternative accounts of 3-year-olds' perseverative inflexibility in the DCCS.

The data challenge accounts that attribute children's inflexibility to qualitative constraints in higher-order knowledge. Although parametric variation in flanker displacement may influence children's understanding that a single object can be described in more than one way, for example, or that predicate cues in postswitch instructions signal the presence of a new problem, it is not clear from these accounts how these effects might be realized. CCC-R theory may be better positioned to accommodate the current findings by arguing that children's performance in the DCCS is influenced not only by quantitative constraints in higher-order knowledge (i.e., the capacity to represent and use higher-order rules) but also by quantitative variation in the activation of lower-order rules. By this account, higher-order rules are necessary for resolving conflicts between alternative pairs of lower-order rules. Because 3-year-olds have difficulty in representing and using higher-order rules, they have difficulty in selecting among conflicting pairs of rules in the standard task and typically perseverate. In the current experiments, however, congruent flankers presented in close proximity to the target stimulus increased the activation of the relevant lower-order rules and allowed children to select the appropriate rules directly. It is possible, then, that congruent flankers facilitate 3-year-olds' performance by obviating the need for higher-order rule use.

Such claims, however, are at odds with evidence that congruent flankers varied but never eliminated conflict. For example, in Experiment 1, all children performed at ceiling when answering knowledge questions that made no reference to previously relevant stimulus dimensions (i.e., eliminated conflict) but were far from ceiling in postswitch trials even when congruent flankers were presented immediately adjacent to the test stimuli (i.e., the Near condition in Experiment 1). Thus, even in conditions where bottom-up support afforded by congruent flankers was maximal, there was still a residual degree of conflict between preswitch and postswitch rules. According to CCC-R theory, resolving conflict of this kind presumably calls for higher-order rule use. One could perhaps assume that conflict in the Near condition was sufficiently attenuated to allow appropriate lower-order rules to be selected directly without any need for a higher-order rule. But then how could performance in the Middle condition that was exactly intermediate between the Near and Far conditions be explained? If higher-order rules were required in the Far condition because conflict was high but not in the Near condition because conflict was low, then how was intermediate performance in the Middle condition achieved? In short, the key limitation of CCC-R is that although it can explain parametric variations in conflict by appealing to variation in the activation of various pairs of lower-order rules, it cannot explain why higher-order rules are required for stronger conflicts but not for weaker conflicts.

Aspects of the current findings are consistent with the idea that children's knowledge is perfectly intact and perseveration is the result of problems inhibiting attention to previously relevant stimulus features (see the attentional inertia account in Kirkham et al., 2003). Certainly, evidence from Experiment 1 can be easily accommodated by this account by assuming that increasing flanker proximity increased the salience of the relevant postswitch features, thereby making it easier for children to inhibit attention to the previously relevant stimulus features. This account has more difficulty in accommodating the results of Experiment 2, in which postswitch performance varied across conditions that differed in environmental support for the use of the new rules but made equivalent demands on attentional inhibition. Although these results do not rule out the importance of attentional inhibition for flexible behavior in the DCCS more generally because demands on attentional inhibition were kept constant in this experiment, they do suggest that environmental support for the use of new rules can have positive consequences for children's flexible behavior independent of inhibitory demands.

The current findings are perhaps most consistent with accounts that posit quantitative constraints in how strongly 3-year-olds maintain the new rules in memory (Chevalier & Blaye, 2008; Morton & Munakata, 2002). According to a graded representations view, for example, control emerges out of dynamic interactions between higher and lower-order representations whose strength varies continuously as a function of environmental support, experience, the developmental status of the individual, and/or damage or dysfunction in particular brain regions (Munakata, 2001). On this account, young children's knowledge of the new rules in the DCCS is weak rather than present or absent (Morton & Munakata, 2002). Such representations falter under challenging conditions involving conflict but are increasingly likely to appear to be intact with incremental increases in environmental support for the use of that knowledge (Munakata & Yerys, 2001). Thus, if previously relevant preswitch features and currently relevant postswitch features strongly conflict, either because of differences in the strength (Morton & Munakata, 2002) or activation (Chevalier & Blaye, 2008; Zelazo et al., 2003) of those features, then young children's knowledge is likely to falter. However, as the degree of conflict between previously relevant and currently relevant features is gradually attenuated by, for example, incrementally decreasing the horizontal displacement of congruent flankers, a weak representation of the new rules becomes increasingly likely to support correct switching. And if conflict is eliminated altogether, such as in basic knowledge questions that refer only to the currently relevant stimulus features, then young children's weak representation of the new rules appears to be perfectly intact (Munakata & Yerys, 2001). These findings are consistent with the idea that 3-year-olds only weakly maintain a representation of the postswitch rules in the DCCS, a representation that is adequate given sufficient environmental support but inadequate under conditions of increasing conflict (for further discussion of gradedness and the DCCS, see Hanania & Smith, 2010).

A potential limitation of these findings is that the flankers change in different ways across conditions in Experiment 2. In the neutral condition, the spatial orientation of the flankers changes, whereas the shape and color remain the same. In contrast, either the color or the shape of the flankers changes from preswitch to postswitch in the congruent condition. It could be argued that changes to the flankers in the congruent condition were more novel and, therefore, attracted more attention. On this account, novelty—not the fact that the flankers were congruent—might have led to better performance in the congruent condition. It remains an empirical question as to whether changes in color or shape would be more novel than changes in spatial orientation. It should be noted that novelty cannot account for the graded congruency effect reported in Experiment 1 because the only difference across conditions was the horizontal displacement of congruent flankers. Furthermore, in a previous study, the congruency effect was observed even when compared with a condition that used irrelevant flankers (i.e., flankers that were different in both color and shape relative to the test stimuli) (see Jordan & Morton, 2008, Experiment 2). It could be argued that the presentation of irrelevant flankers during the postswitch phase would be more novel than congruent flankers. The congruency effect, however, was replicated in this study.

The current findings add to a growing body of literature suggesting that active memory is an important mechanism underlying the control of attention and behavior and its development. Active memory figures prominently in neural network models of cognitive control tasks, including the color word Stroop task (Cohen, Dunbar, & McClelland, 1990) and the continuous performance task (CPT) (Braver, Cohen, & Barch, 2002), and in developmental models of object permanence (Munakata, 1998) and perseverative reaching (Stedron, Sahni, & Munakata, 2005). In these models, active memory units maintain attention-guiding rules or instructions and help to achieve control through biasing activity in other regions of the network. The models offer a formal characterization of the higher-order control of attention and behavior, a mechanistic account of prefrontal cortex function that is consistent with evidence from functional neuroimaging (MacDonald, Cohen, Stenger, & Carter, 2000) and single cell recording (Miller, Erickson, & Desimone, 1996) studies, and an explanation for how age-related changes in prefrontal cortex function contribute to age-related changes in cognitive control (for a review, see Morton, 2010). Future studies involving direct measures of brain function should address these developmental hypotheses.

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