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Preschool Children's Performance in Task Switching on the Dimensional Change Card Sort Task: Separating the Dimensions Aids the Ability to Switch

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Abstract

Fifty-seven children (53% female) at 3 ages (2½, 3, and 3½ years) were tested on the standard Dimensional Change Card Sort (DCCS) task with integrated stimuli (e.g., a red truck) and on a separated-dimensions version where colorless shapes were presented on a colored background (e.g., a black truck on a red background). Roughly twice as many children successfully switched sorting dimensions when color was a property of the background than when color was a property of the shape itself. Children succeeded 6 months earlier in switching sorting criteria when the dimensions were separated. When evidence of both indecision and accuracy was taken into account, a clear and rich developmental progression emerged. These results support an inhibitory control interpretation of preschoolers' problems on the DCCS task. Diamond theorized that young children can have difficulty integrating features not part of a single object and separating features of a single object so that the object can be categorized first by one attribute and then by another. Preschoolers remain stuck in thinking about objects according to the objects' initially relevant attribute (*attentional inertia*; Kirkham, Cruess, & Diamond, 2003). To switch perspectives, the old way of thinking about the objects must be inhibited. Separating color and shape reduced the need for such inhibition; a truck was always a truck, and the background was always red.

PERCEIVING RELATIONS BETWEEN SEPARATED OBJECTS AND SEPARATING FEATURES OF A SINGLE OBJECT

Diamond has theorized that very young children have difficulty *integrating* features that are not part of a single object (e.g., relating the color of the background to the shape of an item in the foreground or relating a reward object to a stimulus object; Diamond, Churchland, Cruess, & Kirkham, 1999; Diamond, Lee, & Hayden, 2003) and, the flip side, that very young children have difficulty *separating* features of a single object (e.g., flexibly reacting to something first in terms of its being a truck and then moments later in terms of its being a red thing; Diamond & Kirkham, 2005; Kirkham, Cruess, & Diamond, 2003; Kirkham & Diamond, 2003). In this article we address the latter—separating features of a single object.

On the Dimensional Change Card Sort (DCCS) task, each card contains a simple drawing of a familiar object (such as a truck or star) in a primary color (Zelazo, Frye, & Rapus, 1996). Children 3 years of age can sort the cards flawlessly by color or shape. When asked to switch

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from sorting by color to sorting by shape (or vice versa), however, most 3-year-olds do not switch; they continue to sort as they had before. This is striking because the experimenter makes a point of saying that the sorting criterion has changed and before every trial either reminds the child of the sorting rules (e.g., "We are playing the color game now, and in the color game, red ones go here and blue ones go there") or asks the child where the red ones (or trucks) and where the blue ones (or stars) go, and the child points correctly. Children of 3 years thus err despite knowing and remembering the rules. This was first observed by Zelazo and colleagues (Zelazo et al., 1996) and has been observed in other laboratories in the United States (Kirkham et al., 2003; Munakata & Yerys, 2001), Austria (Kloo & Perner, 2005; Perner & Lang, 2002), Canada (Bialystok & Martin, 2004; Jacques, Zelazo, Kirkham, & Semcesen, 1999; Zelazo, Mueller, Frye, & Marcovitch, 2003), England (Riggs & Williams, 2003; Towse, Redbond, Houston-Price, & Cook, 2000), and Scotland (Rennie, Bull, & Diamond, 2004).

Diamond and Kirkham hypothesized that the difficulty 3-year-olds have in switching from sorting by color or shape to sorting by the other is a difficulty in thinking about the same thing from two different perspectives. Having thought about the primary feature of a truck being its color, it is difficult for 3-year-olds to then flip their mental focus and think about the same item ignoring its color, attending only to its shape. Diamond and Kirkham named children's tendency to continue to react to a stimulus according to its initially relevant attribute *attentional inertia* (Diamond & Kirkham, 2005; Kirkham et al., 2003; Kirkham & Diamond, 2003). Three-year-olds quickly become used to focusing on the blueness or redness of a stimulus or on its object-kind property (that it is a truck or a star) and have great difficulty switching the way they think about the stimuli. Once they have focused their attention on one dimension, their attention gets stuck there.

> It is not that they fail to realize that something can be both blue and a truck. But, having adopted the mindset that blue things go with the blue model card, they have great difficulty switching to think of a blue truck in terms of its shape and sorting it with the red-truck model card, even though they are told that the correct dimension is now shape. We posit that 3-year-old children's difficulty lies in disengaging from a mindset (a way of thinking about the stimuli) that is no longer relevant. (Kirkham et al., 2003, p. 451)

Even adults have difficulty when required to switch tasks or dimensions, as the rich literature on task switching so clearly demonstrates (e.g., Allport, Styles, & Hsieh, 1994; Mayr & Keele, 2000; Monsell & Driver, 2000; Rogers & Monsell, 1995; Waszak, Hommel, & Allport, 2003). Adults are able to switch sorting dimensions in the DCCS task, but they show the same pattern in their reaction time (RT) as 3-year-olds show in their accuracy (Diamond & Kirkham, 2005). Their inertial "stuckness" on the first dimension is evident not only in their slower RTs when the sorting criterion changes but in slower RTs on the second dimension (faster RTs on whichever dimension they started with) throughout the testing session (Diamond & Kirkham, 2005).

Evidence from a number of different domains supports the conclusion that children 3 years of age have difficulty thinking about the same thing in two different ways. For 3-year-olds, something is either A or B, but not both (e.g., an object is either a bunny or a rabbit, but not both; Perner, Stummer, Sprung, & Doherty, 2002). Many studies have illustrated this mutual exclusivity bias (Carey & Bartlett, 1978; Markman & Wachtel, 1988). Remnants of this can be seen perhaps in adults' difficulty in representing more than one interpretation at a time of an ambiguous figure (Chambers & Reisberg, 1992). For 3-year-olds the problem is more profound: Even when shown the alternatives in an ambiguous figure, many 3-year-olds are still unable to see more than one perspective in the figure (Gopnik & Rosati, 2001). Similarly on appearance-reality tasks (Flavell, Green, & Flavell, 1986), where children are shown something that appears to be one thing (e.g., a rock) but is really something else (e.g., a sponge), 3-year-olds typically say that it looks like a sponge and really is a sponge or that it looks like a rock and really is a rock, but rarely will a 3-year-old give the correct answer that it looks like a rock but really is a sponge. Children 3 years of age can conceive of it as a rock or as a sponge but not as a rock from one perspective and a sponge from another.

It is interesting that 3-year-olds *can* switch tasks if they do not have to switch the focus of their attention. When the stimuli vary along only one dimension, 3-year-olds can switch from sorting trucks with trucks and stars with stars to sorting trucks with stars and stars with trucks (Brooks, Hanauer, Padowska, & Rosman, 2003; Perner & Lang, 2002). Here, they do not have to change how they are thinking about the stimuli; a truck is always a truck and a star is always a star.

If, however, some trucks (and stars) are yellow and others blue (color varying orthogonally with the relevant dimension [shape]), children of 3 years fail the task (although color is never relevant; Brooks, Hanauer, & Rosman, 2001). Similarly, Shepp and Barrett (1991; Barrett & Shepp, 1988; Shepp, Barrett, & Kolbet, 1987) found that children 4 to 5 years of age seem unable to focus on just the relevant dimension when two dimensions are properties of the same integrated stimuli. However, they found that children could successfully focus on just one dimension, ignoring irrelevant variation in the other, when the dimensions were spatially separated. Spatial separation likewise aids adults' performance on the Stroop task. Adults find it difficult to switch between naming the ink color and reading the word of integrated Stroop stimuli (color words, such as *green*, written in the ink of another color, such as red). In that example, the incongruent ink color (red) is an attribute of the word *green*. Adults perform much better if the incongruent color, although present, is not an attribute of the word itself. Thus, adults perform better when the color and word are spatially separated (e.g., the word is written in black ink with a bar of another ink color above or below the word; Kahneman & Chajczyk, 1983; MacLeod, 1998).

There is considerable evidence that when adults attend to one aspect of an integrated stimulus, they, like children, cannot help but process its irrelevant features as well. For example, Garner and Felfoldy (1970) found facilitation with correlated dimensions and interference with orthogonal dimensions in adults when both dimensions were integral properties of all stimuli. When the dimensions were separated and properties of different stimuli, adults showed neither facilitation nor interference. Ridderinkhof, van der Molen, Band, and Bashore (1997) reported similar results in children 5 to 12 years old using a selective attention task. With integrated stimuli, responses were slowest in the correlated conditions, intermediate in neutral conditions, and fastest in orthogonal conditions. At all ages, responses were slower when the dimensions of color and orientation were integrated than when they were spatially separated. Impressively, Pratt and Hommel (2003, Exp. 4) showed that not only is an irrelevant feature (color) of an integrated stimulus processed by adults but if that irrelevant feature (the same color) then appears as part of a wholly irrelevant stimulus (an arrow), that wholly irrelevant stimulus then influences adults' performance.

In a manuscript in preparation, Diamond (2005) proposed an “all or none hypothesis”—that the brain, mind, and body initially work at a gross level and only with fine-tuning act in a more differentiated manner. One example is that it is easier to take into account *all* salient aspects of a stimulus than just its color or just its shape. That is, unbinding (rather than binding) is a problem as far as the properties of individual entities are concerned, as the studies just cited illustrate. Indeed, Schoenfeld et al. (2003) reported evidence at the neural level for rapid, automatic binding. Unbinding would require inhibiting or undoing that process.

INHIBITORY CONTROL IS NEEDED WHEN THE OLD WAY OF THINKING ABOUT THE STIMULI (WHEN ATTENTIONAL INERTIA) MUST BE SUPPRESSED

In accord with Diamond and Kirkham (2005; Kirkham et al., 2003; Kirkham & Diamond, 2003), we contend that inhibition is needed to switch from sorting by color (or shape) to sorting by the other dimension on the standard DCCS because switching sorting criteria requires that the participant flip from thinking about an object (e.g., a truck) first as a blue thing to thinking about it as a truck (or vice versa), and that requires inhibition of the initial mind-set (inhibition of the inertial tendency to continue to attend to the initially relevant attribute, to continue to think about [and react to] the stimuli in the same way one has been thinking about [and reacting to] them). If one is to flexibly switch perspectives (flexibly switch sorting criteria), one must be able to quickly and efficiently inhibit one's previous perspective and previous stimulus-response mappings.

If, however, one's old perspective does not need to be inhibited—if one never has to change how one thinks about a truck—then children should be able to succeed on the DCCS task at a younger age. Changing perspectives is required when color and shape are integral properties of the same thing. No change in perspective is required, however, if color is a property of the background rather than of the shape itself. With the dimensions separated, children would never have to think about the trucks (or stars) as anything but trucks and stars and would never have to think about the background as anything but red or blue. We therefore predicted that more 3-year-olds would successfully switch sorting dimensions if color was not an attribute of the stimulus object but instead a property of the background, even though the same colors and shapes would appear on all stimulus cards. In addition to testing our prediction that children of 3 and 3½ years would be better able to switch sorting criteria when the dimensions are separated, we also investigated whether even children of only 2½ years might be helped by the separated dimensions condition.

EARLIER REPORTS OF PRESCHOOLERS' PERFORMANCE ON SEPARATED-DIMENSIONS VERSIONS ON THE DCCS TASK

There is some disagreement in the literature about whether separating the dimensions only on the sorting cards or only on the model cards is sufficient to help preschoolers succeed in switching sorting dimensions. Mueller (Mueller, Dick, Gela, Overton, & Zelazo, 2004; Zelazo et al., 2003, Exp. 6) tested preschoolers with color and shape separated in a rather unusual way on the sorting cards while remaining integrated on the model cards (using standard DCCS model cards) and found that performance was no better than in the standard condition. Kloo and Perner (2005, Exp. 1) found that separating the dimensions on only the sorting cards greatly increased the number of preschoolers who successfully switched sorting dimensions. Both the Mueller studies and the Kloo and Perner studies found that separating the dimensions only on the model cards did not help; however, studies where the dimensions have been separated on the model cards by providing one model card for each value on each dimension (four model cards) have shown dramatically better switching performance in preschoolers (Rennie, Bull, & Diamond, 2004; Towse, Redbond, Houston-Price, & Cook, 2000).

Only one study, other than the one reported here, has looked at the effect on preschoolers' task switching performance of separating the sorting dimensions on both the sorting and the model cards. Simultaneously and independently, while our study was underway, Kloo and Perner (2005) tested a separated-dimensions condition where their sorting and model cards contained the outline of a colorless (white) shape on one side of a small, white card and a filled-in colored circle on the other side of each card (see Figure 1). In both a between-subjects study (Exp. 1) and a within-subjects one (Exp. 3), they found that significantly more preschoolers were able to succeed when the dimensions were separated.

Our procedure puts the prediction of better performance in the separated condition to a somewhat more rigorous test than did Kloo and Perner (2005), or at least allows certain alternative explanations to be discarded that their procedure did not. With the Kloo and Perner stimuli, children could possibly solve the task by restricting the focus of their attention to the right side of the cards when sorting by color and the left side when sorting by shape. Shape and color were spatially segregated on the cards, and each were properties of things. In our procedure, shape and color are contiguous. Shape is a property of the foreground object and color is a property of the background bordering the object on all sides. Other minor differences are that we included younger children (down to 2½ years of age), administered slightly more trials, and used a slightly more stringent criterion. We administered six trials per dimension, and our criterion for success in switching was getting at least five of the six postswitch trials correct. Kloo and Perner administered five trials per dimension and used a criterion of at least four of five correct.

METHOD

Participants

A total of 57 children provided the data reported here (27 boys, 30 girls). Children in three age groups were tested: 2½-year-olds (*M* age = 32.1 months, range = 29.3–34.4 months, *SD* = 1.7), 3-year-olds (*M* age = 37.6 months, range = 35.8–40.4 months, *SD* = 1.3), and 3½-year-olds (*M* age = 43.1 months, range = 41.2–45.7 months, *SD* = 1.3). At 2½ years of age, 19 children were tested, and 63% were female. At 3 years, 24 children were tested; 46% were female. At 3½ years, 14 children were tested; 50% were female.

Half the children (29) were tested by the Carlson Lab and half (28) by the Diamond Lab. Those studied by the Carlson Lab were recruited from a database of families who expressed an interest in participating in research studies. All were tested by Danielle Beck or Stacy Underwood and were tested in a quiet testing room at the University of Washington, Seattle. Those studied by the Diamond Lab in Massachusetts were tested in a quiet testing room at the Center for Developmental Cognitive Neuroscience, Shriver Center Campus, University of Massachusetts Medical School, Waltham, MA, from a database of families who expressed interest in participating in research studies. All were tested by Aaron Baker or Adele Diamond. Those studied by the Diamond Lab in British Columbia were tested in a quiet room at the children's preschool by Adele Diamond. In all cases, approval by the relevant Human Subjects Committee was obtained prior to testing as was informed consent from a parent of each child, the rights of all study participants were protected, and each child received a small present for participating. Most were Euro-Caucasian from middle-class homes.

We attempted to test another 39 children, but their data could not be used. Five did not know their colors or understand English well enough to pass the training (4 were 2½ years old and 1 was 3 years old). Eight children of 2½ years did not meet the criterion for inclusion in the study because they failed the preswitch phase (described in the Methods section). They tended to sort all cards into the same sorting bin (5 of these children did this for both the separated and the integrated conditions, 3 did this only for the integrated dimension). Three children 3 years of age and 2 children 3½ years of age also failed the preswitch phase and so could not be included. Two children (both 3 years old), tested by the Diamond lab, got 67% or more of the knowledge questions (described in the Methods section) wrong and therefore were deemed not to show sufficient understanding of the task to be included. (The Carlson Lab included children who performed poorly on the knowledge questions and details on that appear in the Results section.) Thirteen children refused to complete testing: 8 children were 2 years old (6

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refused to do the integrated condition and 2 refused the separated condition), 4 children were 3 years old, and 1 child was 3½ years old (all 5 refused the integrated condition). Finally, six sessions were unusable due to experimenter error (four sessions were with 3-year-olds and two were with 2½-year-olds).

Materials

The materials consisted of model (or target) cards and sorting cards (also called stimulus or test cards) for both integrated and separated dimensions conditions with two training cards for each, and two sorting trays. All cards were laminated, white on the reverse side, and the same size (9 × 11 cm). The back wall of each sorting tray was 28 × 13 cm, and the base was 13 × 11 cm.

The two model cards for the integrated condition depicted a red truck or a blue star on a white background. Each was mounted on the back wall of one sorting tray. The sorting cards for the integrated condition depicted a red star or blue truck on a white background. Thus the sorting cards matched the model cards on only one dimension (shape or color), and the correct answer when sorting by color (or shape) was the wrong answer when sorting by the other (see Figure 2). The integrated condition corresponds exactly to the standard DCCS testing condition, and the model and stimulus cards used here for the integrated condition are identical to those used by Kirkham et al. (2003) for their DCCS testing.

The two model cards for the separated condition depicted a black car on a green background or a black phone on a yellow background. Each was mounted on the back wall of one sorting tray. Each sorting card for the separated condition depicted a black phone on a green background or a black car on a yellow background. As with the integrated condition, each sorting card matched a model card on one dimension (shape or color), and the correct answer when sorting by color (or shape) was the wrong answer when sorting by the other (see Figure 3).

For the Diamond Lab's testing, the two training cards for the integrated condition for sorting by color depicted a red boat or blue bird. The corresponding training cards for the Carlson Lab depicted a red or blue bird. The two training cards for the integrated condition for sorting by shape in the Diamond Lab depicted a green truck or yellow star. For the Carlson Lab, the corresponding training cards depicted a yellow truck or star.

For the sessions conducted by the Diamond Lab, the two training cards for the separated condition for sorting by color depicted a black airplane on a yellow background or a black pumpkin on a green background. For the Carlson Lab, the corresponding training cards were a black boat on a yellow background or on a green background. The two training cards used by the Diamond Lab for the separated condition for sorting by shape depicted a black car on a blue background or a black phone on a red background. The corresponding training cards used by the Carlson Lab were a black car on a red background or a black phone on a red background. In all other respects the training cards for both labs were identical to those used for testing—the same size, color (white), and laminate.

Thus, for both labs, the training cards matched the model cards on only one dimension. Whereas in the Diamond Lab each training card contained a different color and shape, in the Carlson Lab the value on the irrelevant dimension was kept constant on the two training cards for a given Condition × Dimension practice.

Procedure

All children were tested on both conditions. Order of presentation of conditions (integrated and separated) was counterbalanced across children within each Age × Gender × Lab cell, and this was crossed with the order of presentation of the sorting dimensions (color and shape), which was also counterbalanced across children within each Age × Gender × Lab cell. All children were tested individually by an experimenter who sat at a preschool-size table with the child. All sessions were videotaped (with parental approval) for detailed analyses. The child was shown the two sorting boxes with the model cards affixed (facing the child). First the experimenter verified the child's object and color knowledge: The experimenter identified one dimension of each of the model cards (e.g., “This is a car and this is a phone.”). Then the experimenter queried the child, “Can you point to the phone? to the car?” and provided enthusiastic, supportive feedback. Then the experimenter identified the other dimension of each card (“This is red and this is blue”) and then queried the child, again with enthusiastic, supportive feedback.

Next the experimenter began the training for the second dimension that would be tested by saying that they could play the color (or shape) game:

> In the color (shape) game, all the red ones (trucks) go here and all the blue ones (stars) go there. [Experimenter pointed to each appropriate tray] So, red ones (trucks) go in this tray, and blue ones (stars) go in this tray. [Experimenter models sort.] Okay? Can you point to where the red ones (trucks) go? And where do the blue ones (stars) go? [For each, the experimenter praised the child if correct, or corrected the child and repeated the instructions if incorrect.] Here's a red one (truck); where does this one go? Here's a blue one (star); where does this one go? [For each, the child sorted the card by placing it in a tray. The experimenter enthusiastically praised the child when correct and gently corrected the child and repeated the instructions when the child erred. If the child placed a card faceup, the experimenter praised the child for the correct sort and turned the card over so that it was facedown.]

Then the experimenter pointed out that they could also play the shape (color) game and repeated the procedure just indicated for sorting by that dimension. Note that there was only one correct answer for sorting any training card, as each card matched only one model and on only the relevant dimension. There was no conflict between the correct answer when sorting by color and the correct answer when sorting by shape.

Each child was given four training cards to sort (one card per value per dimension), and those cards could be presented a maximum of twice (allowing for one error per either value of either dimension). Children had to sort all four cards correctly (both for each dimension) to pass the training phase.

The last dimension sorted during training was always the first dimension administered for testing. Test trials started immediately and seam lessly after training. The same pseudo-random order of card presentation was used for all children. Before each trial, the child was either reminded of both rules for the current game or asked to demonstrate knowledge of both rules for the current game by pointing to the appropriate trays in answer to the experimenter's “knowledge” questions (e.g., “Where do the red ones go in the color game? Where do the blue ones go in the color game?”). On alternating trials the experimenter either reminded the child of the rules or asked the child the knowledge questions. Order of value (e.g., red or blue) mentioned first was randomly varied.

Children were given feedback both during training and on their responses to the knowledge questions during testing, but not on their sorting performance during testing. No comment or reaction of any kind was made to the child's sorts during testing. Each sorting card was left facedown in the tray so that the image depicted on the card was not visible. If a child placed a card faceup, the experimenter simply turned over the card. On the rare occasion when a child answered a knowledge question incorrectly, the experimenter reiterated the rules and asked the knowledge questions again. Immediately after the knowledge questions or the experimenter's reiteration of the rules, a sorting card was presented. The experimenter always labeled only the currently relevant dimension of the card when presenting it (e.g., “Here's a blue one. Where does it go?” or “Here's a truck. Where does it go?”), as is standard practice for DCCS testing in virtually every lab that uses this task (e.g., Kirkham et al., 2003; Kloo & Perner, 2005; Zelazo et al., 2003).

A child had to sort six cards in a row correctly by the first dimension to pass the preswitch phase. Only children who passed the preswitch were included in analyses of postswitch performance. Occasionally, a child did not quite understand the game on the first or second trial. Therefore, children were given up to eight trials to get six trials correct in a row on the first dimension. Then the experimenter announced that they were not going to play that game anymore but were going to start playing the other game instead:

> We're not going to play that game anymore! No way! Let's play the color (shape) game now. Remember, in the color (shape) game, all the blue ones (trucks) go here, and all the red ones (stars) go there. [Experimenter pointed to the appropriate trays.] Can you point and show me where the blue ones (trucks) go? Can you point and show me where the red ones (stars) go? [For each, the child pointed and received feedback.]

Testing on the second dimension then began, “Here's a blue one (truck). Where does it go?” Six trials were administered using the same procedure as just described—reiteration of the two current rules or querying of the child's knowledge of the two current rules with feedback before each trial, only the relevant dimension of each stimulus card labeled on each trial, no feedback of any kind on sorting performance, and each card left facedown in the sorting tray. Cards were not removed between testing of the first and second dimension but were left facedown where they had been placed.

After administering both dimensions of the first condition for a given session, the experimenter announced that the game was over. There was a brief break as the experimenter put away all the cards for the first condition (both the model and test cards), affixed new model cards to the back wall of the sorting trays, and retrieved a new set of sorting cards. The experimenter announced that they would now play two more games, and exactly the same procedure as just described was repeated—first verifying the child's object and shape knowledge, then providing training on both dimensions, testing one dimension, and switching to test the second dimension. For all training and testing, a child's sorting response was counted once the child placed the card in a sorting tray and let go of the card. As long as a child held onto a card, the child was allowed to change his or her mind. Indications of indecision, such as first going toward one tray and then the other, were recorded as “hesitations” and were included in descriptive analyses. The only difference between the two conditions was in the stimuli (the model and sorting cards); in all other respects the testing procedure for both conditions was identical.

RESULTS

Passing training was defined as sorting one card for each value of each dimension correctly (i.e., one yellow truck, one yellow star, one red grapes, and one blue grapes card). Most children (93%) did this in the minimum number of trials possible (four, one per each value of each dimension). Two children at 2½ years of age needed more training trials in the integrate dcondition; one of these children needed one additional trial and another needed two additional trials. One 3-year-old needed one additional trial to pass training in the separated condition. One 3½-year-old needed an additional trial to pass training in the integrated condition.

The vast majority of children needed only six trials to get six correct in a row on the first sorting dimension. Virtually all children (95%) in all conditions sorted all the cards correctly during the preswitch phase. Three children, one in each age group, needed one additional trial (seven total to get six in a row correct on the initial dimension)—a 2½-year-old and a 3-year-old in the integrated condition and a 3½-year-old in the separated condition.

Naturally, studies will find that children perform well on the knowledge questions even if they fail in their sorting responses if those children who fail the knowledge questions are deemed unuseable because they have not demonstrated sufficient understanding of the sorting rules. Therefore, the Carlson Lab did not eliminate any child from the analyses because of poor performance on the knowledge questions. There were three knowledge questions per each pre- and postswitch phase of each condition. Between the two labs, five children (9%) made one error on a knowledge question in the integrated condition, and four children (7%) made one error on a knowledge question in the separated condition. Two thirds of those errors (six errors) occurred during the postswitch phase (i.e., when quizzed about the rules for sorting by the second dimension). In addition, the Carlson Lab included four children who erred on 67% or more of the knowledge questions in the separated condition and three children who failed 67% or more of the knowledge questions in the integrated condition. Again, most of these errors were in the postswitch phase.

After the switch to the second dimension, 77% of the time every card was sorted correctly or every card was sorted incorrectly. In both conditions, almost all the children got either (a) five or six of six trials correct (separated condition, 35%; integrated condition, 16%) or (b) five or six of six trials wrong (separated condition, 56% [most at 2½ years]; integrated condition, 75%). In the separated condition, one child got two postswitch sorts correct, two children were correct on three postswitch trials, and two children were correct on four postswitch trials. Together these five sessions account for less than 10% of the separated-conditions data. In the integrated condition, two children got two postswitch sorts correct, three children were correct on three postswitch trials, and one child was correct on four postswitch trials. These five sessions account for less than 10% of the integrated-conditions data.

Given the lack of variance and the markedly bimodal nature of the data, analyzing the data using an analysis of variance would have been inappropriate, even with transformations of the data, such as logarithmic transforms. Binary logistic regression was used to analyze the dichotomous outcome variable "passed or failed" when looking at performance individually on the integrated or separated condition. For comparing performance between the two conditions, a nonparametric within-subject Wilcoxon signed rank test was used to compare the percentage of correct postswitch responses, the McNemar test was used to compare the percentage of children successfully switching sorting dimensions, and generalized linear mixed models (Diggle, Liang, & Zeger, 1994) for binary outcomes with repeated measures was used to compare performance on the dichotomous measure "passed or failed." These models were fit by the method of Generalized Estimating Equations with a logit link function (Fitzmaurice, 1998; Zeger, Liang, & Albert, 1988). When significant fixed main or interaction effects were found, hypotheses concerning combinations of effects were evaluated by comparing simpler models fit on subsets of the data (Fitzmaurice, 1998; Liang & Zeger, 1986; Palta & Lin, 1999; Stiratelli, Laird, & Ware, 1984; Zeger et al., 1988) by generalized linear mixed models. Models were fit using SAS Proc GENMOD (SAS Institute Inc., 1990).

All significance levels reported are for two-tailed tests, but given that we had a very clear prediction that performance would be better in the separated than in the integrated condition, one-tailed tests would certainly have been justified for all comparisons between the two conditions.

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No significant differences were found by gender, order in which the conditions were tested, order in which the dimensions were tested, or the lab conducting the testing. There were no significant interactions among any of those four variables.

There was no significant difference by age in performance on integrated dimensions (the standard DCCS task). There was a significant improvement over age, however, in whether a child passed the postwitch phase when the dimensions were separated (Wald statistic [3] = 3.98, $p < .05$). Post hoc tests revealed significantly more 3½-year-old children than 2½ year olds successfully switched sorting criteria on separated dimensions (Wald statistic [2] = 4.44, $p < .04$).

Consistent with previous reports (e.g., Rennie et al., 2004; Zelazo et al., 1995, 1996), most of the children tested performed poorly on the standard DCCS task (integrated dimensions). Only 32% successfully switched dimensions. As predicted, however, performance was significantly better in the separated dimensions condition, where 62% successfully switched dimensions. The mean percentages of correct responses on the second dimension (postswitch) are portrayed in Figure 4. As is apparent from the figure, children were able to get roughly twice as many postswitch trials correct when the dimensions were separated than when the dimensions (color and shape) were properties of the same object. Wilcoxon within-subject signed pairs comparisons revealed that this difference in performance on separated versus integrated dimensions was significant overall, $Z(57) = 3.75$, $p < .0001$; for both boys, $Z(27) = 2.98$, $p < .003$; and girls, $Z(30) = 2.35$, $p < .02$; for both the Diamond Lab, $Z(28) = 2.10$, $p < .04$; and the Carlson Lab, $Z(29) = 3.17$, $p < .002$; both for when switching from shape to color, $Z(28) = 3.38$, $p < .001$; and when switching from color to shape, $Z(29) = 1.98$, $p < .05$, and both for when integrated dimensions was tested first, $Z(29) = 1.91$, $p = .05$; and when segregated dimensions was tested first, $Z(28) = 3.35$, $p < .001$. The percentage of correct sorts was significantly better when the dimensions were separated versus when they were integrated for children 3½ years of age, $Z(14) = 2.26$, $p < .03$; and for children 3 years old, $Z(24) = 3.03$, $p < .002$; but not for children 2½ years of age, $Z(19) = 1.13$, ns.

Roughly twice as many children successfully switched to sorting by the second dimension when the dimensions were separated compared with when the dimensions were integrated, a difference significant at $p <.003$ (McNemar test [$N = 57$]; Figure 5). There was no significant difference at 2½ years, but at 3 years the separated condition was passed *three times* more often than the integrated condition ($p < .03$, $n = 24$). At 3½ years, the separated condition was passed almost twice as often as the integrated condition, but due to the small number of subjects ($n = 14$), that difference did not reach statistical significance.

Twelve children successfully switched sorting criteria when the dimensions were separated and failed when the dimensions were integrated. Only 1 child did the reverse—successfully switched sorting criteria when the dimensions were integrated and failed when the dimensions were separated. Put another way, of the children who passed the postswitch in only one condition, 92% passed only in the separated condition, whereas 8% passed only in the integrated condition. At 3 and 3½ years of age, those percentages are 100% and 0%, respectively (i.e., all children who passed the integrated condition also passed the separated condition, whereas many children passed the separated condition but not the integrated condition).

Results of the generalized linear mixed models for binary outcomes (passed or failed on postswitch trials) with repeated measures also showed that performance in the separated condition was far superior to performance in the integrated condition, $\chi^2(1, N = 57) = 9.31$, $p < .002$. Overall, 3½-year-olds succeeded at switching sorting dimensions significantly more often than children younger: versus 3-year-olds, $\chi^2(1, N = 38) = 3.56$, $p < .05$; versus 2½-year-olds, $\chi^2(1, N = 33) = 6.66, p < .01$. On this binary outcome measure, the difference in performance between children of 3 years and 2½ years was not significant, although this difference is significant on the more sensitive percentage of correct responses measure described earlier. The significant effect of age was due to better performance by older children in the separated condition. There was no significant difference in performance over the ages studied on the integrated condition, but older children performed significantly better than younger ones on the separated condition, $\chi^2(1, N = 57) = 5.68, p = .05$. In the separated condition, children 3½ years of age performed significantly better than children of 3 years, $\mu^2(1, N = 38) = 3.80, p < .05$, and than children of 2½ years, $\chi^2(1, N = 33) = 6.31, p < .01$, although there was no significant difference between the performance of 3-year-olds and 2½-year-olds.

Most children of 2½ years and some children of 3 years were so immature in the abilities required by the DCCS task that they failed to switch sorting dimensions in both conditions and showed no awareness of error (no hesitation). Two children were so mature in this ability that they performed exquisitely on both conditions with no hesitation (no vacillation or indecision about where to sort any card). All other children (the vast majority) showed more advanced performance (more hesitation when wrong and less uncertainty when correct) with separated versus integrated dimensions, except for two children, who performed similarly on both. No child at 3 or 3½ years of age showed more advanced performance with integrated than with separated dimensions. Table 1 presents the results for this very clear progression.

DISCUSSION

Summary of Findings

As every aforementioned analysis has shown, preschoolers were significantly better at switching from sorting by color to sorting by shape (or the reverse) when color was a property of the background (i.e., colorless [black] shapes on a background of a single color) than when color was a property of the shape itself (i.e., shapes of a single color on a white background). It does not matter whether one looks at the percentage of correct responses when the sorting criterion changed, the percentage of children successfully switching sorting criteria, or the dichotomous outcome (passed/failed) in switching sorting criteria: Performance was significantly better in the separated dimensions condition. It also does not matter which subgroup one looks at—only boys, only girls, the Diamond Lab, the Carlson Lab, those who received the integrated condition first, those who received the separated condition first, those who sorted by color first, or those who sorted by shape first; postswitch performance was significantly better when color was a property of the background than when it was a property of the shape itself.

Children were able to respond correctly on roughly twice as many postswitch trials when the dimensions of color and shape were separated than when they were properties of the same object. Similarly, roughly twice as many children successfully switched to sorting by the second dimension when the dimensions were separated than when the dimensions were integrated. Twelve children successfully switched sorting criteria when the dimensions were separated and failed when the dimensions were integrated. No child 3 or 3½ years of age and only 1 child 2½ years of age did the reverse (successfully switched sorting criteria when the dimensions were integrated and failed when the dimensions were separated).

As can be seen from Figures 4 and 5, children were about 6 months ahead in their ability to switch sorting criteria when the dimensions were separated than when they were integrated. The percentage of correct sorting responses postswitch (Figure 4) and the percentage of children who succeeded on the postswitch (Figure 5) at 3 years of age in the integrated condition was roughly comparable to those percentages for the separated condition at 2½ years. Likewise, performance at 3½ years in the integrated condition was roughly comparable to performance in the separated condition at 3 years.

At 2½ years old, a number of children could not be included in the analyses because they could not correctly sort according the first dimension (consistent with the findings of others, e.g., Zelazo et al., 1996; Zelazo & Frye, 1997). Most 2½-year-olds who could pass the preswitch phase were still so immature in the ability to switch sorting criteria that it did not matter whether the dimensions were separated or integrated. The vast majority of 2½-year-olds failed to switch sorting criteria in each condition; there was no significant difference in their performance by condition.

At 3 years of age, condition made a huge difference. *Three times* as many 3-year-olds were able to successfully switch to sorting by the second dimension when the dimensions were separated as could successfully switch when the dimensions were integrated. Viewed another way, among 3-year-olds, the percentage of postswitch responses that were correct was almost *2½ times* greater when the dimensions were separated as when the dimensions were integrated. At 3½ years of age, the difference in performance between the two conditions, although significant, was not as marked as at 3 years (percentage correct postswitch and percentage of children succeeding postswitch was roughly 1½ times greater in the separated condition than in the integrated condition).

We found no significant difference over our age range in performance when the dimensions were integrated (the standard DCCS condition). However, older children (even though all children were younger than 4) were able to perform significantly better than younger children when the dimensions of color and shape were separated (with color a property of background rather than of the shape itself). Thus, successful switching (in terms of correct responses or percentage of children responding correctly) showed a clear age-related progression under the facilitative condition (separated dimensions).

When children's hesitations and uncertainty were taken into account, and not simply whether they responded correctly, a very clear and quite rich developmental progression emerged (see Table 1). At the most immature level, children did not switch sorting criteria and showed no awareness of their error. At the next higher level, they showed some awareness in the separated condition that their postswitch responses were wrong, although they still failed to switch sorting criteria in both conditions. Next, although still failing the postswitch phase in both conditions, children showed some awareness in both conditions (not just in the separated condition) that maybe they were not responding correctly, usually showing more evidence of this in the separated than in the integrated condition. At the next higher level, children switched sorting criteria correctly when the dimensions were separated but not when they were integrated, typically showing a bit of uncertainty both about their correct responses in the separated condition and their incorrect responses in the integrated condition. Showing slightly more mature performance were those children who successfully switched sorting criteria in both conditions but were less sure about their correct answers (showed more hesitation) when the dimensions were integrated than when they were separated. Finally, children were able to successfully switch sorting criteria in both conditions with no sign of hesitation.

Different children develop at different rates, and different abilities within the same child develop at different rates. Age is at best an imperfect proxy for a child's developmental level on any given ability. As Table 1 so clearly shows, some younger children showed much more mature performance than some older children. Data on hesitation and accuracy across the two conditions used here provide a far more precise indication of a child's level of maturity on the executive function ability of being able to flexibly switch sorting criteria than does a child's age.

Our results are fully consistent with the only other study to look at separating color and shape on the model and sorting cards (Kloo & Perner, 2005). Further, we have shown that separating the dimensions helps still younger 3-year-olds than Kloo and Perner studied but does not appear to help 2½-year-olds. We demonstrated that color and shape do not have to be on separate sides of the stimulus cards. Indeed, on our stimuli, the color surrounded the shape. We have shown that simply not having color and shape be properties of the same object is critical.

Kloo and Perner (2005) reported the combined results from two different conditions (separating the dimensions on stimulus cards and attaching the dimensions to separate physical objects, instead of using cards) in reporting their within-subject results for separated versus integrated dimensions (their Exp. 3). They have kindly provided us with the raw data for just the separated and integrated dimensions on stimuli cards. Those data are provided in our Figure 6 for direct comparison with our results provided in Figure 4. Kloo and Perner found a much stronger effect than did we at their youngest age (3.33 years). That might be random variation, especially given the relatively small sample in our study and especially in theirs. The difference might be exaggerated a bit by inclusion in our study of children who might not have understood what they were supposed to do (children who had erred on over 50% of the knowledge questions in the Carlson Lab), thereby perhaps artificially depressing the success rate in our separated condition. It might be that where separated versus integrated dimensions makes the most difference is at 3.33 years, rather than at 3.1 or 3.6 years (the ages we studied here). However, the most interesting possibility is that separating color and shape further in space makes it easier to shift the focus of one's attention from one to the other, especially if one can look at the relevant dimension without seeing the irrelevant one.

Most studies that have looked at separated dimensions have spatially segregated the two dimensions, as did Kloo and Perner (2005; e.g., Mueller et al., 2004). We are unaware of other studies that have separated the dimensions by putting one in the foreground and the other in the background, as we have done. Thus, this leads to some novel predictions. For example, we predict that the Stroop interference effect would be attenuated if color were a property of the background rather than of the word, even if the word is on a solid background of an incongruent color. Similarly, we predict that monkeys, which have such a difficult time in switching sorting dimensions (e.g., Moore et al., 2002), would find it much easier to switch sorting criteria if color were a property of the background rather than of the stimulus objects themselves. Implicit in these predictions is the hypothesis that young children, adults, and animals have difficulty with these tasks for similar reasons. It is primarily in the extent of the difficulty that they differ.

Consistency of Our Findings Reported Here, and Elsewhere, With an Inhibitory Account

We have hypothesized that 3-year-olds tend to stay stuck in thinking about something the way they have been thinking about it and that inhibition of their initial mind-set is needed if they are to successfully treat familiar stimuli according to new rules when the correct sorting responses according to the previous rules are the wrong sorting responses according to the new rules, and vice versa. Manipulations that reduce the inhibitory demand should therefore aid performance.

The separated-dimensions manipulation reported here did that by never requiring inhibition of the initial way of thinking about the objects pictured on the stimulus cards. Although a shift in focus of attention from foreground to background (or vice versa) was required, our separated condition did not additionally require inhibition of the initial way of thinking about the objects pictured on the stimulus cards. The star was always a star; children never had to think of it sometimes as a star and sometimes as a blue thing. Three times as many 3-year-olds succeeded as in the standard integrated-dimensions DCCS paradigm. The separated-dimensions conditions of Kloo and Perner (2005) also dramatically improved the performance of children 3 to 4 years of age.

Within-dimension reversal switching also never requires thinking about the stimuli as anything but trucks and stars (although sometimes things go with like items, as trucks with the truck model, and sometimes the rules reverse and things go with the dissimilar model, as trucks with the star model). Here, the focus of attention on shape never waivers. Both labs that have investigated this find that 3-year-olds successfully switch sorting rules on such tasks (Brooks, Hanauer, & Padowska, 2003; Perner & Lang, 2002).

Contrary to other explanations of task-switching performance (e.g., Rogers & Monsell, 1995), Diamond and Kirkham (2005; Kirkham et al., 2003; Kirkham & Diamond, 2003) have argued that *before* the stimulus appears, 3-year-olds are ready to perform correctly. They clearly have in mind both the new sorting criterion and the appropriate rules for that dimension (as their correct responses to the knowledge questions demonstrate). Then a stimulus appears that is relevant to both tasks in incompatible ways (the correct answer when sorting by color is the wrong answer when sorting by shape). That *creates* a problem for the children, triggering the mind-set they are trying to inhibit. Similarly, the familiar target cards, each with a valid value on the previously relevant dimension, serve as attractors, pulling the child to think and act according to the previously relevant rules. Children need to inhibit the pull to focus on the previously relevant dimension and the pull to act according to the previously relevant rules.

Thus, if the postswitch sorting cards are not relevant to the preswitch dimension, children would not have to inhibit the pull to think about the cards according to the preswitch mind-set, and 3-year-olds should succeed in switching sorting criteria. Indeed they do. Children 3 years of age are perfectly capable of switching from sorting red rabbits and blue boats by their color to sorting yellow flowers and green cars by their shape (Zelazo et al., 1995, Exp.3; cf Zelazo & Jacques, 1996; Zelazo et al., 2003, Studies 3 & 4).

Similarly, 3-year-olds succeed in switching sorting criteria when the model cards do not contain the previously relevant values of the previously relevant dimension or when no model cards are present at all (Kloo & Perner, 2003; Perner & Lang, 2002; Towse et al., 2000). Children of 3 years are also able to switch when there are four model cards, each containing only one dimension, so that each model card is relevant only pre- or only postswitch (not both) and the correct answers for one dimension are irrelevant when sorting by the other dimension (Rennie et al., 2004; Towse et al., 2000).

Similarly, if no sorting cards are visible and only the value on the currently relevant dimension is mentioned, 3-year-olds should also be able to switch sorting dimensions, as there is nothing to pull them back to their previous mind-set. Indeed, 3-year-olds perform almost flawlessly on the knowledge questions (Munakata & Yerys, 2001).

When inhibitory demands are essentially eliminated by using different sorting cards pre- and postswitch and by having the sorting cards match any target card on only one dimension, virtually all preschoolers succeed (96%; even those only 2 years old; Rennie et al., 2004). As no relevant values on the previously used dimension were present postswitch, attention to them did not have to be inhibited. Because there was no overlap of stimuli pre- and postswitch, no response to a stimulus had to be remapped.

Further, conditions that help children refocus their attention on the currently relevant dimension and away from the previously relevant dimension should also help preschoolers perform better. Instead of the experimenter labeling the stimulus on each trial of the standard DCCS task, Kirkham et al. (2003) had the child do the labeling, thus having the child actively redescribe the stimuli according to the postswitch dimension. This helped 3-year-olds perform better. Similarly, Towse et al. (2000) found that when they instructed 3-year-olds who had failed to switch sorting criteria to label the relevant dimension of the next sorting card, many were then able to switch correctly.

Finally, if the inhibitory interpretation is correct, then manipulations that increase the inhibitory demand should make it harder for children to succeed. Sorting the cards faceup creates a perceptual pull to continue sorting by the previous dimension and hence increases the demand on inhibition. Indeed, 4-year-olds (who usually do quite well on the standard DCCS task) are much more likely to fail to switch sorting dimensions when the cards are placed faceup in the sorting bins (Kirkham et al., 2003).

Adults also perform much better at switching tasks when there is no conflict, that is, when each stimulus or response option is relevant to only one dimension (univalent stimuli or targets; Allport & Wylie, 2000; Mayr, 2001; Meiran, 1996, 2000; Rogers & Monsell, 1995; Wylie & Allport, 2000). Adults have the same problem in task switching as do children, just in a much less extreme form. Hence, adults are helped by the same conditions that help children and, as noted in the Introduction, show a switch cost on the standard DCCS task in RT comparable to that seen in children in accuracy (Diamond & Kirkham, 2005).

At the same age that children fail to switch sorting dimensions on the standard DCCS task (3 years), they also fail an array of other tasks that similarly require holding two things in mind and inhibiting a prepotent response (Diamond, 2002). At the same age that children first *succeed* on the DCCS task (4–5 years), they likewise first succeed on those other tasks as well. This is true for (a) *appearance-reality tasks* (Flavell et al., 1986), where children must hold in mind what a thing really is as well as what it appears to be and inhibit the strong temptation to say that it looks like what it really is or that it really is what it looks like; (b) *false belief theory of mind tasks* (Perner, Leekam, & Wimmer, 1987; Wimmer & Perner, 1983), where children must hold in mind their own knowledge of the true state of affairs as well as what another person erroneously thinks to be the state of affairs and inhibit both the temptation to blurt out the true state (when asked to report the other person's false belief) and the wish for that very nice other person to find the desirous object; (c) *other false belief tasks* (Perner et al., 1987), which also involve holding in mind both a true and a false belief (the false belief was what the child had previously thought) and inhibiting the true knowledge, which they now have, when asked to say what they previously thought (“knew it all along,” see Fischhoff, 1977; Fischhoff & Beyth, 1975; “hindsight bias,” see Hawkins & Hastie, 1990; Hoffrage, Hertwig, & Gigerenzer, 2000); (d) *tests of spatial perspective*, where children must hold in mind two perspectives and inhibit the pull to give the perceptually salient response (their own current perspective) when asked to say what the perspective would be of someone else at a different vantage point (considered an aspect of “egocentricism,” Piaget & Inhelder, 1956); (e) *ambiguous figures* (Gopnik & Rosati, 2001), where children must try to hold in mind two perspectives and inhibit one when trying to see the other; (f) *conflict tasks*, such as the Day/Night (Gerstadt, Hong, & Diamond, 1994), Tapping (Diamond & Taylor, 1996), Hands (Hughes, 1998a), and Grass/Snow (Carlson & Moses, 2001) tasks, all of which require holding two rules in mind and inhibiting a prepotent response (such as remembering to say *day* when shown a nighttime scene and to say *night* when shown a daytime scene and inhibiting saying what the pictures really represent); and (g) *liquid conservation tasks* (Piaget & Inhelder, 1941), where children must take into account both height and width and must inhibit the strong temptation to say that the beaker with the taller liquid column has more liquid even though it is narrower.

On all of these paradigms, manipulations that reduce the inhibitory demand aid children's performance. One way to reduce the demand on inhibition is to reduce the perceptual salience of the answer children are to inhibit. Thus, telling children where the object is hidden but never actually showing them makes it possible for more preschoolers to succeed on theory of mind tasks (Zaitchik, 1991). Similarly, putting a screen in front of the liquid beakers (so they cannot be seen) helps preschoolers succeed on liquid conservation tasks (Bruner, 1964). Reducing perceptual salience also aids preschoolers' performance on appearance-reality tasks (Heberle, Clune, & Kelly, 1999). Manipulations that reduce inhibitory demands in other ways also help preschoolers to succeed on these tasks. For example, pointing veridically is a well-practiced and much reinforced response in young children, and children of 3 to 4 years of age have trouble inhibiting that tendency when they should point to the false location on theory of mind tasks. Carlson, Moses, and Hix (1998) found that children performed better when given a novel response by which to indicate the false location (see also Hala & Russell, 2001).

If all these tasks have related cognitive requirements (to hold two things in mind and inhibit focusing on, and reacting to, what is most salient in the situation), then one would expect intercorrelations among performance on these tasks. Indeed, that is found. Carlson and Moses (2001) included the DCCS task in their study of the relation between inhibitory control and theory of mind in preschoolers. DCCS performance was significantly correlated with 8 of 9 other inhibition tasks. Even after controlling for age, gender, and verbal ability, DCCS performance remained significantly related to 5 of those measures and to the aggregate Inhibitory Control battery (with DCCS removed, of course). Performance on the DCCS task was most strongly related to performance on the Day/Night (Gerstadt et al., 1994), Grass/Snow (Carlson & Moses, 2001), Spatial Conflict (Simon task; Gerardi-Caulton, 2000), Bear/Dragon (Reed, Pien, & Rothbart, 1984), and Whisper (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996) tasks. A principal components analysis of all 10 inhibition tasks confirmed that the DCCS task loaded on the same factor with these other “conflict” tasks. Carlson and Moses also found that DCCS performance was significantly related to false-belief performance, echoing findings of Frye, Zelazo, and Palfai (1995; see also Fahie & Symons, 2003). Similarly, the emergence of children's ability to accept two labels for the same thing correlates with the emergence of successful switching on the DCCS task (Stummer, 2001) and with the emergence of success on theory of mind and other false belief tasks (Doherty & Perner, 1998; Perner et al., 2002).

Having said this, we feel it is important to acknowledge that children 3 and 3½ years of age in our study, although clearly aided by the separated dimensions condition, did not perform perfectly. One reason that performance was not even better in our separated-dimensions condition may be that we did not reduce *all* the inhibition required by the task. Even though children did not have to think about the same object in two different ways, they did need to switch the focus of their attention from the foreground to the background (or vice versa). Even greater reductions in inhibitory demand should result in even better performance (as did the manipulations of Kloo & Perner, 2005, and Rennie et al., 2004). There is likely another reason that performance was not even better in our separated-dimensions condition: Although difficulty in keeping the rules in mind while inhibiting the prepotent tendency to continue to respond on the same basis as one has been responding is *part* of the problem for 3-year-olds, it is unlikely to be the whole story. For example, although 3-year-olds clearly seem able to handle higher order rules, doing so may be sufficiently difficult for them that some errors are caused by having to deal with that complexity.

Our Interpretation of Why 3-Year-Olds Perform as They Do on the DCCS Task Compared With Other Interpretations

The conceptual redescription interpretation—The redescription hypothesis offered by Kloo and Perner (2005) shares much in common with our attentional inertia hypothesis. Both have at their core the fundamental hypothesis that 3-year-olds have difficulty thinking about the same thing in two different ways; they have difficulty flipping from one perspective to another. “Having adopted the mindset that blue things go with the blue model card, they have great difficulty switching to think of a blue truck in terms of its shape and sorting it with the red-truck model card” (Kirkham et al., 2003, p. 451). Both Kloo and Perner and Kirkham and

Diamond have stated that 3-year-olds' problem is one of cognitive rigidity when it is cognitive flexibility that is required by the DCCS task.

Our interpretation differs from that of the redescription interpretation of Kloo and Perner (2005) in that we see the fundamental requirement of the DCCS task to be in having to hold information in mind and inhibit the perspective one had been using in order to switch to a different perspective. Three-year-olds'fundamental problem on the task, as we see it, is in insufficiently developed inhibitory control. Kloo and Perner (2005) saw the problem for 3-year-olds on the task to lie in an insufficiently developed conceptual ability: Children of 3 years do not yet understand

> that objects can be described in different ways … . The difference is that the re-description hypothesis sees the observed developmental progress in solving the DCCS in a conceptual change in understanding that objects can be re-described as being of a different kind without assuming any changes in executive control over these years. (p. 53)

It is too early to know which interpretation is correct, but ours appears to have an advantage in parsimony and in the diversity of phenomena for which it can account. It is more parsimonious in that we attribute the problem of adults on switch tasks, including switching dimensions on the DCCS task, to the same source as the problem for children—the difficulty of exercising sufficient inhibitory control to flexibly and readily switch mental sets. Kloo and Perner would presumably need to attribute the task-switching cost seen in adults to a different source than that for children, for adults presumably have a mature conceptual understanding of objects. Similarly, both our interpretation and that of Kloo and Perner can readily account for preschoolers' problems on theory of mind, other false belief, appearance-reality, and ambiguous figures tasks, but our interpretation can also account for why problems on measures require holding two items in mind and inhibiting a prepotent tendency that do *not* involve a conceptual redescription (e.g., the Day/Night task, Gerstadt et al., 1994) are also seen at the same ages and also resolve around the same time.

Improvements in the ability to hold information in mind, inhibiting distractors and pulls to act in ways inconsistent with that mentally represented information, and the cognitive flexibility that that affords appear to be critical for many of the cognitive advances of early childhood, such as conceptual redescription and theory of mind. Three studies have looked longitudinally at the relation between the development of executive control functions such as inhibitory control and the appearance of theory of mind understanding (Carlson, Mandell, & Williams, 2004; Flynn, O'Malley, & Wood, 2004; Hughes, 1998b). All three of these independent studies, conducted in different laboratories, found the same result: Advances in inhibitory control (specifically, inhibition plus holding information in mind) predicted theory of mind advances and not the reverse, even controlling for factors such as age and verbal ability. A cross-cultural study has also found that in China, as in the United States, individual differences in inhibitory control were significantly related to theory of mind performance (Sabbagh, Xu, Carlson, Moses, & Lee, in press). Advances in the ability to simultaneously hold information in mind and inhibit prepotent action tendencies appear to be among the necessary ingredients for cognitive advances such as a theory of mind and conceptual redescription.

Cognitive complexity and control theory—The developers of the DCCS task (Zelazo & Frye, 1997) theorized that the key requirement for success on the task is the ability to represent a hierarchical, embedded rule structure and that 3-year-olds lack that relatively sophisticated representational ability. Their theory is called the cognitive complexity and control (CCC) theory. In the DCCS task, there are two higher order categories (color and shape), and within each are embedded two rules (e.g., “the red things go here and the blue ones there”) so that if one is playing the color game, blue trucks go with a blue-star model card, but if one is playing the shape game, then blue trucks go with the red-truck model card. That is the cognitive complexity part of CCC theory. Cognitive complexity corresponds to the levels of embedding, and 3-year-olds cannot yet represent a sufficiently complex rule structure to succeed at the DCCS task according to this theory. CCC theory also claims that reflection on, and formulation of, higher order rules then makes inhibition and refocusing possible.

There is compelling evidence against CCC theory as an explanation of why 3-year-olds have difficulty switching sorting dimensions on the DCCS task. None of the manipulations that reduce the demand on inhibition and thereby aid success on the DCCS task change the complexity of the rule structure. Hence CCC theory cannot account for their efficacy. Examples include the following.

1. Within-dimension reversal tasks have the same hierarchical, embedded rule structure as does the DCCS task (in the sensible game, trucks go with trucks and stars with stars; in the silly game, stars go with trucks and trucks go with stars), yet 3-year-olds can successfully switch sorting rules on these tasks but not on the DCCS task (Brooks et al., 2003: Perner & Lang, 2002).

2. Three-year-olds easily switch sorting dimensions on the DCCS task if no target cards are used, or if the previously relevant values are no longer present on the target cards when the sorting criterion switches, although the rule structure, of course, is unchanged (Kloo & Perner, 2003; Perner & Lang, 2002; Towse et al., 2000).

3. If the values on the stimulus cards for both dimensions change when the sorting criterion changes, preschoolers can successfully switch sorting dimensions on the DCCS task (Zelazo et al., 1995, Exp. 3), yet again, this manipulation does nothing to change the embedded rule structure of the task. Sorting red rabbits and blue boats by their color and then switching to sort yellow flowers and green cars by their shape has the same rule structure.

4. Having the children rather than the experimenter label the relevant dimension on each new sorting card helps preschoolers to perform better by helping them refocus on the currently relevant dimension (Kirkham et al., 2003; Towse et al., 2000), but it does not change the rule structure of the task or help children acquire a more sophisticated conceptual structure. Therefore it should not be effective according to CCC theory, but it is.

5. Last, as shown in the study presented here and by Kloo and Perner (2005), 3-year-olds, who fail the standard DCCS task, are able to succeed if the same color and shape values appear on the cards, but instead of being properties of the same object, they are separated. For CCC theory, this change in the stimuli should not make a difference. Indeed, Zelazo et al. (2003) explicitly stated that CCC theory predicts that children should not perform better with separated dimensions than with integrated ones because in the separated condition one must still "cross major branches of a tree-like [rule] structure" (p. 57). The embedded rule structure remains the same.

Conversely, correlational evidence has shown that performance on the DCCS task is related to performance on several executive function tasks, some of which have a simple, rather than an embedded, rule structure (Carlson & Moses, 2001), such as the Day/Night or Grass/Snow tasks. Even the false belief task, which several investigators have found to be related to the DCCS task, can be construed as having a simple rule structure (Perner, Stummer, & Lang, 1999).

In response to new data and criticisms such as those just listed, CCC theory has been revised (CCC–r; Zelazo et al., 2003). It now incorporates elements of competing interpretations, such as our attentional inertia theory, blurring distinctions between the theoretical perspectives. In so doing, CCC–r theory has lost much of the elegance and clarity of the earlier CCC theory.

In addition, the same argument concerning parsimony raised in relation to the redescription theory is also relevant here. Adults, too, show switch costs on the DCCS task (Diamond & Kirkham, 2005). We argue that those costs have their origin in having to overcome attentional inertia, in having to inhibit the previously relevant mind-set—the same origin as in preschoolers' problems in switching. Adults are capable of mentally representing embedded, hierarchical rule structures, so one might expect that proponents of CCC theory would argue that adults show switch costs for a different reason than do children. Proponents of CCC theory argue that formulating and using higher order rules is effortful; although adults are capable of doing it, it requires resources and hence produces switch costs. Higher order rules are relevant to all trials, though, yet adults are slower specifically when switching. Older adults show greater switch costs than younger adults, including on tasks similar to the DCCS task (Zelazo, Craik, & Booth, 2004), which is due, we think, not to their greater problems with embedded, hierarchical rule structures but to their greater problems with effortful, inhibitory control.

Readers might wonder if we are really arguing that infants fail to switch where they search when a toy is hidden at a second location on the A-not-B task, frontal patients fail to switch sorting criteria on the Wisconsin Card Sort Test, and adults show task-switching costs for the same reason as many 3-year-olds fail to switch sorting dimensions on the DCCS task. The answer is basically *yes*. On the A-not-B task, babies need to hold one piece of information in mind plus inhibit a dominant tendency. The DCCS, Wisconsin Card Sorting Test, and all task-switching paradigms require holding two pieces of information in mind plus inhibiting a dominant tendency. Adults show the same problems and biases in switching as do young children, though more subtly (e.g., in relative speed rather than accuracy). If memory is more severely taxed, adults can show switch costs even in accuracy. Memory develops rapidly during infancy and then is quite robust (Diamond, 1995), although it declines noticeably beginning in early adulthood (Bialystok & Craik, in press), so memory accounts for more of the variance in infants and adults than it does in young children. Inhibitory control is one of the key challenges for young children. It shows a very slow developmental progression from 3 to 13 years (Diamond, 2002). Between those years (and likely up to age 20) we hypothesize that it accounts for more of the variance than does memory.

A negative priming interpretation—Mueller (Mueller et al., 2004; Mueller & Zelazo, 2001) has proposed a very interesting negative priming interpretation of preschoolers' problem on the DCCS task. Negative priming refers to the cost of having to reverse inhibition (or reverse an "ignore" tag) when what had been the distractor (e.g., the irrelevant dimension on DCCS stimulus cards) then becomes the target (e.g., the relevant dimension; Milliken & Tipper, 1998; Neill, & Valdes, 1992; Neill, Valdes, & Terry, 1995; Tipper, 1985). To flexibly change the focus of one's attention, one must not only institute inhibition of what had been relevant but also reverse inhibition of what had been irrelevant. A reader might think at first that a negative priming interpretation posits just the opposite of an inhibition account, that is, overly strong inhibition (of the irrelevant dimension) rather than weak inhibition. However, there is a great deal of evidence that if it is difficult for one to inhibit something, then having instituted that inhibition, it is particularly difficult to reverse it. For example, the cost of switching from reading Stroop words to naming the color of the ink is much less than the cost of switching from naming the ink color (where the dominant response of reading the word had to be inhibited) to reading the word (because greater inhibition was initially required in the latter condition; Allport & Wylie, 1999, 2000; Wylie & Allport, 2000; Meiran, 2000). Hence, the general, well-replicated rule is that there is a greater cost in switching to doing what is easier (because more inhibition had been required to resist doing that before the switch) than to switch to doing what is more difficult.

Although Diamond and Kirkham have emphasized that children must shift their attention away from the previously relevant dimension, Mueller and Zelazo (2001) rightly pointed out that for children to shift their attention toward the currently relevant dimension they must undo their previous inhibition of that dimension. “Difficulty in exerting the required disinhibition prevents children from drawing their attention to the values of the currently relevant dimension resulting in a negative priming effect” (p. 5).

Evidence consistent with a negative priming interpretation includes that if the values of the previously relevant dimension are changed for the postswitch phase (eliminating the pull to continue to use those values to guide one's responses) but the values of the previously irrelevant dimension are left unchanged (requiring that any previous suppression of attention to them be reversed), children 3 years of age have difficulty switching sorting criteria on the DCCS task (Zelazo et al., 2003, Study 4).

Current performance is codetermined by what you are switching *from* and what you are switching *to*. The relation between the two is key. Thus, Meiran (2000) showed that if the preswitch stimuli had been relevant only to the initial task, it is easier to switch dimensions than if the preswitch stimuli had been relevant to both tasks. Hence, in 2001, Diamond made a rather strong prediction that 3-year-olds should successfully switch sorting dimensions on the DCCS task and adults should show less switch cost, if the first block has stimuli relevant only to the first dimension (e.g., colorless [black] stars and trucks on a white background when sorting by shape), even though the postswitch block would be administered *exactly* as in the standard condition (the condition that 3-year-olds fail). The only thing that would change is the context in which that postswitch block occurs. Thus, 3-year-olds should *successfully* switch from sorting red and blue blobs (by color) to sorting red and blue stars and trucks (by shape), although they *fail* to switch from sorting red and blue grapes and birds (by color) to sorting red and blue stars and trucks (by shape; Zelazo et al., 1995).

A graded memory interpretation—Munakata (2001) and colleagues (Morton & Munakata, 2002b; Munakata, Morton, & Yerys, 2003; Munakata & Yerys, 2001), citing evidence that memory can be graded, argued that children may succeed on one measure of memory on the DCCS task (the knowledge questions) and yet not have sufficient memory to correctly switch sorting criteria on the task. Neural network models demonstrate that stronger memory representations are required for a task when greater conflict is present (Morton & Munakata, 2002a). “Children may have limited memory for a new rule, which is sufficient for tasks that do not involve conflict, but insufficient for tasks that involve conflict” (Munakata et al., 2003, p. 472). We agree, and we contend that is so precisely because a conflict situation adds an additional inhibitory requirement not present in the nonconflict situation. As we see it, in the conflict situation the conflicting information pulls the child's attention away from the rule the child knows and remembers. The child needs to inhibit the pull of the conflicting information and focus on the relevant stimulus dimension and its attendant rule.

Evidence that would appear to be inconsistent with a memory interpretation is that 3-year-olds perform better on the DCCS task when memory demands are increased (when no model cards are present; Perner & Lang, 2002; Towse et al., 2000) and fail even when memory demands are minimized, such as when the experimenter reminds the child at the outset of each trial how to sort the cards by the currently relevant dimension.

Another argument offered by Munakata et al. (2003) against our inhibitory control interpretation of problems in switching dimensions on the DCCS task, and offered by many others to account for the costs of switching tasks in general (e.g., Monsell, 2003), is that a memory interpretation alone is sufficient to account for the results. Such memory interpretations often involve enhanced activation of (or strengthened links to) the correct representation and diminished activation of (or weakened links to) the incorrect dimension (Munakata, 1998, 2001) and thus incorporate inhibition directly into the memory account.

Maintaining focus on something in memory (or in visual attention) requires concentrating on what is relevant and inhibiting attention to irrelevant, compelling distractors. Switching tasks requires not only activating or retrieving the rules appropriate for the new task but also inhibiting or disengaging from the mind-set relevant to the previous task (Allport & Wylie, 1999, 2000; Mayr & Keele, 2000; Rogers & Monsell, 1995). It is an open question whether memory and inhibition can be dissociated. We tend to think they can. For example, although strengthening the activation of appropriate links causes activation of inappropriate links to decline (McClelland & Kawamoto, 1986; Waltz & Pollack, 1985), Gernsbacher and Faust (1991) found that as inappropriate links decreased in activation, appropriate links did *not* necessarily increase in activation.

Perceiving Relations Between Separated Things as the Flip Side of Separating Features of Integrated Things

We have demonstrated that a simple change in testing procedure, which involved only changing the stimuli (so that the two dimensions of color and shape were separated and not part of the same physical object, although the same colors and shapes still appeared on all cards), enabled children to switch tasks in the DCCS paradigm 6 months earlier than they are otherwise able. Diamond and colleagues (Diamond et al., 1999; Diamond et al., 2003) have demonstrated that another simple change in testing procedure *halved* the age at which infants could demonstrate the ability to deduce the abstract rule: “Choose the item that does not match (i.e., that is different from) the sample.” There it was a matter of unseparating (attaching) stimulus and reward objects, where normally the reward sits just below the correct stimulus in a shallow well. Participants must deduce that reaching to the novel stimulus is always the correct response. Children cannot normally succeed on this delayed nonmatching to sample task, even at the 5-sec training delay, until they are almost 2 years old (20–21 months; Diamond, 1990; Diamond, Towle, & Boyer, 1994; Overman, 1990; Overman, Bachevalier, Turner, & Peuster, 1992). Their problem is that they do not “get” that the reward object and stimulus object are somehow related when they are not physically connected.

It turns out that infants' ability to relate the reward object to the stimulus object does *not* depend on the two objects being physically close (spatial proximity) or on the reward being received (or appearing) just after the infant acts on the stimulus (temporal proximity). Even if the stimulus is directly in front, or on top, of the reward and the reward pops up the instant the infant grasps the stimulus, infants do not understand the relation between stimulus and reward. *Physical connection* is the key: Infants of 9 or 12 months succeed if the stimulus and reward are velcroed together (Diamond et al., 1999). Indeed, they succeed even if the stimulus and reward are some *distance* apart and the reward does not appear until 5 sec *after* acting on the stimulus *if both are connected to the same piece of apparatus* (Diamond et al., 2003). Without the perception that stimulus and reward are components of a single thing, even close spatial *and* temporal proximity are insufficient. In its presence, *neither* close spatial or temporal proximity is needed (Diamond et al., 2003; Ross, Shutts, & Diamond, 2000; Shutts, Ross, Hayden, & Diamond, 2001). Even for adults, detecting a conceptual connection is aided by physical connection and may not occur in its absence. When Blaser (2003) asked adult observers to report only individual parts of a visual display, adults spontaneously encoded and learned the combinations of parts *if* the parts were physically connected.

Related findings from other paradigms include those of Rudel (1955), who found that when the reward is placed *inside* the stimuli, children 1½ to 3½ years of age learn to choose on the basis of relative size in far fewer trials than do even older children when tested with the reward *underneath* the stimuli (Alberts & Ehrenfreund, 1951; Kuene, 1946). Similarly, DeLoache and Brown (1983) found that 18- to 22-month-olds performed much better when a reward was hidden *in* a piece of furniture rather than *near* it.

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DeLoache (1986) varied whether a reward was hidden in one of four distinctive containers or whether the distinctive containers were mounted on top of plain boxes into which the rewards were placed. When the boxes were scrambled, 21-month-olds were 80% correct when the rewards were *in* the distinctive containers but only 35% correct when the distinctive containers *marked* where the rewards were hidden (the reward being in the box *underneath*). "When the same distinctive visual information was a less integral aspect of the hiding location, age differences appeared" (DeLoache, 1986, p. 123).

Difficulty in seeing conceptual connections between physically unconnected things is also documented in apes and monkeys. Adult chimpanzees may take 100 trials or more to learn a color discrimination with red and blue plaques placed over shallow wells and the reward always under the blue (or red) plaque. Changing just one aspect of the testing procedure (e.g., instead of placing the peanut reward in the shallow well under the plaque, attaching the peanut to the underside of the plaque) enables chimpanzees to learn the color discrimination rule after just *one trial* (Jarvik, 1956; analogous to the velcro condition of Diamond et al., 1999).

Many studies have documented impairments in the acquisition of conditional associations in monkeys with lesions of the periarcuate region (e.g., Goldman & Rosvold, 1970; Petrides, 1982, 1985, 1986; Lawler & Cowey, 1987; Passingham, 1988). Halsband and Passingham (1982, 1985; Passingham, 1985a, 1985b) reported that monkeys with premotor lesions invading the arcuate sulcus (the periarcuate region) can learn "if blue cue, pull handle; if red, turn handle" *if* color is a property of the handle itself but not if it is a property of the background. This brings us back to the preschool period, because children of 3 years also have difficulty with such conditional discriminations. In the classic paradigm, participants first learn to always respond to one member of a pair of stimuli. After reaching a high level of accuracy, the stimuli are presented against a different background, and the reward contingencies are reversed.

When children are tested with minimal instruction and so must deduce the rules, they cannot succeed at such conditional discriminations until they are 4½ to 5½ years of age (Doan & Cooper, 1971; Gollin, 1964, 1965; Gollin & Liss, 1962; Heidbreder, 1928; Jeffrey, 1961). The work with monkeys suggests that younger children (perhaps at 3 or 3½) might succeed if color were a property of the stimuli themselves rather than of the background. Making color a property of the stimulus objects might enable 3-year-olds to see the relevance of variations in that attribute to the response rules for those stimuli. Conversely, as we have shown here, separating the attributes so that they are not properties of the same stimulus object makes it easier for 3-year-olds to switch between the two attributes when the currently correct sorting response conflicts with the previously relevant one.

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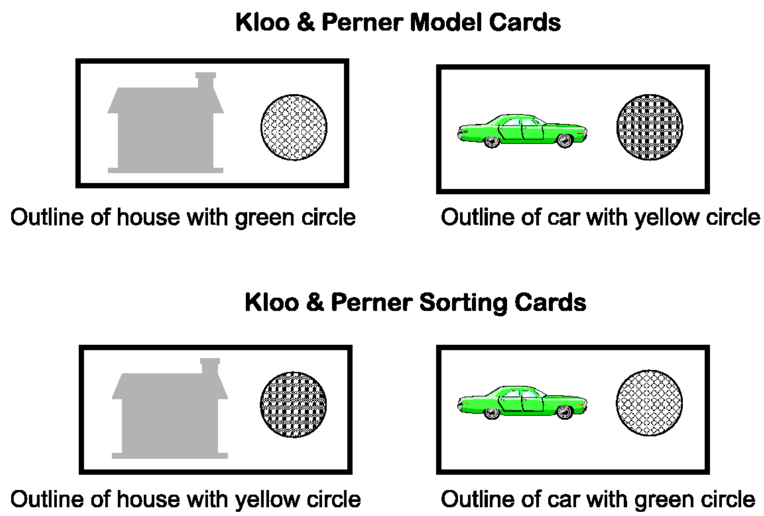

FIGURE 1.
An illustration of the stimuli used for the separated dimensions condition by Kloo and Perner (2005) in their Experiment 3.

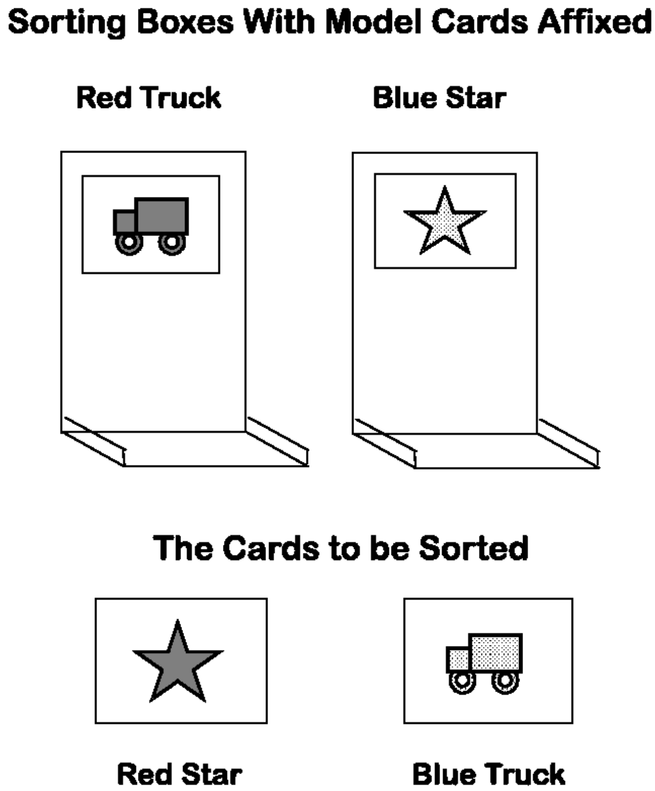

FIGURE 2.
An illustration of the stimuli used in the work reported for the integrated condition. Reprinted from Kirkham, Cruess, and Diamond (2003), with permission.

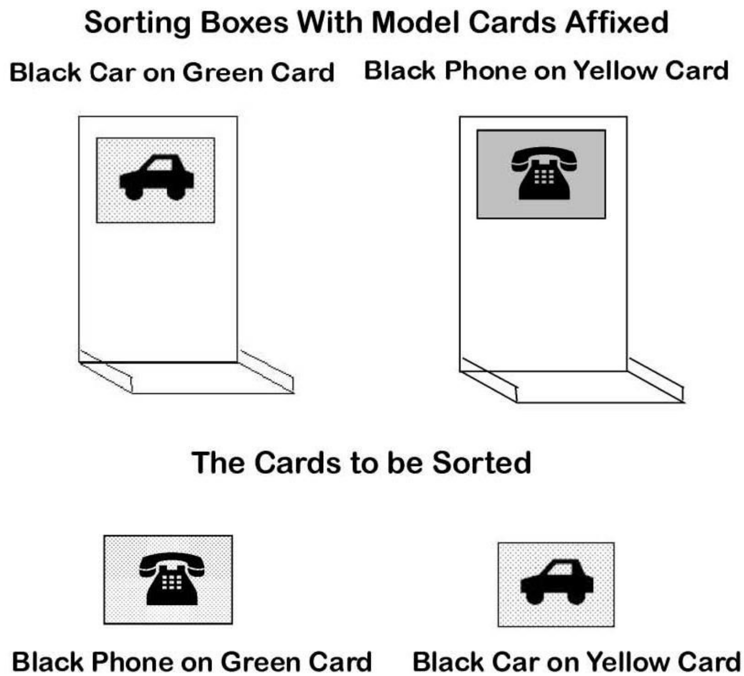

FIGURE 3.
An illustration of the stimuli used in the work reported for the separated condition.

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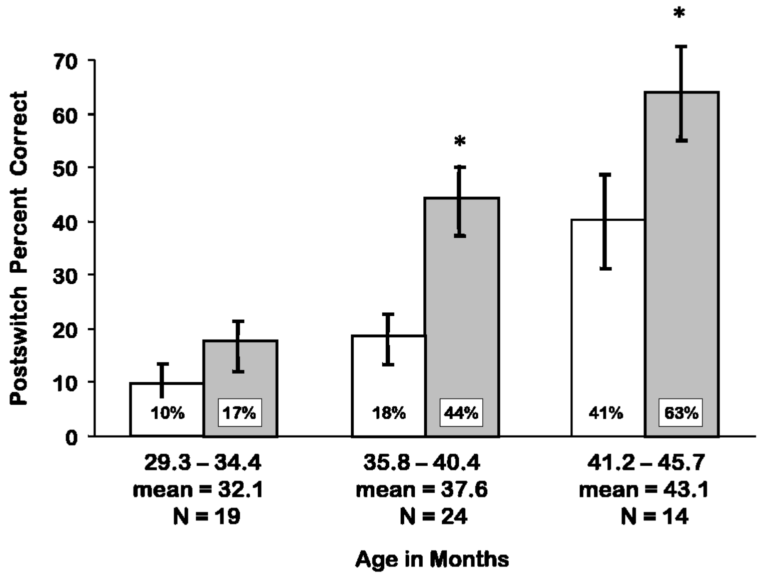

FIGURE 4.

The percentage of correct sorting responses after the sorting criterion had changed by age group and condition. *Note.* The error bars show the standard error of the mean; the gray bars show the separated-dimensions condition; white bars show the integrated condition.

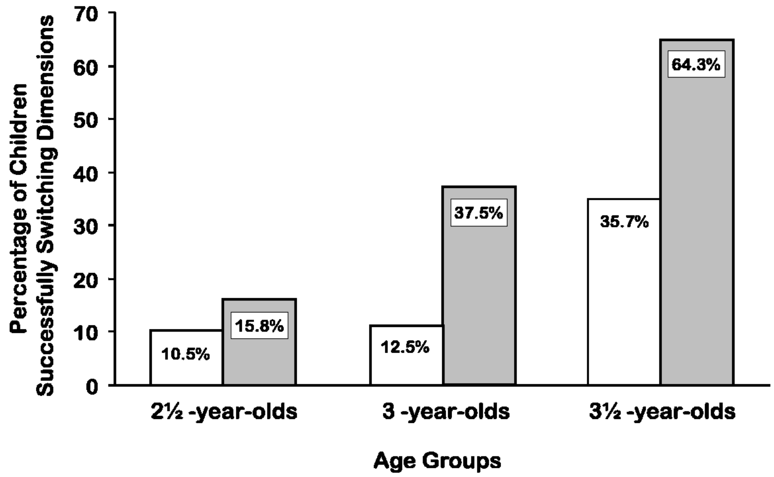

FIGURE 5.

The percentage of children who successfully switched sorting criteria by age group and condition. *Note*. Criterion for success was five or more out of six responses correct postswitch; the gray bars show the separated-dimensions condition.

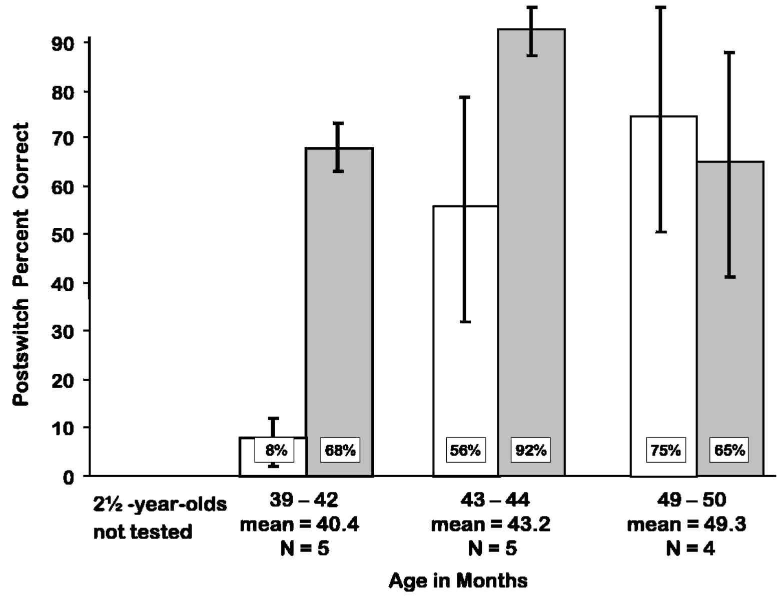

FIGURE 6.
The percentage of correct sorting responses with card stimuli only after the sorting criterion had changed, by age group and condition (data from Kloo & Perner, 2005, Exp. 3). *Note*. The error bars show the standard error of the mean; the gray bars show the separated-dimensions condition.

TABLE 1

Developmental Progression in the Ability to Switch Sorting Dimensions as Indicated by Accuracy and Hesitation on Two Versions of the DCCS Task

		Number of Trials on Which the Child Hesitated in the …	
Subject Number	**Age in Months**	**Separated Condition**	**Integrated Condition**
Those who failed to switch sorting dimensions in both conditions and showed no hesitation or awareness of their error			
#A	31.5	0	0
#B	33.9	0	0
#C	36.3	0	0
#D	37.9	0	0
#E	45.1	0	0
Those who, although they failed the postswitch in both conditions, showed some hesitation when the dimensions were separated (some inkling that maybe their response was wrong), but no hesitation when the dimensions were integrated			
#F	29.5	1	0
#G	33.5	1	0
#H	36.7	1	0
#I	36.9	1	0
#J	37.8	1	0
#K	37.8	1	0
#L	38.1	1	0
#M	32.8	2	0
#N	36.0	2	0
#O	38.5	2	0
#P	42.6	3	0
#Q	44.2	3	0
Those who, although they failed the postswitch in both conditions, showed some hesitation in both conditions, although usually more hesitation in the separated condition			
#R	34.4	1	1
#S	43.1	2	2
#T	39.3	3	2
#U	45.7	4	3
#V	40.2	6	4
Those who successfully switched sorting criteria when the dimensions were separated, but failed when the dimensions were integrated			
#W	37.5	1 (correct)	2 (wrong on both)
#X	42.5	1 (correct)	1 (wrong)
#Y	36.5	2 (correct on both)	0 (wrong)
#Z	33.9	2 (correct on both)	2 (wrong on both)
#AA	42.1	2 (correct on both)	2 (wrong on both)
#BB	41.3	0 (correct)	0 (wrong)
#CC	42.6	0 (correct)	3 (wrong on all 3; correct on next 3, no hesitation)
Those who successfully switched sorting criteria in both conditions, but showed more uncertainty (more hesitation) when the dimensions were integrated than when they were separated			
#DD	34.0	0	1
#EE	41.2	0	1
#FF	42.0	0	1
#GG	43.0	2	3
Those who succeeded in switching sorting criteria in both conditions without hesitation			
#HH	36.2	0	0
#II	37.0	0	0

Note. Evidence of the presence or absence of hesitation on each postswitch trial was coded only for children of 3 and 3.5 years because children of 2.5 years were so immature in the ability to switch tasks that the vast majority of them fit in the first category above (failed both conditions and showed no awareness of their error). Videotape records were unavailable for three of the children; therefore, they could not be included in the table as evidence of hesitation was coded from the videotapes. A hesitation was defined as clear behavioral evidence of uncertainty about which response tomake, such as vacillating between putting a sorting card in one bin or the other.