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When Seeing is Knowing: The Role of Visual Cues in the Dissociation Between Children's Rule-Knowledge and Rule-Use

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Abstract

The Dimensional Change Card Sort (DCCS) task requires children to switch from sorting cards based on shape or color to sorting based on the other dimension. Typically, 3-year-olds perseverate, while 4-year-olds flexibly sort by different dimensions. Zelazo et al. (1996) asked children questions about the post-switch rules and found an apparent dissociation between rule-knowledge and rule-use: 3-year-olds demonstrate accurate knowledge of the post-switch rules despite sorting cards incorrectly. Here, we show that children's success with these questions is grounded in their use of available visual cues: children who fail sorting use the target cards to correctly answer questions; when the cards are unavailable, they guess. This suggests that there may not be a dissociation between children's rule-knowledge and rule-use in the DCCS.

Flexible cognition and behavior is a pervasive aspect of everyday life and a hallmark of executive function. Inflexibility in the form of perseverative errors can occur, though, when we repeat a recently performed or well-practiced behavior that is no longer appropriate. For example, we may take a more practiced route to the grocery store and realize at some point along the way that we intended to go to a different store. Perseverative errors such as these are commonly seen in early development across various paradigms and often cannot be remedied with simple reminders or instructions (Zelazo, Müller, Frye, & Marcovitch, 2003; Diamond, 1985; Morton, Trehub, & Zelazo, 2003). How does cognition change in early development to allow behavioral flexibility?

The Dimensional Change Card Sort (DCCS) task is a particularly useful paradigm to study this question because it gives insight into some of the earliest forms of flexible cognition. In this task, children must switch from sorting cards based on the dimension of shape or color to sorting by the other dimension. Trays mark two locations where test cards are to be sorted, while target cards affixed to these trays provide cues for which features go where in the different games. The test cards that children sort are typically designed so that the color and shape rules conflict with one another (see Figure 1A). For example, children could sort test cards featuring a red circle or a blue star to target cards featuring a red star or blue circle. In this case, the test cards would be sorted to opposite locations for the different games. This task reveals dramatic changes in children's ability to use rules between 3 and 4 years. While 4-year-olds can successfully switch between conflicting sets of rules, 3-year-olds perseverate and use the initial set of rules when asked to switch (Zelazo et al., 2003; Müller, Dick, Gela, Overton, & Zelazo, 2006; Perner & Lang, 2002; Munakata & Yerys, 2001).

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Three-year-olds' perseveration in the DCCS task is robust and persists despite repeated reminders of the new rules and various manipulations to the task (Zelazo et al., 2003; Garon, Bryson, & Smith, 2008). Indeed, young children's perseveration seems impenetrable to passive instruction. Rather, 3-year-olds require either demonstrations of the second set of rules (Towse, Redbond, Houston-Price & Cook, 2000), explicit feedback that they are sorting incorrectly (Bohlmann & Fenson, 2005), or manipulations to the low-level stimulus features to switch rules (e.g., changing the features on the cards between the pre- and post-switch phases, making the features relevant for the post-switch phase more salient, or using test cards that match the targets along both dimensions during the pre-switch phase; Fisher, 2010; Zelazo et al., 2003; Müller, et al., 2006).

How do children's representation and understanding of rules change to allow autonomous application of a second conflicting set of rules in the post-switch phase after mere instruction? To investigate this, Zelazo, Frye, and Rapus (1996) assessed what children know about the post-switch rules by asking children questions about the rules after the sorting task (e.g., "Where do stars go in the shape game?"). Surprisingly, the majority of children—even children who perseverated in their sorting behavior—were able to correctly report the location where the post-switch features should be sorted. From this, Zelazo and colleagues concluded that *there is a dissociation between children's rule-use and rule-knowledge*: children appear cognizant of the actions required for the post-switch phase, but cannot act on this knowledge when sorting cards.

Although 3-year-olds appear to know rules before they can use them, is this really the case? One factor which could underlie the successful performance of perseverators on the post-test questions is the level of conflict present during this phase of the task. Specifically, the questions only refer to a single dimension while the cards that children sort match both target cards along different dimensions. It could be that children performed better on the questions because they were tested in an easier context.

To probe whether conflict in the post-test questions influences children's performance, Munakata and Yerys (2001) equated the level of conflict between the sorting task and the questions by asking children conflict questions (e.g., "Where do blue stars go in the shape game?"). They also asked the same group of children the standard unidimensional questions posed by Zelazo et al. (1996). Overall, children were significantly more likely to answer conflict questions incorrectly compared to unidimensional questions (see Table 1). Thus, perseverators no longer showed a dissociation between rule-use and rule-knowledge—they failed both aspects of the task. Interestingly, however, switchers now showed differential performance during rule-use and rule-knowledge phases of the task—they correctly switched rules during the post-switch phase but did not reliably answer the questions.

If switchers knew the rules well enough to sort cards, then why did they not answer the conflict questions correctly? One possibility is that 3-year-olds have difficulty understanding complex verbal stimuli such as the conflict questions. This would explain the increased failure rate of *all* 3-year-olds with conflict questions. This suggestion is consistent with data probing rule-use in a purely verbal version of the DCCS task. Morton and Munakata (2002b) and Morton, Trehub and Zelazo (2003) administered a version of the DCCS with verbal stimuli and verbal responses. For example, the child would be told to interpret someone's speech based either on the content (e.g., "I won a prize.") or the manner in which it was spoken (e.g., with a sad falling off tone). In this verbal paradigm, children are not able to reliably switch rules until 7 years of age. While the primacy and complexity of verbal and visual information are likely different (Robinson & Sloutsky, 2010; Chevalier & Blaye, 2009), it is important to note that the rule-structure between this verbal version and the standard DCCS task are the same. Thus, the fact that children cannot switch rules in the verbal task until 7 years of age while children can switch rules in the DCCS at 4 years of age raises the possibility that selectively attending to verbal information is more difficult than selectively attending to visual information.

In summary, results to date using post-test questions have shed important light on the relationship between rule-use and rule-knowledge in early development. The apparent dissociation observed in the DCCS has been explained in various ways. Zelazo et al. (1996) suggest that knowledge is intact, but children lack the control to inhibit rule-representations that were active during the pre-switch phase and engage a new rule representation when asked to switch rules. Munakata and Yerys (2001) present a different view. They suggested that these data can be best explained by developmental changes in the strength of rule-representations. In particular, young children's rule-representations are not strong enough to be acted on in complex situations such as when children are asked questions that contain conflict. In such cases, weak representations of the post-switch rule (i.e., knowledge that stars should be sorted to the right) are overcome by strong latent traces of the pre-switch dimension (i.e., blue things go to the left). When both representations are activated by conflict questions, latent traces tend to win and young children fail to demonstrate knowledge of the rules. By contrast, when only the post-switch dimension is activated by easier unidimensional questions, children have no latent traces to overcome and they answer the knowledge questions correctly (Morton & Munakata, 2002a).

The present study builds on these previous investigations by focusing on perhaps the most striking result from the original report by Zelazo et al. (1996): how are 3-year-old perseverators able to correctly answer the unidimensional post-task questions despite failing to switch rules? According to the weak representation account, children successfully answer unidimensional knowledge questions by relying on activated latent knowledge: they activate the 'star' feature, the 'shape' rule, and map these onto a representation of where stars go in the game (i.e., to the right). Here, we examined an alternative possibility—that perseverators succeed when answering "easy" post-test questions because the content of the question uniquely overlaps with a *visible* target feature in the task space. Children might simply point to the star target card when asked to indicate, "where do stars go in the shape game". In this case, the visual cues in the task-space effectively 'tell' children the correct response—no weak representation of the rules is needed.

Interestingly, the visual cues and weak representation views make opposite predictions which we tested in the present study. According to the visual cues hypothesis, perseverators rely on the target cards when responding to the "easy" unidimensional post-test questions. If this is the case, then their responding on the questions should drop to chance levels *when the visual cues are removed during the post-test questions*. If, however, perseverators do have access to a weak representation of the rules that can support correct responding on easy post-test questions, then they should respond correctly even when the visual cues are removed. Note that we expected that children who succeed in the post-switch sorting phase would correctly answer the post-task questions regardless of the presence of visual cues. Indeed, this is necessary to demonstrate that children can tap into their understanding of the game in the absence of visual cues when such understanding exists.

Method

Participants

A sample of 74 children (30 children in both conditions, 2 excluded participants, and 12 participants in the control condition) between the ages of 37 and 45 months (M = 41.1 months, SD = 1.3 months) were recruited from a small Midwestern city. Gender and task-order (i.e., the order in which the shape or color rules were used across the pre- and post-switch phases) were balanced across conditions. Children received a small toy in exchange for their participation.

Procedure

Experiments were conducted individually in a quiet room. Children completed the standard version of the DCCS and were then asked unidimensional questions about the post-switch rules as in Zelazo et al. (1996). Trays containing target cards (a red star and a blue circle) were displayed throughout the card sorting procedure. Children sorted test cards containing a blue star or a red circle, and were given 5 cards for the pre-switch phase and 5 cards for the post-switch phase. No direct feedback was given for children's sorting performance, but the rules were repeated if they sorted incorrectly.

After completing the sorting task, children were then asked questions about the post-switch rules. The critical difference between the two conditions was the visual structure available in the task-space while the questions were administered. The *Standard* condition replicated the conditions of Zelazo et al. (1996; see Figure 1B). In the *Cues-Absent* condition, the visual cues were removed before questioning (see Figure 1C). All children were asked unidimensional questions about each post-switch rule (i.e., for the Shape-Color task order, "Where do red ones go in the color game?" and "Where do blue ones go in the color game?"). No feedback was given based on children's question performance.

Finally, a control group was included to help interpret results of the *Cues-Absent* condition. This group of children was given only the pre-switch phase followed by questions about the rules under the same circumstances as the *Cues-Absent* condition. Given that children typically sort cards correctly during the pre-switch phase, this would create a situation where there is a strong latent representation of the rules which was used successfully. If children in this condition are able to correctly answer post-task questions in the absence of visual cues, then we can be confident that children understand the questions even in this potentially more challenging context. This condition might also shed light on why children have difficulty answering questions in the absence of visual cues in the key experimental condition.

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Results

We first discuss results of the control condition. These children received only a pre-switch phase and then were asked questions about the rules in the absence of visual cues (as in the *Cues-Absent* condition). Of the 12 children in the control condition, 11 children sorted all 5 cards correctly while 1 child sorted only 4 cards correctly. On the questions, 11 children answered both questions correctly while 1 child answered both questions incorrectly. Thus, asking children questions in the absence of visual cues appears to tap into the understanding of rules required for the DCCS task.

Next, we turn to the results of the critical conditions. For inclusion in the analysis, children were required to sort at least 4 cards correctly during the pre-switch phase (Zelazo et al., 2003). Two children were dropped from the analysis due to failure to meet this criterion (2 *Standard*; 0 *Cues-Absent*). In addition, because the aim of this study was to investigate the relationship between card sorting behavior and knowledge of rules, we need a clear view of what children are doing during both the post-switch sorting phase and the question phase. Thus, we filtered the data using strict criteria for passing and failing for both measures of performance. Specifically, children were categorized as passing the post-switch sorting phase if they sorted 4 or more cards correctly, and as failing if they sorted 1 or 0 cards correctly. Similarly, children were categorized as passing the question phase if they answered both questions correctly, and as failing if they answered both questions incorrectly. Both of these criteria remove intermediate levels of switching or question

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performance from the data set. This resulted in the filtering of 4 children and the inclusion of 26 children in each condition (in the *Standard* condition, 3 children failed to meet the question criterion, 1 child failed to meet both question and sorting criteria; in the *Cues-Absent* condition, 2 children failed to meet the question criteria, and 2 children failed to meet the sorting criteria).

Table 2 shows the distribution of children who passed and failed sorting in the post-switch phase and answered the post-task questions correctly or incorrectly (the numbers in parentheses represent the number of children in each cell for the full data set before the strict filtering). As shown in Table 2, across both conditions, the majority of children failed to switch rules during the post-switch phase (65%), following the pattern typically seen in the literature. Moreover, data from the *Standard* condition replicate results from Zelazo et al. (1996) and Munakata and Yerys (2001): the majority of switchers *and* perseverators passed the standard knowledge questions (96%). Performance in the *Cues-Absent* condition showed a drastic departure from this pattern: children who correctly switched rules in the DCCS task tended to answer questions correctly (80%), but perseverators performed at chance levels as a group—half of these children answered the questions correctly, half answered the questions incorrectly.

These data were analyzed using a hierarchical log-linear model. This analysis method models the natural logarithm of the distribution of observations as a linear combination of main effects and interactions of question condition, sorting performance, and question performance. The partial-associations of the saturated model which includes all possible interactions and main effects and, thus, fits the data perfectly showed a significant main effect of sorting performance ($\chi^2(1)= 5.004$, $p= 0.025$), as well as a significant main effect of question performance ($\chi^2(1)= 18.425$, $p< 0.001$). Thus, significantly more children overall perseverated than correctly switched rules, and significantly more children overall answered the post-task questions correctly than failed in this phase of the experiment. Critically, there was also a significant interaction of question performance and condition ($\chi^2(2)= 11.731$, $p= 0.001$) [1]. *Without visual cues, children showed significantly poorer performance in the question phase*. Note that there was no interaction of condition and sorting performance ($\chi^2(2)= 1.532$, *ns*), suggesting that children showed the same level of post-switch performance across conditions.

Next, we conducted a backward elimination procedure on the hierarchical log-linear model to determine the most parsimonious model equation that fit the data as effectively as the saturated equation. In this procedure, an effect or interaction is first removed, starting with the highest-level interaction, to determine whether it significantly contributes to the variance in the distribution of observations. Non-significant factors are removed, while significant factors are retained. This procedure prunes away effects to determine the critical factors influencing the distribution of observations. The resulting model equation is a good fit if it produces a chi-squared value that is not significantly different from the saturated model which perfectly predicts the distribution of observations across cells. The backward elimination analysis indicated that the most parsimonious model equation included the question performance by condition interaction as the highest order term in the non-saturated model along with a main effect of sorting performance ($\chi^2(6)= 3.551$, $p= 0.314$). In this method, all lower order effects of the highest-order significant effect must also be included in the final model. Thus, the interaction of question performance and condition along with the main effects of question performance, sorting performance, and condition fit the distribution of children across conditions as well as the saturated model.

[1]Note that the statistical results are robust even when all the data are included. Most critically, the partial association of the question-performance by condition interaction for the log-linear analysis with the full data set was significant, $\chi^2(2)= 4.514$, $p< 0.05$.

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The final analysis we conducted followed-up on the significant question performance by condition interaction. In particular, we conducted two post-hoc chi-squared analyses to determine whether the difference across conditions was primarily driven by a particular group of participants. For children who perseverated during the post-switch sorting phase, question performance was dependent on condition ($\chi^2(2)= 8.597$, $p= 0.003$), while these factors were independent for children who switched rules ($\chi^2(2)= 1.8$, $p= 0.180$). Thus, perseverators showed a significant decrement in question performance when the visual cues were removed, while switchers could robustly bring their knowledge to bear in answering the post-task questions regardless of the available visual cues.

Discussion

The present study contributes to the growing body of evidence on the nature of children's rule-representation and perseveration in the DCCS task by demonstrating how visual cues can influence children's rule-knowledge. Zelazo et al. (1996) suggested that a dissociation exists between children's rule-use and rule-knowledge. Specifically, perseverators were able to correctly answer questions about the post-switch rules despite failing to use those rules when sorting cards. This suggests that children can know rules before they can use them. Subsequent work by Munakata and Yerys (2001) suggested a critical caveat to this conclusion: perseverators have weak representations of the rules and can use them, provided children are placed in a context with relatively easy post-task questions.

Here, we tested an alternative possibility—that perseverators answer correctly when asked unidimensional post-task questions because they rely on the available visual cues. In particular, when questions contain only one dimension of information (shape or color) and there are salient visual cues (the target cards), children might correctly answer questions by simply pointing to the information referred to in the question (e.g., pointing to the star when asked, "Where do stars go in the shape game?"). Our results are consistent with this hypothesis: when visual cues were removed from the task space during questioning, perseverators showed significantly poorer performance on the rule questions, performing at chance levels as a group. By contrast, two groups of children correctly answered the post-task questions when the visual cues were removed—children in the control condition and switchers in the *Cues-Absent* condition.

What do these data indicate about the knowledge-action dissociation reported by Zelazo et al. (1996)? *We contend these data suggest that there is no knowledge-action dissociation in the DCCS task*. Consider the control condition first. Here, children built a strong latent memory of the pre-switch rule as they sorted cards correctly. When they were asked about the rule using unidimensional questions in the absence of visual cues, they responded correctly. Knowledge and action went hand-in-hand. Next, consider the switchers in the *Cues-Absent* condition. Here, children sorted cards correctly and built a latent memory of the pre-switch rule. Next, they activated the post-switch rule robustly, sorted cards correctly, and built a latent memory of the post-switch rule. When they were asked about the post-switch rule using unidimensional questions in the absence of visual cues, they responded correctly. Knowledge and action went hand-in-hand.

What about the perseverators? These children built a latent memory of the pre-switch rule and sorted cards correctly. Next, they continued to sort by the same rule in the post-switch phase. This strengthened the latent traces for the pre-switch rule even further. When they were asked about the post-switch rule using unidimensional questions in the absence of visual cues, they performed at chance levels. Thus, children's sorting behavior showed a lack of knowledge about the post-switch rule, and their answers to the post-task questions also showed a lack of knowledge about the post-switch rule. Knowledge (or lack thereof) and action went hand-in-hand.

The present findings are not consistent with existing theories of children's knowledge and action in the DCCS task. Zelazo et al. (1996) argued that perseverators know the post-switch rule, but fail to use this rule when sorting because they fail to inhibit the pre-switch rule representation. This interpretation is not consistent with our data: perseverators showed no evidence of knowing the post-switch rule when asked unidimensional questions designed to tap this knowledge. If this is the case, then how did perseverators succeed in answering the question in the *Standard* condition? It appears that when these children were asked "where do stars go in the shape game?" they simply point to the star in the task space.

At face value, our data are also not consistent with the model proposed by Munakata and colleagues to explain children's performance on sorting and knowledge questions in the DCCS task (Morton & Munakata, 2002a; Munakata & Yerys, 2001). This model robustly explains children's performance in the control condition, switcher's performance in both conditions, and perseverator's performance in the *Standard* condition. Critically, however, the model predicts that perseverator's should succeed in the *Cues-Absent* condition. In particular, the model predicts that the unidimensional question should activate children's latent knowledge about 'stars' and their latent and weak representation of the 'shape' rule. These should be combined at the level of the model's hidden layer to correctly map the star to the correct sorting location. As long as the strong, latent traces of the pre-switch rule and pre-switch features are not activated, the model—and children—should answer the knowledge question correctly. This was not the case in the present experiment.

Although the connectionist model is not consistent with our findings, this may not be surprising given that there is no explicit input in the model that captures the perceptual features of the target cards. Rather, the output mapping—the connections from the features in the hidden layer to the sorting bins in the world—is fixed *a priori*. These connections can be modified by learning across trials, but the manner in which the hidden layer units are connected to the output layer has an *a priori* structure. Consequently, the model predicts that a manipulation of the presence or absence of the target cards should not matter because this mapping is given by the task and will be retained when the cues are no longer present. Clearly, this aspect of the model needs to be modified.

Interestingly, it may not be so transparent how to fix the model in this regard. For instance, adding another input layer for the target cards would not be sufficient because this would only influence learning between the input and hidden layers. What is needed is a way for the target input to influence the connections between the hidden and output layers. More generally, this suggests that one would need to add a process that effectively binds the individual features to their locations in space. We have developed an account of children's performance in the DCCS task that does this (Buss & Spencer, 2011), but we have yet to probe how our dynamic neural field model performs on knowledge questions like the ones examined here.

We conclude with a few observations regarding perseverator's performance in the *Cues-Absent* condition that provide constraints for future efforts to model our findings. First, although performance at the group level was at chance levels, it is worth noting that children were not strictly guessing on every trial. If they were strictly guessing, then more perseverators should have shown intermediate levels of question performance. This was not the case. Our interpretation of these data is that perserverators did guess on the first post-task question in the absence of visual cues. This was then followed by generating the opposite response when queried with a different feature value.

It is also notable that perseverators did not fall back on their just-previous sorting behavior when asked the post-task question. For example, if a child just perseveratively sorted a star card to the rightward location, one might expect that he would point to the right when asked, "Where stars go in the shape game?" This was not the case. Interestingly, this resonates with aspects of Munakata et al.'s connectionist model. In particular, the model does not learn about 'stars' when perseveratively sorting by colors. Thus, at the level of learned latent traces, the model should have no basis for sorting stars after perseverating in the post-switch phase. Note that if one were to modify the model so it could 'guess' in the absence of visual cues and if this sorting response left a latent trace, this trace might be sufficient to enable the model to generate the opposite response on the second post-task question. These observations suggest that a modified version of the connectionist model could capture our findings.

In summary, the present data inspire a new interpretation of children's rule-use and rule-knowledge in which children's knowledge and action are more closely aligned than previously thought. Between 3 and 4 years, children clearly develop the ability to form robust memories associated with rules and learn to efficiently deploy attention to the relevant features of objects in the task space based on verbal instructions, eventually rising above potential conflict in the task. But our data suggest that their performance is intimately tied to the full range of visual cues available. By this view, rule-use and rule-representation may not lie solely in the head of the child; rather, behavior in the sorting and question tasks emerges in the interaction of the child and the environment (for a related discussion, see Recker & Plumert, 2008; Thelen & Smith, 1994). The present research shows that children are 'smart' when they are able to capitalize on the structure of the task space to answer questions for which their knowledge is insufficient, but they are not quite smart enough to fail at sorting yet still accurately represent task rules.

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- Children seem to know rules before they can use them
- We removed visual cues during questioning
- Children performed at chance level on rule questions
- These results suggest there is no dissociation between knowledge and action

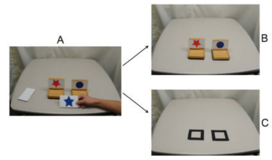

Figure 1.

Depiction of task space during sorting (A), during the *Standard* Questions condition (B) and during the *Cues-Absent* Questions condition (C).

Table 1

Data from Munakata & Yerys (2001). The distribution of children based on their post-switch sorting performance and their performance for the different types of questions

	Post-Switch Sorting	
Standard Questions	**Pass**	**Fail**
Pass	6	7
Fail	0	3
Conflict Questions		
Pass	3	4
Fail	3	6

Table 2

Distribution of children based on performance on post-switch sorting trials and question trials in the three experimental conditions after filtering (the numbers in parentheses indicate the number of children in each cell for the entire sample)

	Post-Switch Sorting	
Standard Questions	**Pass**	**Fail**
Pass	8 (8)	17 (17)
Fail	0 (1)	1 (4)
Cues-absent Questions		
Pass	8 (8)	8 (10)
Fail	2 (2)	8 (10)