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# Not all labels develop equally: The role of labels in guiding attention to dimensions

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ABSTRACT

The emergence of cognitive flexibility is a central aspect of cognitive development during early childhood. Cognitive flexibility is often probed using verbal rules to instruct behavior. In this study, the types of labels that were provided during instruction were manipulated. In one condition, children were instructed in the standard manner with dimensional labels (e.g., "shape") and featural labels (e.g., "star"). In a second condition, children were provided only with dimensional labels. When switching to color, 4-year-olds performed equally well regardless of the type of instruction. However, when switching to shape, children perseverated at a significantly higher rate when only dimensional labels were provided. These results suggest that children's understanding of labels is a critical aspect of developing cognitive flexibility and that their understanding of the labels "shape" and "color" are different.

## 1. Introduction

Language is a central aspect of many theories of executive function (EF) development. EF refers to the higher order processes that regulate cognition and behavior in a goal directed fashion (for a recent review, see Wiebe & Karbach, 2017). Most measures of EF use verbally administered rules to instruct behavior which requires that children use language to guide their behavior. Although language is often invoked as a central component of EF development, the relationship between language and EF remains under-specified. In this report, we examine the impact of one specific aspect of language, namely the information carried by different types of labels (i.e., labels for dimensions and features) used during instruction of a task on a specific aspect of executive function: flexible dimensional attention.

One canonical task used to measure the early development of flexible dimensional attention is the dimensional change card sort (DCCS) task (Zelazo, 2006). In this task, children are instructed to first sort cards by shape or color and then to switch and sort by the other dimension. In this task, target cards are affixed to the trays where children sort cards as illustrated by the blue circle and red star in Fig. 1. The test cards that children sort contain conflict such that they match either target card along different dimensions as illustrated by the blue star and red circle in Fig. 1. This task has received much attention in the literature because it reveals a qualitative change over a relatively short period of time. Specifically, most 3-year-olds perseverate and continue using the initial set of rules when instructed to switch, but most 4-year-olds have little difficulty switching rules (for a review of the literature with this task see Buss & Spencer, 2014).

Research has revealed that how language is used in this task can influence cognitive flexibility. For example, Yerys and Munakata (2006) showed that switching is easier when the labels used during the pre-switch phase are uninformative. Specifically, the pre-

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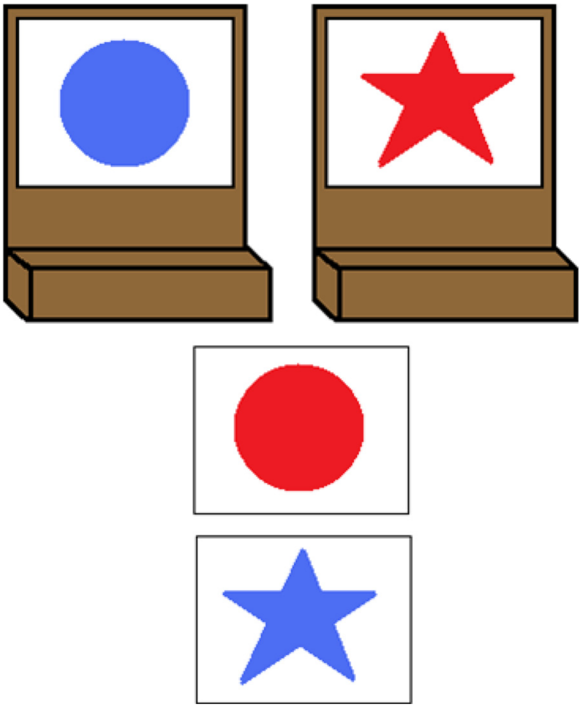

**Fig. 1.** Depiction of stimuli used in the standard dimensional change card sort (DCCS) task.

switch phase was described as a “sorting” game rather than a “shape” or “color” game as in the standard version of the task. Similarly, if novel features with novel labels are used during the pre-switch phase (for example, off-shades of colors or random shapes that were given novel labels) then 3-year-olds have less difficulty switching rules. In these examples, switching is facilitated by using familiar features or labels during the post-switch phase and unfamiliar features or labels during the pre-switch phase. Doebel and Zelazo (2016) exposed children to contrastive language in a series of tasks prior to performing the DCCS task. For example, in one task children could be shown an apple, and the experimenter would say, “This isn’t a banana. It’s different. It’s an apple.” In another task, children could be shown an array of objects and instructed to “circle the ones that are not hearts, that are different from hearts.” With this pre-exposure to this type of language, children showed significantly better switching ability compared to other groups of children who were exposed to similar tasks without the use of contrastive language. These two examples highlight that multiple aspects of language, from simple familiarity with the labels used during instruction to priming with language that highlights contrasts, can influence children’s attentional flexibility skills.

### *1.1. Theories of cognitive flexibility development*

Various language-based theories have been applied to explain general aspects of cognitive flexibility (Cragg & Nation, 2010; Deak, 2003). In the context of the DCCS specifically, cognitive complexity and control (CCC) theory proposes that flexible rule-use is driven by linguistically mediated representation of the rules involved in the task (Jacques & Zelazo, 2005; Zelazo, Muller, Frye, & Marcovitch, 2003). In this way, language is used in the construction of a hierarchical representation of the rules that says, for example, “if I’m playing the shape game and the card shows a star then I should sort it here, but if I’m playing the color game and the object is blue, then I should sort it there”. Importantly, obtaining higher degrees of complexity in rule representations is brought about through an active process of reflection, or reprocessing the stimuli, which allows for multiple aspects of an object to be considered (e.g., not only is an object a star, but it is also red). In the context of this theory, development is driven by maturational changes in frontal cortex that support the representation of hierarchical rules (Bunge & Zelazo, 2006). Specifically, children become capable of constructing increasingly complex hierarchies of contingencies and become more likely to engage in reflection as they develop. In the context of the DCCS task, children who fail to switch rules only represent the task at the level of feature and spatial locations (e.g., “if it’s red, then sort it here”). Children who can switch rules, however, are capable of doing so through the representation of a further degree of complexity in their rule representation (e.g., “if I’m playing the color game and if it’s red, then sort it here”). Thus, development in this theory is driven by the ability to use language in increasingly complex ways, which is supported by changes in rule-representation hierarchies in frontal cortex.

An alternative approach to understanding the development of cognitive flexibility has been put forth in the framework of dynamic field theory. Buss and Spencer (2014) describe a dynamic neural field (DNF) model that simulates the emergence of flexible attention across numerous variations of the DCCS task. In this theory, flexibility is dependent upon the strength of association between labels and visual features. Specifically, the model is composed of two overlapping neurocognitive systems. One is an object representation system that functions by binding visual features to spatial locations. This system is comprised of a parietal cortex component which processes spatial information and a temporal cortex component which processes object features. These components are reciprocally connected such that the presentation of a visual feature can lead to the activation of a spatial location, and the activation of a spatial location can lead to the activation of a visual feature. When making a decision in the context of the DCCS task, the model binds visual features on the test card to the spatial location of the left or right sorting tray. In the DCCS task, there are multiple sources of conflict. One source of conflict is inherent to the configuration of the features on the test cards and target cards. As illustrated in Fig. 1, the test cards match both target cards along different dimensions. In the model, this fact means that the presentation of a target card in the task will activate neural representations of both sorting locations. A second source of conflict arises from the pattern of memories that are established while sorting during the pre-switch phase. That is, if sorting by color during the pre-switch phase, then neural representations associated with sorting the blue and star features at the leftward location and the red and circle features at the rightward location become primed. During the post-switch phase, these primed neural representations will conflict with the task demands which dictate that those features should be sorted to the opposite locations. Thus, because the object representation system makes decisions by binding visual features to spatial locations, this system is sensitive to these sources of feature-space conflict which are created as the features on the test cards are sorted to the left and right spatial locations of the task.

To resolve these multiple sources of conflict, the second system in the model learns representations of dimensional and featural labels. This system is comprised of a frontal cortex component which represents labels for visual features/dimensions. This system forms associations with visual features which are processed in the temporal cortex component. These connections are reciprocal such that the presentation of a visual feature can lead to the activation of a label, and the presentation of a label can lead to the activation of a visual feature. In this way, activating a label through instruction can serve to enhance processing of associated visual features. Buss and Spencer (2014) demonstrated that a key aspect of flexible dimensional attention in the model is the strength of association between labels and visual features. With weak associations between labels and features, the model performs at a similar level as 3-year-olds: successful sorting during the pre-switch phase, but predominantly perseverating during the post-switch phase; however, with strong associations between labels and features, the model performs at a similar level as 4-year-olds and predominantly switches rules during the post-switch phase. The extant literature provides numerous examples of manipulations to the spatial or featural properties of the task which the model has successfully replicated across 15 different effects so far, and has generated both behavioral and neural predictions that have been successfully tested with 3- and 4-year-olds (Buss & Kerr-German, 2019; Buss & Spencer, 2014, 2018; Perone, Molitor, Buss, Spencer, & Samuelson, 2015; Perone, Plebanek, Lorenz, Spencer, & Samuelson, 2017).

As this review indicates, language influences flexible attention and is a central aspect of the most prominent theories of flexible attention development. Language development is an appealing mechanism because it provides a way to think about how learning in a particular domain can give rise to general cognitive flexibility skills that are presumably not tied to any particular domain (Ionescu, 2012). Importantly, however, language is used in different ways by these theories. In CCC theory, rule representations are mediated by language; however, changes in flexible attention are dependent upon the ability to construct hierarchical rule representations through reflection. Thus, learning language is not a direct developmental mechanism in this theory. In the DNF model, the ability to use and switch between rules depends upon a dimensional attention process that prioritizes visual dimensions. In this framework, development is brought about through increases in the strength of association between labels and visual features. Thus, learning labels for visual features and dimensions directly contributes to children's cognitive flexibility skills in this theoretical account. In this report we explore whether 4-year-olds switching performance is influenced by the types of labels used in instructions.

### *1.2. The development of dimensional labels*

A central hypothesis of the DNF model is that the strength of associations between labels and features is a key element of dimensional attention. Research on dimensional label learning suggest that children learn labels for features (e.g., "red" or "star") more readily than they learn labels for visual dimensions (e.g., "color" or "shape"). This is due to the more abstract nature of labels for dimensions. As Sandhofer and colleagues (Sandhofer & Smith, 1999) explain, learning labels for features involves a straight-forward mapping that associates a label such as "red" with the visual feature of the red hue. However, learning the label for a dimension such as color requires learning that the label color is associated with other specific labels such as red or blue and then using those labels to survey the visual environment to determine which visual features are present that map onto the associated feature labels. Thus, learning dimensional labels involves not only mapping labels to features, but using attention to visual dimensions to pick out the relevant feature from the visual environment.

Previous research has explored the development of dimensional label learning using simple comprehension (e.g., "show me the red one") and production (e.g., "what color is this?") tasks. This research suggests that children are able to perform above chance levels by the age of 30 months with both color and shape labels (Sandhofer & Smith, 1999; Verdine, Lucca, Golinkoff, Hirsh-Pasek, & Newcombe, 2016); however, research has not explored the mastery of color and shape labels beyond this age, nor have they systematically compared the learning of shape and color labels within the same group of children. Such research would shed important light on whether differences exist in the nature and time course of learning labels for different dimensions and how attention in other tasks is impacted by this learning. Of note, however, is that other research has demonstrated that children's understanding of labels such as "big" and "small" impact flexibility in an object categorization task (Schonberg, Atagi, & Sandhofer, 2018). Thus, it is possible that children's understanding of labels for visual dimensions and features also impacts flexible attention in the DCCS task.

To examine this central hypothesis of the DNF model, in this report we test the ability of different types of labels to guide flexible dimensional attention. To this end, the CHILDES database provides valuable information regarding children's exposure to different types of labels used to instruct the DCCS task. We examined the corpus of data to examine whether there are differences between dimensions in the types of labels that children hear and produce. First, we examined the labels that children are exposed to in child-directed speech.[1] Specifically, the DNF model shows that stronger representations of labels gives rise to the development of cognitive flexibility. If this is the case, then children's exposure to labels for features and dimensions should be related to how well children have learned these labels and, in turn, how well they are able to use these labels to guide attention to visual dimensions. We also examined children's spontaneous production of these labels from the CHILDES database.[2] In these cases, we examined the frequency of the labels "shape" and "color" as well as the labels for specific shapes and colors (here, we sampled color labels "red", "blue", "green", "yellow", "purple", and "orange" and the shape labels "circle", "square", "star", "triangle", "heart", and "rectangle"). First, Table 1 summarizes the frequency of child-directed production by adults. Note that the frequency of the label "color" is much higher than that of "shape", and the frequencies of labels of features are much higher within the color dimension than within the shape dimension. Moreover, Fig. 2 shows the frequency of children's own production for the labels "color" and "shape" (Fig. 2A) and for specific feature labels within these dimensions (Fig. 2B). Again, children's production of "color" is much higher in early development compared to "shape" and the frequency of specific color labels is much higher compared to that of specific shape labels. These observations motivate two hypotheses. First, children should be able to use the label "color" to guide attention to the color dimension given the very high rate of exposure and use to this label. Second, children should be poorer at using the label "shape" to guide attention to visual dimensions given their relatively low amount of exposure and use of this label.

### *1.3. Current study*

To explore the role of different types of labels in children's cognitive flexibility we studied a group of 4-year-olds who are expected to be proficient in performing the DCCS task. We then manipulated how instructions were given to these children. Half of these children were given the standard instructions that used both feature labels and dimensional labels. In a second group of children we used only dimensional labels to instruct behavior. Task order was counterbalanced such that half of the children in each group were given color rules first and then shape rules and the rest were given the instructions in the opposite order. Thus, this study included 4 conditions that uniquely combined the type of instruction and the order of dimensions. If dimensional labels are more difficult for children to use when guiding attention to visual dimensions, then we would expect 4.5-year-olds to have more difficulty when only instructed with dimensional labels. Moreover, if children have fewer opportunities to learn labels for the shape dimension, then we would expect children's difficulty to be selectively apparent when switching to shape.

## 2. Method

### *2.1. Participants*

Forty-eight children (19 females) between the ages of 46- and 61-months ($M$ = 55 mo, $SD$ = 3.97 mo) were recruited from the Iowa City community. One additional child participated but was dropped from the analysis for failing to sort correctly during the pre-switch phase (in the shape-color task order of the dimensional label condition). Parents completed an informed consent document and research protocols were approved by University of Iowa Institutional Review Board. Performance in the DCCS task is robust and well documented (for a review, see Buss & Spencer, 2014). Across the four conditions, we expect this sample size to provide a reliable estimate of children's performance in this task (Kirkham, Cruess, & Diamond, 2003; Munakata & Yerys, 2001).

### *2.2. Procedure*

Experimental sessions were conducted in a quiet laboratory room. Children were seated at a table on which sorting trays with target cards were displayed. Target cards featured a blue star and a red circle. The test cards that children sorted featured a red star and a blue circle. Children were randomly assigned to one of four conditions that differed in the type of instructions that were provided and the order of dimensions. In the standard conditions, children were told, "We are going to play the shape [color] game. In the shape [color] game we are going to sort cards by shape [color]. That means that stars [blue ones] go here [pointing to the blue-star target card image], but circles [red ones] go there [pointing to the red-circle target card image]". In the dimension label conditions, children were told, "We are going to play the shape [color] game. In the shape [color] game we are going to sort cards by shape [color]. That means that this shape [color] goes here [pointing to the blue-star target card image], but this shape [color] goes there [pointing to the red circle target card image]". The experimenter then demonstrated the pre-switch rules the same way in all conditions by sorting a card to each sorting location, saying, "See? This one goes here [experimenter sorts card to the relevant location], but this one goes there [experimenter sorts to other location]." Half of the children had color as the pre-switch dimension and shape as the post-switch dimension. The other half of children had dimensions administered in the opposite order.

In all conditions, children were given 5 cards to sort on their own during the pre- and post-switch phases. On a test trial, the experimenter presented the card to the child and said, "where does this one go?". After these pre-switch trials, children were then

[1] Parental production frequencies are taken from http://childes.psy.cmu.edu/ derived and are based on Ping Li's processing of these CHILDES corpora: Bates, Belfast, Bernstei, Bliss, Bloom, Brown, Clark, Cornell, Demetras, Fletcher, Gathercole, Hall, Higginso, Howe, Kuzczaj, Macbosy, Macros, Peters, Post, Sachs, Snow, Suppes, Valian, Vanhout, Venkleec, Warren, and Wells.

[2] Child production frequencies were obtained from http://childfreq.sumsar.net (Bååth, 2010).

**Table 1**
Parent frequencies from the CHILDES database for different labels within the color and shape dimensions.

| Frequency | Frequency | Shape Words | Frequency |
|---|---|---|---|
| Color | 1009 | Shape | 128 |
| Red | 1029 | Circle | 238 |
| Blue | 1025 | Square | 184 |
| Green | 1061 | Triangle | 64 |
| Yellow | 598 | Star | 175 |
| Orange | 609 | Heart | 133 |
| Purple | 172 | Rectangle | 28 |

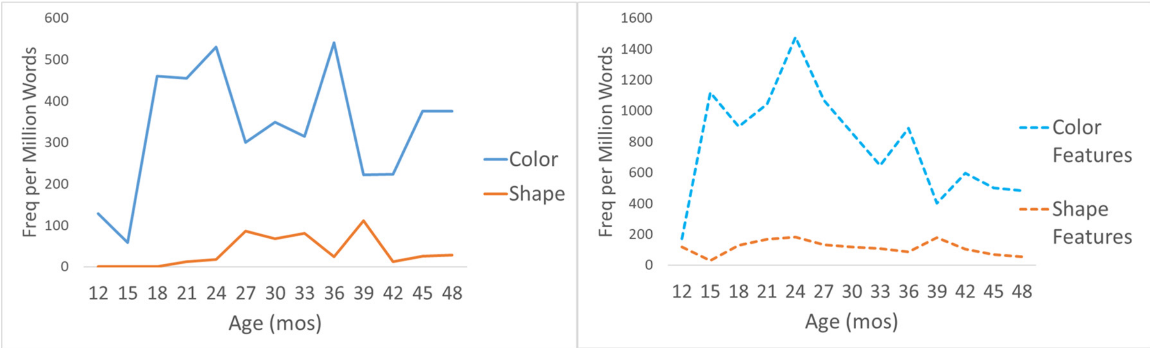


**Fig. 2.** Left: Frequency of labels "shape" and "color" from CHILDES database. Right: Frequency of specific color feature labels ("red", "blue", "green", "yellow", "orange", "purple") and specific shape feature labels ("circle", "square", "star", "triangle", "heart", "rectangle") also from the CHILDES database.

told, "We're all done playing that game, now we are going to play a new game." Rules were then administered as described above based on the condition. Children were never given direct feedback regarding their sorting behavior. However, if a child sorted incorrectly, they were reminded of the rules of the game they were supposed to play in the same manner described above based on the condition. Some studies repeat the rules before every trial (e.g., Kharitonova, Chien, Colunga, & Munakata, 2009; Müller, Dick, Gela, Overton, & Zelazo, 2006; Zelazo et al., 2003) whereas other studies only repeat the rules after incorrectly performed trials (e.g., Buss & Spencer, 2012; Buss & Spencer, 2014; Kloo & Perner, 2005). Children typically perform in an all-or-none fashion during the post-switch phase and it is not common that a child will start sorting correctly and then revert to perseverative responses (e.g., van Bers, Visser, van Schijndel, Mandell, & Raijmakers, 2011); thus, rules were only repeated after incorrectly sorted trials to provide those children with reminders of the rules they were supposed to be using.

## 3. Results

All children included in the final analyses sorted all five cards correctly during the pre-switch phase. Children were categorized as passing if they sorted at least four trials correctly during the post-switch phase and as failing otherwise. In our sample, all children either sorted 5 or 0 cards correctly during the post-switch phase except for one child who sorted 4 cards correctly (incorrectly on the first post-switch trial in the Shape-Color Dim Labels condition). Table 2 shows the number of 4-year-olds who correctly switched rules or perseverated as a function of task dimension and instruction type. Given that the data are binary (i.e., pass/fail) and our independent variables are categorical, we conducted binary logistic regression and chi-squared tests. Binary logistic regression using forward selection tested whether main effects of dimension order or instruction type, along with an interaction of factors accounted for patterns of performance. This analysis yielded a regression equation ($-2$ log likelihood = 55.129, Nagelkerke $R^2$ = .267) that indicated the task order and the interaction between task order and instruction type (B= -2.43, Wald (1) = 8.08, $p$ = 0.004, Exp(B)

**Table 2**
Number of children who switched and perseverated as a function of rule type and dimension.

| | Post-switch Dimension | | | |
|---|---|---|---|---|
| | Color | | Shape | |
| | Standard | Dim Label | Standard | Dim Label |
| Switch | 9 | 8 | 8 | 2 |
| Perseverate | 3 | 4 | 4 | 10 |

= 0.088, upper C.I. for Exp(B) = .470, lower C.I. for Exp(B) = .016) significantly influenced model fit. To follow-up on the interaction effect, we compared rates of switching based on instruction type within each task-order. A chi-squared test using linear-by-linear association (Campbell, 2007) revealed that children switched equally well when color was the post-switch dimension regardless of instruction type, $\chi^2(1) = 0.193$, $p = .660$. However, when shape was the post-switch dimension, 4-year-olds perseverated at a significantly higher rate when only dimensional labels were provided in the instructions, $\chi^2(1) = 5.914$, $p = .015$, $\phi = 0.507$. The phi value for this test suggests that this is a large effect size.

## 4. Discussion

In the present study, we manipulated the labels used in the instructions of the DCCS task with 4-year-olds. Results showed that these older children performed equally well between instruction types when color was the post-switch dimension. However, when switching to the shape dimension, 4-year-olds perseverated at a significantly higher rate when only dimensional labels were provided compared to when both dimension and feature labels were provided. Interestingly, the only child to sort incorrectly during the pre-switch phase was given the dimensional label instructions with shape as the pre-switch dimension.

These results add to a growing body of findings suggesting that children's understanding of labels for visual features and dimensions play a central role in children's cognitive flexibility (Schonberg et al., 2018). Based on the CHILDES database, children have less exposure to the label "shape". Further, children were less able to use the label "shape" alone when switching rules. Together, this suggests that differences in label-learning influences children's ability to use labels to guide their behavior. Although various lines of work have manipulated aspects of the DCCS task to make switching easier for 3-year-olds, this is the first demonstration of manipulations to the standard DCCS task which impair the performance of older children. Kirkham, Cruess, and Diamond (2003) also reported an examination of switching with 4-year-olds. In this version of the task they had children sort the test cards face-up which increased the representational strength of the pre-switch dimension. In their results, 57 % of 4-year-olds switched compared to 92 % of children in the standard condition. In our study, however, only 17 % of 4-year-olds correctly switched rules when shape was the post-switch dimension and only dimensional labels were provided in the instructions.

We interpret these results as indicating that label learning is a central aspect of the development of flexible dimensional attention and, further, that children learn labels for shape and color dimensions differently. There could, however, be a common cause for why shape is both talked about less frequently and why children have greater difficulty switching to this dimension. Specifically, it could be that shape features are processed differently in the brain. Research using fMRI with adult participants has revealed distinct areas of temporal cortex that are specialized for processing shape in lateral occipital complex (e.g., Kourtzi & Kanwisher, 2000) or color information in ventral occipital cortex and fusiform gyrus (e.g., Beauchamp, Haxby, Jennings, & DeYoe, 1999; Simmons et al., 2007). Color populations of neurons typically respond based on the preferred tuning to hues, whereas shape populations respond to more abstract dimensionality of shape contours that can be expressed as components in Fourier space (Drucker & Aguirre, 2009). Moreover, studies that have attempted to manipulate visual salience of features have had differing levels of success with the shape and color dimensions. For example, Fisher (2011) manipulated similarity of color features to make these features less salient than shape. However, attempts to use shapes that were metrically similar to make shapes less salient than colors were not successful. Additionally, there have been differential effects of pre-exposure to visual dimensions and subsequent ability to shift attention to the shape and color dimensions (Perone et al., 2015, 2017). In the explanation offered by the DNF model, differences in processing of these dimensions arises from a compressed representational space. That is, inputs for specific features are allocated less neural space which increases inhibitory competition among representations. Thus, it remains possible that the complexity of representing shape information also contributes to children's difficulty in attending to shape information above and beyond limitations in children's exposure to labels for the shape dimension.

It is noteworthy that evidence from other lines of research suggest that there are persistent differences in processing shape and color dimensions throughout adulthood with slightly mixed results. Erb, Moher, Song, and Sobel (2017) measured the trajectory of reaching as children and adults sorted cards by shape and color. Participants showed significantly larger curvature when switching to shape compared to switching to color, indicating greater uncertainty or competition when sorting by shape. Diamond and Kirkham (2005) also observed longer reaction times when adults sorted by color in the DCCS. Ellefson, Shapiro, and Chater (2006) showed a pattern of differences in performance when shape or color is a relevant sorting dimension with 7- to 8-year-old children and adults. Specifically, reaction time were equivalent between shape and color during switch trials, but reaction times were faster for color trials relative to shape trials during repeat trials. Although reaction time was not recorded in the current study, future research could examine this in relation to the emergence of correct switching behavior. In general, correctly switching likely takes more cognitive work than perseverating; thus, it could be expected that reaction times would be longer during the post-switch phase for children who switch rules compared to children who perseverate. It might also be the case that responses also take longer when switching to shape compared to switching to color.

Various theories have suggested that language is a central aspect of the development of cognitive flexibility. Similar to CCC theory, Cragg and Nation (2010) suggest that language provide the means by which children can access task set representations. Deak (2003), on the other hand, suggests that, experience with the symbol mapping system provided by language facilitates the ability to think flexibly about objects in the world. The proposal here, however, is more specific. The details of the labels being learned and how those labels are used to instruct or think through a task are central to the ability to flexibly shift dimensional attention. The results of this study are consistent with CCC theory (Jacques & Zelazo, 2005; Zelazo, 2004) if we assume that more specific labels in the instructions increases the likelihood of reflection. However, it is not clear how this theory would account for differences between the shape and color dimensions.

The central proposal in our interpretation of the results presented here is that learning associations between labels and aspects of the visual world is a key mechanism which gives rise to flexible dimensional attention. We ground this explanation in a dynamic neural field model which has been used to explain the development of performance in the DCCS task (Buss & Spencer, 2014, 2018; Perone et al., 2015, 2017). This model implements a dimensional attention mechanism that arises from the modulation of neural populations tuned to visual feature dimensions, such as shape and color. This modulation is, in turn, driven through the activation of labels for visual features and dimensions. For example, when the neural representation for the label "color" is activated, the processing of color features becomes enhanced, and the model displays rule-like sorting behavior in the context of the DCCS task. During the pre-switch phase, however, the model learns feature-space associations based on where the features on the test cards were sorted. These memory traces create a habit for sorting by the pre-switch dimension. With weak coupling between labels and features, the model only weakly modulates activation of the associated visual dimension and perseverates based on its habits. With stronger associations between labels and visual features, the model will strongly modulate activation of the relevant visual dimension and will overcome its habits to correctly switch rules. In this way, switching is an emergent phenomenon that arises through strengthening associations between verbal labels and visual features and dimensions.

This model has simulated the developmental transition in performance across a wide array of variations of the DCCS task through increasing the strength of connectivity between label representations and visual feature representations. This model has also been applied to explain the manipulations to attentional saliency and pre-exposure to visual dimensions. In the model, the impact of these manipulations arise from the relative proximity of inputs for the shape or color features, suggesting that shapes have a more condensed representational space compared to colors (Buss & Spencer, 2014; Perone et al., 2015, 2017). Although this model has been developed in the context of this specific task, we propose that this is a general purpose mechanism that can adapt not only to changes in the properties of the DCCS task, but also generalizes to other tasks that involve attending to visual dimensions. In a recent paper, it was demonstrated that the attention mechanism which gives rise to flexibility in the DCCS task also gives rise to selective attention in a free-classification task as well as stable attention in a dimensional priming task (Buss & Kerr-German, 2019).

There are limitations to this study that warrant consideration. First, although we interpreted our results as being reflective of children's understanding of labels, we did not independently test children's comprehension of these labels. Second, we had a relatively limited sample size. Future work could aim to replicate these results with a larger sample of children. Thus, future work can include larger samples of children and measures of label comprehension outside of the context of the DCCS task. Lastly, the DNF model proposes that learning labels trains a network of frontal and posterior cortical regions interact to give rise to dimensional attention. However, it is not clear how manipulation to the types of labels impacts neural activation. Thus, future work can also explore the neural basis of dimensional label learning and how manipulations to labels in the DCCS task impacts neural activation during this task.

In summary, the results reported here suggest that the dimensional label for the shape dimension is more weakly coupled to visual feature representations of shape in 4-year-olds. Moreover, this work points to an exciting possibility that a learning mechanism may underlie the development of EF as measured in the DCCS task. Specifically, it is possible that as children learn labels for visual features, the connectivity between the frontal and posterior regions of cortex strengthens, which in turn allows representations in frontal cortex to more strongly modulate processing in posterior cortex (Buss & Spencer, 2018). Future work should further explore the role of label learning in the context of the emergence of attention to visual features and dimensions.

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