# THE DEVELOPMENT OF EXECUTIVE FUNCTION IN EARLY CHILDHOOD

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## Abstract:

According to the Cognitive Complexity and Control (CCC) theory, the development of executive function can be understood in terms of age-related increases in the maximum complexity of the rules children can formulate and use when solving problems. This *Monograph* describes four studies (9 experiments) designed to test hypotheses derived from the CCC theory and from alternative theoretical perspectives on the development of executive function (memory accounts, inhibition accounts, and redescription accounts). Each study employed a version of the Dimensional Change Card Sort (DCCS), in which children are required first to sort cards by one pair of rules (e.g., color rules: "If red then here, if blue then there"), and then sort the same cards by another, incompatible pair of rules (e.g., shape rules). Study 1 found that although most 3- to 4-year-olds failed the standard version of this task (i.e., they perseverated on the preswitch rules during the postswitch phase), they usually performed well when they were required to use four rules (including bidimensional rules) and those rules were not in conflict (i.e., they did not require children to respond in two different ways to the same test card). These findings indicate that children's perseveration cannot be attributed in a straightforward fashion to limitations in children's memory capacity. Study 2 examined the circumstances in which children can use conflicting rules. Three experiments demonstrated effects of rule dimensionality (uni- vs. bidimensional rules) but no effects of stimulus characteristics (1 vs. 2 test cards; spatially integrated vs. separated stimuli). Taken together, these studies suggest that conflict among rules is a key determinant of difficulty, but that conflict interacts with dimensionality.

Study 3 examined what types of conflict pose problems for 3- to 4-yearolds by comparing performance on standard, Partial Change, and Total Change versions of the DCCS. Results revealed effects of conflict at the level of specific rules (e.g., "If red, then there"), rather than specific stimulus configurations or dimensions per se, indicating that activation of the preswitch rules persists into the postswitch phase.

Study 4 examined whether negative priming also contributes to difficulty on the DCCS. Two experiments suggested that the active selection of preswitch rules against a competing alternative results in the lasting suppression of the alternative.

Taken together, the results of these studies provide the basis for a revision of the CCC theory (CCC-r) that specifies more clearly the circumstances in which children will have difficulty using rules at various levels of complexity, provides a more detailed account of how to determine the complexity of rules required in a task, takes account of both the activation and inhibition of rules as a function of experience, and highlights the importance of taking intentionality seriously in the study of executive function.

**Article:**

# I. THE DEVELOPMENT OF EXECUTIVE FUNCTION

## *THE "FUNCTION" OF EXECUTIVE FUNCTION*

Executive function is a popular topic in contemporary research, but definitions of executive function differ widely. One approach treats executive function as a higher order cognitive mechanism or ability. Denckla and Reiss (1997), for example, followed an influential line of authors (e.g., Baddeley, 1996; Norman & Shallice, 1986) when they suggested that *"Executive function* refers to a cognitive module consisting of effector output elements involving inhibition, working memory, and organisational strategies necessary to prepare a response" (p. 283, italics in original). Unfortunately, this approach essentially hypostatizes homuncular abilities and leaves unanswered questions concerning how executive function is accomplished (Parkin, 1998; Zelazo & Muller, 2002b).

Another approach to studying executive function involves devising comprehensive neuropsychological batteries for children and using factor analysis in an attempt to reveal the underlying structure of executive function (see Zelazo & Muller, 2002b, for a review). These studies generally reveal three or four factors a result that has been taken to suggest that there are dissociable dimensions of executive function, consistent with efforts to "fractionate" executive function based on lesion studies in nonhuman animals (e.g., Robbins, 1996). This approach can be used to generate hypotheses about processes involved in executive function that can then be tested experimentally. However, the results of factor-analytic studies are potentially misleading: Providing labels for factors may lead to the impression that researchers actually understand the cognitive processes underlying performance on various tasks, but this is rarely the case. Note that the same tasks are often clustered in different ways, and characterized by different labels. Thus, for example, the Wisconsin Card Sorting Test is considered by Levin et al. (199 1) to be part of a "Perseveration/ Disinhibition" factor but is considered by Pennington (1997) to be part of a "Set Shifting or Cognitive Flexibility" factor. In the absence of an understanding of underlying cognitive processes, it is unclear what this approach can tell us about the structure of executive function. For example, does set shifting rely on inhibitory control or is inhibition a consequence of set shifting? It is also impossible to determine the extent to which correlations among tasks are due to shared method variance or are influenced by differential sensitivity to individual differences at different ages.

Another approach, following Luria (e.g., 1973), views executive function as a *functional* construct that makes reference to (but cannot be equated with) the psychological processes involved in goal-directed problem solving (Zelazo, Carter, Reznick, & Frye, 1997). Like all functions, executive function can be defined in terms of what it accomplishes. The various subfunctions of problem solving, from initially representing a problem to eventually evaluating the adequacy of an attempted solution, can all be seen as contributing to this outcome (see Figure 1). For example, when searching for a hidden toy, children need to represent the problem, select a plan for action, actually execute the plan, and then evaluate the outcome. Treating executive function as a functional construct does not *explain* executive function (it remains an explanandum), but it does lay the groundwork for an explanation by facilitating the formulation of specific hypotheses regarding the role of basic cognitive processes (e.g., attention, memory, action monitoring) in different aspects of executive function. Moreover, this approach (a) suggests relatively well-defined measures of executive function (e.g., measures of rule use for which problem representation, planning, and evaluation are not required), (b) clarifies the way in which diverse aspects of executive function work together, and (c) avoids conceptualizing executive function as a homuncular ability (e.g., as a Supervisory Attentional System; Shallice, 1988).

## *INFLEXIBILITY AND PROBLEM SOLVING: A DEVELOPMENTAL PERSPECTIVE*

Inflexibility has been recognized as an important impediment to problem solving at least since the 1940s, when psychologists working in the Gestalt tradition made problem solving a central topic of research. In Dunker's (1945) classic experiments on functional fixedness, for example, participants rigidly represented objects only in terms of their canonical functions. Another set of classic studies (Luchins, 1942) revealed that people frequently persisted in applying a particular problem-solving strategy (for adding and subtracting the contents of water jars) even when it was no longer efficient to do so.

In contemporary research, inflexibility is often studied under the rubric of perseveration, which has been defined as the repeated production of an action or thought in the absence of an appropriate stimulus (e.g., Hauser, 1999; Sandson & Albert, 1984, 1987; Werner, 1946). Perseveration is a hallmark of various types of psychopathology and brain injury, including damage to prefrontal cortex. For example, when asked to draw a circle, patients with prefrontal cortical damage sometimes draw dozens of circles, as if they cannot inhibit a motor program once it has been activated (Luria, Pribram, & Homskaya, 1964).

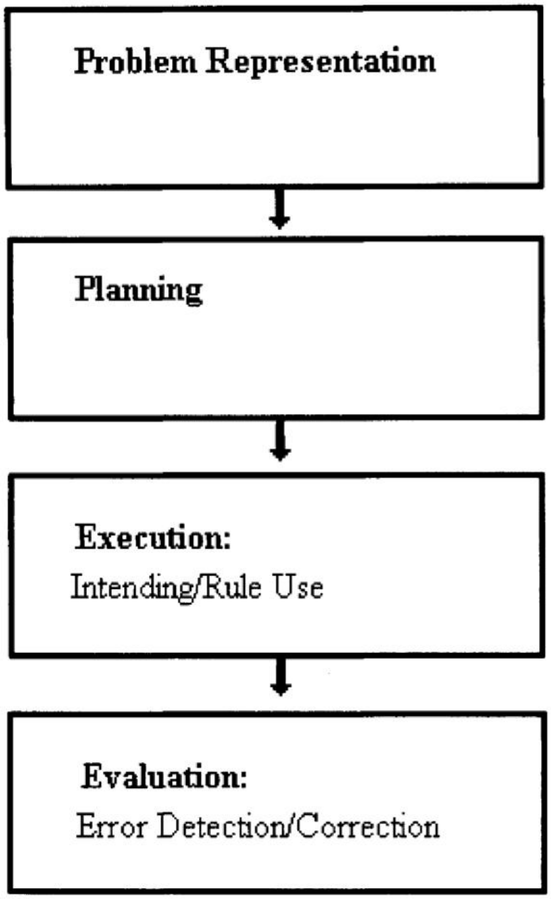

FIGURE 1.—A problem-solving framework for understanding executive function as a functional construct. (Reprinted with permission from P. D. Zelazo, A. S. Carter, J. S. Reznick, & D. Frye [1997]. Early development of executive function: A problem solving approach. *Review of General Psychology*, **1**, 198–226).

Patients with prefrontal cortical damage also perseverate on the Wisconsin Card Sorting Test. In this test (Grant & Berg, 1948), participants are presented with four target cards that differ on three dimensions (number, color, and shape), and asked to sort a series of test cards that match different target cards on different dimensions. Participants must discover the sorting rule by trial and error, and, after a certain number of consecutive correct responses, the sorting rule is changed. Patients with prefrontal damage often continue to sort according to the old rule, despite feedback indicating that the rule has changed (e.g., Milner, 1963; Stuss et al., 2000; but see Anderson, Damasio, Jones, & Tranel, 1991).

As these examples may suggest, inflexibility can occur at the level of representations (e.g., problem-solving sets), or at the level of responses (e.g., motor programs), or both (Goldberg & Bilder, 1987; Zelazo, Reznick, & Pinon, 1995). When performance fails because of difficulty inhibiting an incorrect problem representation and establishing a correct one, as in Dunker's (1945) study, this might be characterized as an error based on *representational inflexibility.* Representational inflexibility can be contrasted with *failures of response control,* which occur when one fails to inhibit an incorrect response *despite* establishing and maintaining a correct intention to act.

Developmental research indicates that inflexibility occurs in different contexts at different ages. One of the most widely studied examples of infant perseveration is the A-not-B error. As originally described by Piaget (1954), the A-not-B error occurs when infants (typically between of 8 and 10 months of age) successfully retrieve an object at one location (location A), and are then allowed to search for it when it is conspicuously hidden at another location (location B). Remarkably, infants at this age often search at the first location despite having last seen the object at location B. The basic finding has proved to be robust (for a recent meta-analysis, see Marcovitch & Zelazo, 1999). Whereas Piaget attributed the error to an immature understanding of the object concept, a popular contemporary interpretation of the error is that infants have difficulty using a representation of an object's location to override a prepotent response (e.g., Diamond, 1991)—that is, they exhibit a failure of executive function, or more precisely, a failure of response control.

Studies with older infants and with preschoolers indicate that the development of representational flexibility and response control follows a protracted course. For example, DeLoache (e.g., 1987) observed changes between 2.5 and 3 years of age in children's ability to use a three-dimensional model of a room to guide search for an object hidden in the room itself. In particular, DeLoache (1999; Sharon & DeLoache, 2003; see also O'Sullivan, Mitchell, & Daehler, 2001) observed that 2.5-year-olds often committed perseverative errors, searching for the object at the location where it had been found on a previous trial. Three-year-olds, in contrast, searched successfully. DeLoache (1995) suggested that the age-related changes observed in this task reflect an increase in representational flexibility: 2.5-year-olds persist in thinking of the model as a three-dimensional object (e.g., a toy room) rather than thinking of it in terms of the thing it represents (viz., the room).

There is also a large body of research indicating that 3- to 4-year-olds have difficulty switching between incompatible perspectives on a single object—they perseverate in representing objects in a particular way even when it is no longer appropriate to do so. In tasks assessing understanding of appearance and reality, for example, children are shown a misleading object such as a sponge painted to look like a rock and asked about its appearance ("What does it look like?") and its true nature or function ("What is it really?"). Three-year-olds are much more likely than 5-yearolds to give the same answer to both questions (Flavell , Green, & Flavell , 1986).

Further evidence of representational inflexibility in 3- to 4-year-olds has been obtained in research on numerous topics, including understanding false beliefs (see Wellman, Cross, & Watson, 2001, for a meta-analysis), reasoning about physical causality (e.g., das Gupta & Bryant, 1989; Frye, Zelazo, Brooks, & Samuels, 1996), moral reasoning (e.g., Zelazo, Helwig, & Lau, 1996), reasoning about delayed representations (e.g., Povinelli, Landau, & Perilloux, 1996; Zelazo, Sommerville, & Nichols, 1999), predicting outcomes based on past experience (Kessen & Kessen, 1961), inferring word meanings (Deck, 2000), and generating multiple labels for a single object (e.g., Doherty & Perner, 1998; Markman, 1989; but see Deal( & Maratsos, 1998), among other topics. In each case, younger preschoolers seem to have difficulty switching between conflicting representations; they tend to perseverate on a salient representation, and there are age-related increases in flexibility between about 3 and 5 years of age. How best to interpret these increases in flexibility is currently a matter of debate, but there is a growing consensus that these increases may be usefully studied under the rubric of executive function (e.g., Carlson & Moses, 2001; Deak, 2000; Frye, 1999; Halford, Wilson, & Phillips, 1998; Kirkham, Cruess, & Diamond, in press; Munakata & Yerys, 2001; Perner, Stummer, & Lang, 1999; Zelazo, 1999; Zelazo & Frye, 1997; Zelazo & Muller, 2002b) .

## The Dimensional Change Card Sort

One widely used measure of executive function in early childhood is the Dimensional Change Card Sort (DCCS; see Figure 2; Frye, Zelazo, & Palfai, 1995; Zelazo, Frye, & Rapus, 1996). In this task, children are shown two target cards (e.g., a blue rabbit and a red boat) that vary along two dimensions (e.g., color and shape), and they are asked to sort a series of bivalent test cards (e.g., red rabbits and blue boats), first according to one dimension (e.g., color, for which they are told, "If it's blue it goes here; if it's red it goes there.") and then according to the other (e.g., shape, for which they are told, "If it's a rabbit it goes here; if it's a boat it goes there."). Regardless of which dimension is presented first, 3- to 4-year-olds typically perseverate by sorting cards by the first dimension. Moreover, they do this despite being told the new rules on every trial, despite having sorted cards by the new dimension on other occasions, and despite correctly answering questions about the postswitch rules (e.g., "Where do the flowers go in the shape game?"). In other words, 3- to 4-year-olds typically exhibit inflexibility on this task. In contrast, by 5 years of age, children typically perform well.

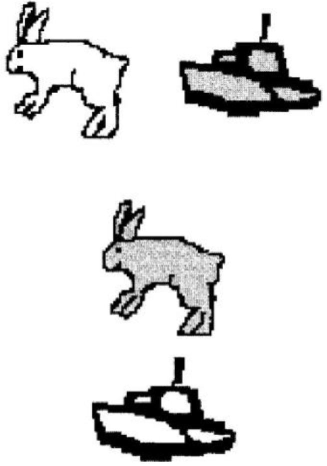

FIGURE 2.—Sample target cards (top row) and test cards in the standard version of the Dimensional Change Card Sort (DCCS). Children are first asked to sort test cards by one dimension (e.g., color: "If it's blue it goes here; if it's red it goes there.") and then by the other (e.g., shape). Note: white indicates blue; grey indicates red.

Children's performance on the DCCS is correlated with their performance on a variety of measures of executive function—even after controlling for age and verbal ability (Carlson & Moses, 2001; Lang & Perner, 2002), and age-related changes in performance on the DCCS indicate that executive function develops rapidly during the preschool years. However, the cognitive processes underlying executive function in children (and by implication, what develops) remain unclear. This *Monograph* describes a series of studies in which different features of the DCCS are manipulated experimentally in order to elucidate these processes. By determining the circumstances in which children are susceptible to inflexibility on the DCCS, it should be possible to describe the development of executive function more precisely and reveal the way in which basic cognitive processes are orchestrated in order to fulfill the higher order function of problem solving. Four studies (including 9 experiments) are described. These studies are interpreted in the context of four leading approaches to the study of executive function and its development, including complexity theories, memory accounts, accounts emphasizing inhibitory control, and accounts emphasizing the redescription of representations. These theories will now be reviewed in turn and described with reference to the assessment of executive function in young children.

## *COMPLEXITY THEORIES*

Several theories of executive function and its development emphasize the importance of complexity. The importance of complexity has long been recognized in the developmental literature (e.g., Inhelder & Piaget, 1964; Vygotsky, 1962) , and it is also starting to be appreciated in the neuroscience literature (Dias, Robbins, & Roberts, 1996; Stuss et al., 1999; Wise, Murray, & Gerfen, 1996). One influential complexity theory, proposed by Halford and colleagues (1998), suggests that as children develop they are able to understand increasingly complex relations among objects. Halford et al. defined complexity in terms of the number of relations that can be processed in parallel. According to these authors, each argument of a relation, such as "X" in the relation "X is greater than Y," represents a source of variation, or a dimension. Processing a single relation (i.e., a "unary" relation) is less complex than processing a binary relation, which is less complex than processing a ternary relation, and so forth. Although increases in relational complexity are related to experience rather than age on this account, Halford and colleagues have found that unary relations are processed at a median age of 1 year, binary relations at 2 years, ternary relations at 5 years, and quaternary relations at 11 years.

To date, Halford and colleagues (1998) have focused on explaining age-related increases in *understanding,* as opposed to executive function. However, the relational complexity framework has recently been extended to the study of prefrontal cortical function by Holyoak and colleagues (Robin & Holyoak, 1995; Waltz et al., 1999), who argued that relational complexity theory provides a useful framework for characterizing the deficits associated with prefrontal cortical damage. Moreover, Kroger et al. (2002) have recently shown using fMRI that regions of left prefrontal cortex appear to be selectively activated when solving nonverbal problems high in relational complexity.

The Cognitive Complexity and Control Theory (CCC) theory (e.g., Frye, Zelazo, & Burack, 1998; Zelazo & Frye, 1998) also emphasizes the importance of complexity, and this theory is specifically intended to be a theory of executive function and its development. As will be explained, this approach defines complexity in terms of the *hierarchical structure of children's rule systems,* rather than the number of relations that can be processed in parallel. According to this theory, age-related changes in executive function—considered as a functional constructare due to age-related changes in the maximum complexity of the rules that children can formulate and use when solving problems. These age-related changes in maximum rule complexity are, in turn, made possible by age-related increases in the degree to which children can reflect on the rules they represent.

On this account, rules are formulated in an ad hoc fashion in potentially silent self-directed speech. These rules link antecedent conditions to consequences, as when we tell ourselves, "If I see a mailbox, then I need to mail this letter." When children reflect on the rules they represent, they are able to consider them in contradistinction to other rules and embed them under higher order rules, in the same way that we might say, "If it is before 5 p.m., then if I see a mailbox, then I need to mail this letter, otherwise, I'll have to go directly to the post office." In this example, a simple conditional statement regarding the mailbox is made dependent on the satisfaction of yet another condition (namely, the time).

The tree diagram in Figure 3 illustrates the way in which hierarchies of rules can be formed the way in which one rule can be embedded under another higher order rule and controlled by it. Rule A, which indicates that consequent 1 (c1) should follow antecedent 1 (a1), is incompatible with rule C, which connects al to c2. Rule A is embedded under, and controlled by, a higher order rule (rule E) that can be used to select rules A and B, as opposed to rules C and D. This higher order rule makes reference to setting conditions (s1 and s2; e.g., Reese, 1989) that condition the selection of lower order rules. Notice that in order to formulate higher order rules and deliberate between rules C and D, on the one hand, and rules A and B, on the other, children need to be aware of the fact that they know both pairs of lower order rules.

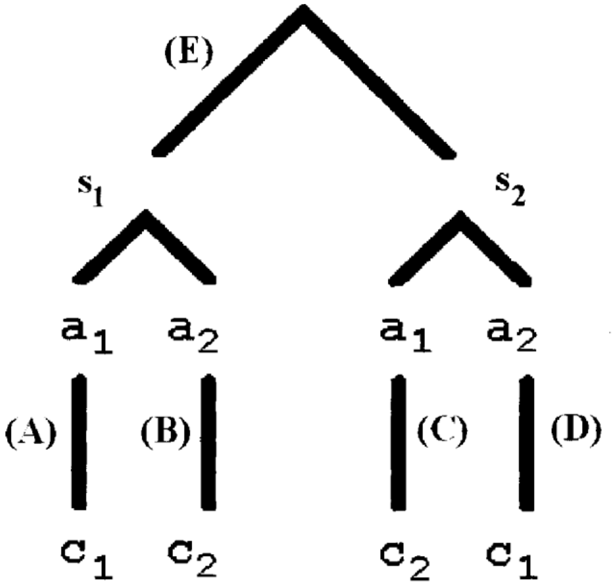

FIGURE 3.—Hierarchical tree structure depicting formal relations among rules (adapted from Frye, Zelazo, & Palfai, 1995). Note: $s_1$ and $s_2$ = setting conditions; $a_1$ and $a_2$ = antecedent conditions; $c_1$ and $c_2$ = consequences.

Thus, increases in reflection on lower order rules are logically required for increases in embedding to occur. However, it is the increases in embedding that provide the metric for measuring the degree of complexity of the entire rule system that needs to be kept in mind (i.e., in working memory) in order to perform particular tasks. That is, complexity is measured as the number of degrees of embedding in the rule systems that children formulate when solving a particular problem. More complex rule systems permit the more flexible selection of certain rules for acting when multiple conflicting rules are possible. This allows for flexible responding, as opposed to perseveration; it allows for cognitive control, as opposed to stimulus control.

According to CCC theory, several age-related changes in executive function occur during childhood, and for each developmental transition, a general process is recapitulated. Specifically, a rule system at a particular level of complexity is acquired, and this rule system permits children to exercise a new degree of control over their reasoning and their behavior. However, the use of this rule system is subject to limitations that cannot be overcome until yet another level of complexity is achieved. In particular, the rule system cannot be selected when there is a salient, conflicting rule system. Consequently, according to the CCC theory, abulic dissociations dissociations between having knowledge and actually using that knowledge—occur until incompatible pieces of knowledge are integrated into a single, more complex rule system via their subordination to a new higher order rule. On this account, reflection and higher order rule use are the primary psychological functions accomplished by systems involving prefrontal cortex (although different regions of prefrontal cortex are associated with reflection on different kinds of rules; e.g., abstract vs. motivationally significant; see Zelazo & Muller, 2002b).

In terms of the DCCS, rule A might be, "If it's red, put it here," and rule B might be, "If it's blue, put it there" (see Figure 3). To sort flexibly by color, children would need to reflect on rule A and contrast it with rule B. According to the CCC theory, 2-year-olds typically only represent a single rule at a time (e.g., "If red ... here"), and hence have difficulty even on the preswitch phase of the DCCS (they perseverate on one of the rules). By 3 years, children can easily consider a pair of rules simultaneously (e.g., "If red ... here" vs. "if blue ... there"). Indeed, on this account, 3- to 4-yearolds know both the first pair of rules (e.g., "If red ... here" vs. "if blue ... there") and the second pair of rules (e.g., "If rabbit ... here" vs. "if boat ... there"), and they can use either pair of rules if presented alone or in separate contexts, but because they typically fail to reflect on these rule pairs in relation to one another, the two pairs of rules remain unintegrated (see Figure 4). As a result, the particular pair of rules that underlies responding in a single context is determined by relatively local considerations, such as the way in which the question is asked or the way in which they have approached the situation in the past. In other words, they can exhibit knowledge of one pair of rules in one context, and knowledge of the other pair of rules in a different context, but they fail to recognize the incompatibility between rule pairs; therefore, the particular rule pair they end up selecting and using to sort test cards may be determined associatively rather than deliberately. In contrast, by 4 years of age, children typically represent a higher order rule (such as E) that allows them to integrate incompatible rules into a single rule system and appreciate that different rule pairs apply under different setting conditions. They can then use this higher order rule deliberately to select between two different pairs of rules ("If we're playing by color, then if red ... here, if blue ... there, but if we're playing by shape, then if rabbit ... here, if flower ... there"), and hence, to switch flexibly in response to situational demands.

On this account, then, 3- to 4-year-olds' difficulty with the DCCS might be described as a kind of representational inflexibility: During the postswitch phase, 3- to 4-year-olds persistently select the preswitch pair of rules. In terms of the problem-solving framework, performance breaks down during problem representation; in the absence of a change in context, children actually try to sort according to the preswitch dimension (Frye & Zelazo, 2003).

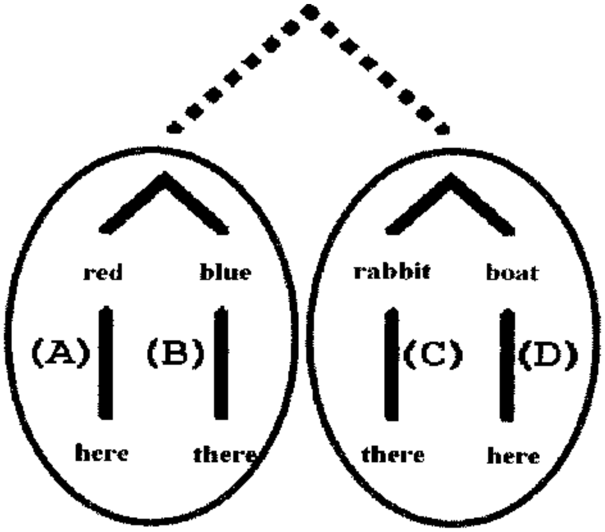

FIGURE 4.—Unintegrated rule systems, in the absence of a higher order rule. Note: $a_1$ and $a_2$ = antecedent conditions; $c_1$ and $c_2$ = consequences.

Although CCC theory is similar in many respects to Halford's relational complexity theory, Halford and colleagues (Halford, Andrews, Dalton, Boag, & Zielinski, 2002) correctly note that an increase in the number of dimensions processed simultaneously is not the same as the creation of a hierarchical (if-if-then) relation between dimensions. The difference has implications for psychological processing. For example, CCC theory makes a distinction between the function of switching between dimensions, as in the DCCS, and the more difficult function of making *simultaneous* judgments according to two dimensions, as in matrix classification tasks (Frye et al., 1995, Exp. 3). According to CCC theory, the former function requires a hierarchical relation but does not require simultaneous consideration of two dimensions. Relational complexity does not distinguish between these functions because both are believed to involve the processing of two relations.

CCC theory and relational complexity theory also postulate different mechanisms for the construction of increasingly complex knowledge structures (see Zelazo & Muller, 2002a, for further discussion of the differences between these approaches). According to CCC theory, a functional process of reflection (mediated by reprocessing of information in prefrontal cortex) is required in order to make a deliberate decision to use the postswitch rules in the DCCS, and it is largely through age-related changes in reflection that cognitive development unfolds. In contrast, according to relational complexity theory, age-related changes in complexity are attributed to increases in effective processing capacity brought about by experience in particular domains.

## *MEMORY ACCOUNTS OF THE DEVELOPMENT OF EXECUTIVE FUNCTION*

An alternative approach to study of the development of executive function emphasizes the importance of memory, especially working memory. The term "working memory" is used in different senses by different authors but is most often taken to refer to the simultaneous manipulation and maintenance of a representation so that this representation can guide responding (e.g., Baddeley, 1986; Daneman & Merikle, 1996). As Roberts and Pennington (1996, p. 109) put it, "Working memory is used not only for holding information online, but also for using that information along with contextual specifics to generate upcoming action." Consequently, measures of working memory typically require both processing and storage (Daneman & Merikle, 1996). Lesion studies (e.g., Goldman-Rakic, 1987; Jacobson, 1936) as well as single-unit recording studies (e.g., Fuster, 1995) have demonstrated that the short-term storage of trial-unique information depends importantly on prefrontal cortex. Research with human participants has also implicated prefrontal cortex in the manipulation of information in working memory (e.g., Petrides, 2000).

An influential account of both the processing and storage demands of working memory has been provided by Baddeley (1996, 1998). According to Baddeley, working memory comprises three components: a central executive, a phonological loop, and a visuo-spatial scratchpad. The latter two components are slave systems specialized for the processing and storage of limited amounts of information within specific domains: whereas the phonological loop operates on sound-based information, the visuo-spatial scratchpad operates on spatial and visual information. In contrast to these slave systems, the central executive is capable of coordinating and integrating information of either type.

In terms of this account, the capacity of the phonological loop can be assessed by memory span tests such as digit span and other serial recall tests. These tests show that memory span (a measure of the maximum number of unrelated verbal items that can be remembered in correct sequence) increases from two to three items at 4 years of age to about six items at 12 years (e.g., Cowan, 2001; see Gathercole, 1998, for a review). The span of the visuospatial scratchpad is measured in an analogous fashion (e.g., using a pattern span task; Gathercole, 1998) and shows similar age-related improvements in childhood.

In contrast to these relatively simple span tasks, which mainly measure storage, the capacity of the central executive is assessed by relatively complex working memory tasks such as reading and listening span. In these tasks, children need to process incoming information (either reading or listening to sentences) while remembering old information (e.g., the final words of the preceding sentences). Another complex measure of the central executive is backward digit span, in which children are asked to remember a list of digits and repeat them in the reverse order. Performance on these tasks also improves with age (Gathercole, 1998).

Several theoretical accounts have suggested that the development of executive function and behavior related to executive function is made possible by the growth of short-term or working memory (e.g., Case, 1992, 1995; Demetriou, Christou, Spanoudis, & Plastidou, 2002; Gordon & Olson, 1998; Olson, 1993; Pascual-Leone, 1970). It is possible that the growth of memory, perhaps particularly of the phonological loop (which would be required for rehearsing verbal rules), constrains the number of rules that children can use in the DCCS. For example, perhaps 3- to 4-year-olds can only hold two rules (i.e., a preswitch pair of rules) in mind (e.g., Gordon & Olson, 1998), and consequently fail the postswitch phase.

A memory account of the development of executive function has also been suggested by Morton and Munakata (2002), who presented a connectionist model of children's performance on the DCCS. Morton and Munakata distinguished between *active memory representations* and *latent memory traces.* Active memory representations take the form of sustained activity in the prefrontal cortex, whereas latent memory traces are formed in more posterior cortex when processing a stimulus brings about a change in the subsequent processing of that stimulus. Because latent traces are instantiated implicitly as changes in the strength of connections between units, they are not accessible to other brain regions, although they influence the processing of these other regions via changes in the activation of subsequent stimuli. In contrast, active representations are accessible to other brain regions, and they can influence processing in these areas even if the stimulus is no longer perceptually available.

The architecture of Morton and Munakata's (2002) network model of the DCCS consists of three input layers ("Visual Features, Verbal Features, and Rule") for representing test cards, instructions, and the relevant dimension; an internal representation layer (i.e., a layer of hidden units); a prefrontal cortex layer that corresponds to active memory of the relevant dimension (shape or color); and an output layer corresponding to sorting trays. The units interact through connections of various types. For example, feedforward connections are established between input and hidden units and between hidden and output units, and the strength of these connections changes with experience according to a Hebbian learning rule (i.e., connections between units that are simultaneously active increase in strength). Consequently, when the network sorts by color, for example, the feedforward connections for color become stronger and the network develops a latent memory for sorting by color. There are also feedfoward connections to the prefrontal cortex units that change with experience, but these change at a much slower rate, such that the prefrontal cortex part of the model (which represents the relevant dimension) is less susceptible to bias than the rest of the system.

Other connections include the recurrent excitatory connections that the prefrontal cortex units have to themselves. These connections allow the prefrontal cortex units to remain active even in the absence of external input. To examine the basis of developmental changes in behavior, the experimenters modeled age-related improvements in active memory by increasing the strength of the recurrent connections.

When tested on the DCCS with weak recurrent connections (i.e., at a young age), Morton and Munakata's model performed perfectly on preswitch trials (because the network became biased toward the preswitch rules as category exemplars were entered) and perseverated during the postswitch phase. When the recurrent connections were strengthened, the network switched appropriately on the postswitch trials, simulating the developmental progression observed in children.

According to Morton and Munakata's (2002) model, age-related changes in performance on the DCCS are attributable to increases in the strength of active memory. However, the likelihood of perseveration is jointly determined by the strength of active memory and the strength of a conflicting latent bias. This approach is similar in some respects to the framework proposed by Roberts and Pennington (1996), according to which working memory demands and inhibitory control demands interact and jointly determine task difficulty. Like Gerstadt, Hong, and Diamond (1994), Roberts and Pennington (1996, p. 112) suggested that task difficulty can be increased either by increasing the inhibitory demands or by increasing the working memory demands of a task (see also Carlson & Moses, 2001; Hala, Hug, & Henderson, 2003). Morton and Munakata's model differs from these proposals, however, in that inhibitory control (or, conversely, perseveration) is seen to be a functional consequence of memory (or the lack thereof). That is, Morton and Munakata see no need to postulate a separate inhibition mechanism.

## *INHIBITION ACCOUNTS OF THE DEVELOPMENT OF EXECUTIVE FUNCTION*

Another possibility is to attribute the development of executive function to the growth of an inhibition mechanism—a mechanism for suppressing behavior (e.g., Dempster, 1993, 1995; Harnishfeger & Bjorklund, 1993). Starting perhaps with Luria (1961) and White (1965), numerous authors have suggested that the growth of an inhibition mechanism occurs in parallel with the growth of prefrontal cortex. In terms of the DCCS, 3- to 4year-olds may know perfectly well what they are supposed to do, and even try to do it, but still have difficulty inhibiting prepotent responses due to an immature inhibition mechanism.

One class of inhibition accounts has emphasized lack of response control (e.g., Barkley, 1997; Carlson, Moses, & Hix, 1998; Cuneo & Welsh, 1992; Diamond & Gilbert, 1989; Gladstone, 1969; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Luria, 1959, 1961; Perner et al., 1999; Reed, Pien, & Rothbart, 1984; Tikhomirov, 1978; White, 1965). Following Luria (e.g., 1961), these accounts hold that children frequently fail to suppress overlearned, or otherwise prepotent, response tendencies despite representing an appropriate plan or rule (i.e., despite knowing what to do). Carlson and Moses (2001) and Perner et al. (1999) have specifically suggested that 3- to 4-year-olds acquire a prepotent response tendency, or action schema, during the preswitch phase of the DCCS, and then have difficulty inhibiting this response tendency during the postswitch phase despite knowing what to do. For Perner et al . (1999), this difficulty is overcome by the emergence of "executive inhibition," which depends on children's conceptual understanding of the unintended consequences of action schemata.

In contrast to accounts emphasizing lack of response control, Kirkham, Cruess, and Diamond (in press) have interpreted 3- to 4-year-olds' perseveration in the DCCS as an example of representational inflexibility caused by an immature inhibition mechanism. On their account, "the problem for children is *not* in representing incompatible sets of rules," as claimed by CCC theory, but rather in shifting attention to the postswitch dimension, which "requires inhibiting the pull to the previously correct dimension" (p. 27 of the ms., italics in the original). They refer to 3- to 4-year-olds' difficulty as one of "attentional inertia" that is eventually overcome by maturation of dorsolateral prefrontal cortex.

## *REDESCRIPTION AND THE RELATION BETWEEN EXECUTIVE FUNCTION AND CONCEPTUAL FLEXIBILITY*

Perner, Stummer, Sprung, and Doherty (2002) recently developed a new account of the development of executive function—one with precursors in work by Flavell (1988) and Inhelder and Piaget (1964), among others. Although similar in many respects to Perner's earlier accounts (e.g., Perner et al., 1999), this new account suggests that 3- to 4year-olds exhibit representational inflexibility because they lack a concept of perspectives and, hence, cannot understand that a single stimulus can be redescribed in a different, incompatible way from two different perspectives. This account can be applied to the DCCS in a straightforward fashion. For example, in the preswitch phase of the DCCS, when sorting by color, children may describe a red rabbit as a *red one.* Then, in the postswitch phase, they may need to describe that same stimulus as a *rabbit.* If 3- to 4-year-olds fail to understand that it is possible to provide multiple descriptions of a single stimulus, then they will persist in describing the test cards in terms of the preswitch dimension, as suggested by Zelazo and Frye (1997) and Frye (1999). Another version of this account suggests that even 3-year-olds can, in principle, understand alternative descriptions in the DCCS, but that they become much more likely to do so at around 4 years of age (Perner & Lang, 2002). In either case, the changes occur at about 4 years of age because this is when children acquire the concept of perspectives, which allows them readily to appreciate that a single stimulus can be described in two different ways.

Perner's redescription account can be distinguished from another account emphasizing redescription. According to Karmiloff-Smith's (1992) Representational Redescription model, knowledge is originally represented in an implicit, procedural format (called "level I"). Knowledge in this format is modular and inflexible: the procedures are data-driven and they must be "run off" in their entirety. With sufficient practice, behavioral mastery of these procedures is achieved and the knowledge is automatically redescribed into a more abstract, explicit format (called "E 1") that reveals the structure of the procedures. Although this newly redescribed knowledge is explicit, it is not conscious. At this level of redescription, separate aspects (or components) of the knowledge can interact with aspects of other explicitly represented knowledge, but they cannot be consciously manipulated. Consciousness comes with yet additional levels of redescription or "explicitation," that occur "spontaneously as part of an internal drive toward the creation of intra-domain and inter-domain relationships" (1992, p. 18). Level E2 is conscious but cannot be verbalized, whereas Level E3 is conscious and verbalizable. The Representational Redescription model would account for 3- to 4-year-olds' inflexibility on the DCCS by proposing that their knowledge of the rules is less than fully explicit (due to lack of experience, not age). For example, children's knowledge might be represented at Levels E 1 or E2 but not E3.

## *REVIEW OF EXTANT RESEARCH ON THE DIMENSIONAL CHANGE CARD SORT*

The four approaches just described complexity theories, memory accounts, accounts emphasizing inhibitory control, and accounts emphasizing redescription—emphasize different aspects of the development of executive function and postulate different underlying mechanisms. Although all of these approaches can be applied in a straightforward fashion to the basic finding that 3- to 4-year-olds often perseverate on the DCCS, they make different predictions about the effects of experimental manipulations of features of the DCCS. The research reported in this *Monograph* will be discussed in terms of these accounts, but before describing this research we will first review the existing literature, starting with some background information regarding the rule-use paradigm.

The DCCS is an example of the rule-use paradigm, which was developed during the 1920s by Vygotsky, Luria, and Leontiev in their work on the verbal regulation of behavior. Rules are statements (usually if-then statements) that specify relations between antecedent conditions and actions to be executed or inferences to be made. In any rule-use task, participants are presented explicitly with rules and required to use them to guide their behavior. For example, in one series of studies (Luria, 1961), children were told to squeeze a bulb when a red light flashed, but to refrain from squeezing when a green light flashed. To succeed on this task, it is necessary to keep the rules in mind (i.e., in working memory) and to follow them. The instructions may be represented as follows: "If the red light's on, press the bulb. If the green light's on, don't press it." In this example, the apodoses of the rules refer to actions to be (or not to be) executed.

The rule-use paradigm is useful for studying executive function because it is relatively simple compared to many other paradigms. For example, unlike a variety of *rule-learning* tasks (e.g., Bruner, Goodnow, & Austin, 1956; Gollin, 1966; Grant & Berg, 1948; Kemler, 1978; Kendler & Kendler, 1959; Rudy, Keith, & Georgen, 1993), rule-use tasks do not require participants to *discover* the relevant rules; rather, this information is provided explicitly. In rule-learning tasks, such as the Wisconsin Card Sorting Test, young children could have difficulty at any one of the subphases of problem solving identified in Figure 1. As a result, the origin of errors on this task is relatively difficult to determine (e.g., see Delis, Squire, Bihrle, & Massman, 1992). Similarly, tasks designed to assess strategic problem solving (e.g., the Tower of Hanoi; Bidell & Fischer, 1994; Klahr & Robinson, 1981; Welsh, 1991) require rule use in addition to other problem solving phases, such as planning, and error correction. On the other hand, because the rule-use paradigm isolates crucial steps in the course of problem solving, and is therefore relatively simple, this paradigm makes it easier to interpret children's errors.

## The Use of a Single Pair of Rules by 2.5- and 3-Year-Old Children

Zelazo and Reznick (1991, Exp. 1) examined the use of rules to sort cards by children aged 31, 33.5, and 36 months. One task was a deductive card sort in which children were required to sort cards according to a single pair of rules. Two target cards were affixed to each of two boxes (e.g., a garden hose and a truck, and a bed and a chair), and children were told two rules for separating test cards, such as, "If it's something found inside the house, then it goes in this box. If it's something found outside the house, then it goes in that box." On each of 10 test trials, children were shown a card (depicting items such as a snowman, a telephone, and a swing set), which was labeled at the basic level (e.g., "Here's a snowman,"), and they were asked, "Where does this go?" A knowledge task was identical to the sorting task except that instead of being asked to sort items on each trial, children were simply asked which rule's antecedent condition each item satisfied. For example, children were shown a card, told, "Here's a snowman," and asked, "Is it something found inside the house or is it found outside?" The two tasks employed the same rules and the same items, but they differed in the extent to which they required children to use their knowledge to execute the actions prescribed by the apodoses of the rules. There were two main findings. First, 3-year-olds performed equally well (and better than chance) on both tasks. Because successful responding was underdetermined by the nonlinguistic aspects of the task (e.g., the perceptual similarity of the exemplars), one can be confident that the children were representing the rules and using them to govern their behavior. In fact, in an additional, unpublished experiment, Zelazo and Reznick confirmed that when children were given the cards in the same procedure but not told specific rules, 3-year-olds failed to create the categories.

In contrast to the 3-year-olds, children in the two younger age groups (31 and 33.5 months) failed to use the rules despite possessing knowledge about the cards (i.e., correctly answering questions such as, "Does this [a snowman] go inside the house or outside?"). Across a variety of categories, children in the two younger age groups performed better on the knowledge task than on the sorting task, indicating that they failed to use their knowledge in the service of the rules. A later study (Zelazo, Reznick, & Pinon, 1995, Exp. 1) found that 32-month-olds had difficulty even when (a) cards were labeled at the superordinate level (i.e., in terms of the rule; e.g., as "something found inside"), (b) children were reminded of the rules, and (c) children were rewarded for responding correctly. In one condition, 32month-old children were told, "Remember, inside things go here, outside things go there. Look, here's something that goes outside, which box does it go in?" and then given a sticker for correct responding. Surprisingly, children in this condition were still unable to use the rules systematically to sort the 10 test cards. Analyses of errors revealed a tendency to repeat responses. Although children rarely put all the cards into the same box, when they made an error, it usually involved putting a card into the box in which they had put a card on the previous trial. These results were interpreted as evidence that 2.5-year-olds represented the rules at some level, and actually *started* to use them, but were susceptible to perseverative errors and ultimately failed to sort systematically. The ability to use a pair of rules seems to be acquired rapidly at the end of the third year of life. However, the DCCS revealed lingering limitations in 3-year-olds' rule use.

## The Standard Version of the DCCS

In the first study using what is now considered the standard version of the DCCS, Frye, Zelazo, and Palfai (1995, Exp. 2) gave 3- to 4-year-olds and 5-year-olds a task like the one illustrated in Figure 2. The procedure was as follows. Target cards were affixed to two trays. On each of 5 preswitch trials, the experimenter told children the rules for separating test cards by one dimension (e.g., color: "All the red ones go here, but all the blue ones go there."), showed children a card, and asked them, "Where does this go in the ____________ (e.g., color) game?" Children were required to place the card face down into one of the trays. When they had completed 5 trials, children were told to stop playing the first game and to switch to a new game. They were then given 5 postswitch trials involving the same test and target cards. The procedure for these trials was identical to that for the preswitch trials except that children were told the rules for sorting by the other dimension (e.g., shape). In addition to color and shape, children were also tested using other dimensions, such as color versus size, shape versus number, and size versus number. The order in which dimensions were presented (e.g., color first) was counterbalanced.

All children were correct on the preswitch trials. Children were classified as passing the postswitch phase if they sorted correctly on at least 4 out 5 trials. Children who sorted the same number of cards incorrectly were classified as failing. All children could be classified by these criteria (and in 89% of the cases, children were correct or incorrect on all 5 trials). The majority (65%) of 3- to 4-year-olds failed, whereas the majority (75%) of 5-year-olds passed. When these same children were administered a second DCCS involving two different dimensions, the results were nearly identical (70% of 3- to 4-year-olds failing; 70% of 5-year-olds passing).

This initial study also tested the complexity of the reasoning involved in the DCCS. In Experiment 3, preschool children were presented with three versions of a task based on Fischer and Bidell (1991). In one version, they were required to sort objects by a single dimension (e.g., red ones here, blue ones there). In another version, children were required to switch between dimensions, as in the DCCS (e.g., sorting objects first by color and then by shape). Finally, in the third version, children were required to sort using two dimensions simultaneously (e.g., locate an object by both shape and color in a 2 x 2 matrix; cf. Inhelder & Piaget, 1964). Results revealed that the three versions were ordered in difficulty, with matrix classification being the most difficult (as predicted by CCC theory, but not, for example, relational complexity theory).

## Experimental Manipulations of the Standard DCCS

In several subsequent studies, researchers modified aspects of the standard DCCS in an effort to discover the determinants of 3 - to 4-yearolds' difficulty. Zelazo, Frye, and Rapus (1996, Exp. 1) asked 3 - to 4-yearolds who were perseverating on the preswitch rules questions designed to determine whether they understood what they were supposed to be doing. For example, children who were supposed to be sorting by shape were asked, "Where do the boats go in the shape game? And where do the rabbits go?" Almost invariably, children answered these knowledge questions correctly, pointing to the correct box. Nonetheless, when children were told to go ahead and sort the cards according to these rules ("Okay, good, now play the shape game: Where does this rabbit go?"), nearly all of them perseverated (e.g., they sorted by color). In other words, children correctly answered an explicit question about the new rules, showing that they knew these rules in some sense, but then they immediately persisted in using the old ones. This finding makes it unlikely that perseveration on the DCCS can be attributed to the use of specific rule representations that are less than fully explicit. That is, this finding would seem to indicate that 3- to 4-yearolds persistently select inappropriate rules despite conscious, verbalizable knowledge of both the pre- and postswitch rules.

This study also showed that 3- to 4-year-olds perseverated even after a single preswitch trial (Zelazo, Frye, & Rapus, 1996, Exp. 2), which makes it unlikely (although not impossible) that their difficulty was in inhibiting an overlearned pattern of responding or in overcoming latent memory traces. Further experiments revealed perseveration even when verbal rather than manual responses were required (Exps. 3 & 4), which suggests that children's inflexibility can be observed in multiple modalities (i.e., it is not dependent on a particular type of motor persistence; Luria, 1961). In one experiment (Exp. 4), familiar figurines were attached to each of the boxes and the boxes were labeled as "Ernie's box" and "Big Bird's box." Children were told rules such as, "If it's red, then you have to put it over here in Ernie's box; blue ones go there in Big Bird's box." Then they were presented with a test card, which was labeled by the relevant dimension only, and they were asked, "Whose box does this go in?" Children were asked to place their hands on hand prints (to prevent manual responding) and to refer to the boxes by name only. Nearly all children failed to switch. These same children, however, answered knowledge questions correctly. This produced exchanges between experimenter and child in which the experimenter would ask, "Whose box do the rabbits go in, in the shape game?"; the child would answer, "Ernie's"; the experimenter would say, "Okay, now, play the shape game. Here's a red rabbit. Whose box does this go in, in the shape game?"; and the child would say, "Big Bird's."

Jacques, Zelazo, Kirkham, and Semcesen (1999) sought to determine more directly whether 3- to 4-year-olds' inflexibility on the DCCS, coupled with their success on the knowledge questions, could be attributed to lack of response control—difficulty inhibiting an overlearned motor response. Instead of having children sort cards themselves, these authors created a Puppet version of the DCCS in which they asked children to evaluate the sorting of a puppet on the DCCS. Thus, the response execution requirement was removed from the task altogether, so there was no overlearned motor response to inhibit. Results indicated clearly that when 3- to 4-year-olds watched the puppet perseverate, they judged the puppet to be correct. When they saw the puppet sort correctly, they judged the puppet to be wrong. They also judged the puppet to be wrong when the puppet switched sorting rules gratuitously (i.e., incorrectly in the absence of being told to do so). Moreover, children's judgements of the puppet were highly correlated with their own performance on the DCCS. These findings show that 3- to 4-year-olds have difficulty formulating what should be done and not just difficulty doing it. Poor response inhibition cannot account for the findings from the Puppet version, although it remains possible that 3- to 4-year-olds have difficulty inhibiting attention to particular aspects of the target cards (e.g., Kirkham et al., in press).

A study by Munakata and Yerys (2001) also speaks to the question of response inhibition. Munakata and Yerys sought to explore further the nature of the knowledge-action dissociation observed by Zelazo, Frye, and Rapus (1996). On the surface, this dissociation would seem to suggest that children intend to sort by the postswitch rules and simply fail to act on the basis of their intention—a failure of response control. As Munakata and Yerys noted, however, the knowledge questions only make reference to the relevant dimension (e.g., "Where do the *trucks* go in the shape game?"), whereas the test cards possess both dimensions, and hence require children to select postswitch rules as against preswitch rules. When the knowledge questions were made more complex (e.g., "Where do the *red trucks* go in the shape game?"), 3- to 4-year-olds often had difficulty on the knowledge questions too (and hence, there was no dissociation between knowledge and action). This finding demonstrates limits to children's knowledge in the postswitch phase, and it shows that it is the complexity of the inferences required that is important, not the modality of the required responses.

Towse, Redbond, Houston-Price, and Cook (2000) also tested children's performance on modified versions of the DCCS. In Experiments 1 and 2, the experimenter not only explained the postswitch rules, but also demonstrated them by sorting test cards. This change to the procedure appeared to scaffold 3- to 4-year-olds' use of the postswitch rules, resulting in improved performance. In contrast, in Experiment 3, no demonstration was provided, and children 42 months and younger frequently failed. Children's difficulty with the postswitch phase of the DCCS evidently consists in formulating what to do on the basis of verbal information (i.e., the postswitch rules) alone.

Experiment 4 of the study by Towse et al. (2000) yielded particularly interesting results. In this experiment, children who failed the postswitch phase of the standard version were encouraged (one way or another) to label the test cards correctly. That is, these children were shown a test card, and asked, "What is this?" If they did not answer in terms of the postswitch dimension only, then they were asked a specific contrast question (for example), "Is it a red card or a green card?" Some of these children (about 40%) answered the first question in terms of the postswitch dimension only, and the remaining children correctly answered the specific contrast question. All children were then asked to sort, and roughly a third of them now sorted correctly. According to these authors, most 3- to 4-year-olds fail to sort correctly during the postswitch phase because they think of the card in terms of its preswitch attributes (Towse et al., 2000, p. 361), an interpretation also proposed by Frye (1999, p. 123) and Zelazo and Frye (1997, p. 145).

Kirkham et al. (in press) also found that when required to label the stimuli, 3- to 4-year-olds (who normally failed) tended to pass (78% of 3- to 4-year-olds passed), and when cards were left face up in the sorting trays (as opposed to the usual practice of putting them face down), 4-year-olds (who normally passed) tended to fail. The authors suggested that these two manipulations helped and hindered (respectively) children's efforts to inhibit attention to a previously useful aspect of the stimulus, and refocus on another, conflicting aspect of the same stimulus. Leaving the test cards face-up may have increased the salience of the preswitch dimension, whereas labeling the test cards may have helped children to refocus their attention to the currently relevant dimension.

In a final study to be considered, Perner and Lang (2002; see also Brooks, Hanauer, Padowska, & Rosman, 2003) found that children performed well on two new versions of the DCCS. In one version, called the Reversal Shift version, all cards (test and target) varied only in shape, and children were not, in fact, required to make a "dimensional change." Rather, children were first asked to play the "correct" animals game ("All the horses go to the horse. And all the fish go to the fish."), and then, during the postswitch phase, children were asked to play the "wrong" game ("Now, all the horses go to the fish. And all the fish go to the horse."). These authors also found that children performed well in a version of the DCCS in which (a) no target cards were used, and (b) the switch was explained in terms of a change in desires. Instead of target cards, each sorting tray was associated with a picture of a boy or a girl. During the preswitch phase, each target character was described as wanting all the cards of a particular color (e.g., "The girl wants all the green ones"). Then, during the postswitch phase, children were asked to switch from sorting by color to sorting by shape, and this switch was justified by a change in the children's desires (e.g., "The girl now wants all the fish."). To account for their findings, Perner and Lang (2002) suggested that their new versions of the DCCS provide more explicit clues than the standard version to the fact that an alternative description is required.

## Correlational Studies

A growing number of studies have found that performance on the DCCS is correlated with individual and group differences. For example, several studies, starting with Frye et al. (1995), have found that performance on the DCCS is correlated with performance on tasks assessing theory of mind (e.g., understanding false beliefs), even when controlling for age and vocabulary (e.g., Carlson & Moses, 2001; Perner et al., 2002). These findings support the suggestion that the DCCS provides a marker of relatively domain-general aspects of executive function.

Similar results have also been found in studies with clinical samples known to have impairments in theory of mind and executive function. Zelazo, Jacques, Burack, and Frye (2002) found relations between executive function (including DCCS performance) and autism in a small group of moderately high functioning individuals with autism-spectrum disorders. Colvert, Custance, and Swettenham (2002) replicated this finding in a larger sample, and also found that this group exhibited impairments on the DCCS (and theory of mind) relative to two mental-age matched comparison groups. Zelazo, Burack, Benedetto, and Frye (1996) reported similar findings for a group of individuals with Down syndrome, suggesting that correlations between theory of mind and performance on the DCCS are robust across a range of individual and group differences, and that several different types of developmental disorder may result in impaired executive function as measured by the DCCS. Finally, a study by Bialystok (1999) suggests that performance on the DCCS tasks may be related to bilingualism. In this study, a group of Chinese-English bilingual children (tested in Toronto) were better at the DCCS than were non-Chinese monolingual children, although the basis for this advantage remains to be determined. One possibility considered by Bialystok is that experience switching between different languages improves children's cognitive control.

## *THE CURRENT STUDIES*

The CCC theory and the various alternative theories of the development of executive function make different predictions about the circumstances in which perseveration on the DCCS ought to occur. The present studies subject several predictions to an empirical test by presenting 3- to 4year-old children with different, experimental versions of the DCCS. Study 1 was designed to test the hypothesis that 3- to 4-year-olds' poor performance on the standard version of the DCCS can be attributed to limitations on short-term or working memory. In three experiments, children were given new versions of the DCCS in which they were told to match test cards to four target cards according to four separate criteria (either 4 colors, 2 shapes and 2 colors, or 4 superordinate rules). Thus, these versions required children to use the same total number of rules as in the standard version, but the rules were not in conflict in the sense that children did not need to apply different rules to the same stimulus under different circumstances. Consequently, according to CCC theory, because these new versions do not require the use of a higher order rule they should be easy for 3- to 4-year-olds. Contrary to what would be expected if perseveration resulted from memory capacity limitations alone, children performed remarkably well on all three new versions. It may also be noted that one of these versions required sorting by bidimensional rules (2 shape rules and 2 color rules), so bidimensionality per se does not appear to be the source of children's difficulty either.

Study 2 was designed both to sharpen our understanding of the circumstances in which 3- to 4-year-olds perseverate on the DCCS and to explore more directly the role of conflict among rules. To this end, three experiments examined the roles of rule dimensionality (bidimensional vs. unidimensional) and various stimulus characteristics (one vs. two test cards; integrated vs. separated stimuli) that might be expected to affect task difficulty. In these experiments, bidimensional rules always involved conflict among rules, whereas unidimensional rules did not. Results revealed an effect of rule dimensionality qua conflict among rules, but not the stimulus characteristics tested. These experiments also showed that 3- to 4-year-olds were able to treat a single stimulus in two different ways when doing so did not require consideration of two different dimensions.

Study 3 examined further what types of conflict pose problems for 3- to 4-year-olds by asking what it is that children are perseverating on when they perseverate on the standard version of the DCCS. According to the CCC theory, children perseverate on a pair of rules such as, "Red ones go here; blue ones go there." That is, children represent and continue to use the preswitch rules even though they know the postswitch rules. Alternatively, children could perseverate on the preswitch dimension per se (e.g., they may attend selectively to the color of the stimuli while ignoring shape), or they could perseverate in their responses to particular stimulus configurations (e.g., putting the red boat in the left-hand box). Results showed that children often perseverated on a Partial Change version in which only the values of the dimension that was relevant on the preswitch phase were retained during the postswitch phase (e.g., children sorted red and blue rabbits and boats by color during the preswitch phase, and red and blue flowers and cars by shape during the postswitch phase). In contrast, they usually did not perseverate in a Total Change version in which values of both dimensions were changed on the postswitch phase (e.g., children sorted red and blue rabbits and boats by color during the preswitch phase, and yellow and green flowers and cars by shape during the postswitch phase). These findings suggest that children exhibit effects of conflict at the level of specific rules (e.g., "If it is red, then put it there."), consistent with the hypothesis that the preswitch rules are activated when selected during the preswitch phase and that this activation persists during the postswitch phase, creating a bias toward their selection and use.

Study 4 was designed to replicate these findings and consider whether negative priming, in addition to persistent activation of the preswitch rules, contributes to children's difficulty on the DCCS. Focusing on the relevant rules during the preswitch phase may result in inhibition of the competing rules (i.e., what will become the postswitch rules). As a consequence, the activation level of the postswitch rules may be suppressed below their baseline level during the postswitch phase and resist activation. Experiment 8 examined performance on a

Negative Priming version of the DCCS, in which the values of the dimension that was relevant during the preswitch phase are removed during the postswitch phase (e.g., if children were required to sort red rabbits and blue boats according to color in the preswitch phase, they might be required to sort green rabbits and yellow boats according to shape in the postswitch phase). This version would allow negative priming, but not activation, of the preswitch rules to interfere with postswitch performance. Results indicated that the Negative Priming version was as difficult as the standard version, as would be predicted if the postswitch rules are negatively primed during the preswitch phase. Conversely, however, negative priming alone cannot account for children's difficulty on the Partial Change version because in this version the values of the dimension that was irrelevant during the preswitch phase (i.e., the values that would be negatively primed) are removed during the postswitch phase. Experiment 9 replicated this finding and also suggested that negative priming depends on the active selection of one pair of rules against a competing alternative.

A summary of these experiments, describing the different versions and the results obtained, is presented in the Appendix. Considered together, the results of these experiments provide the basis for a revision of the CCC theory. This revised theory is designed to specify more clearly the circumstances in which children will have difficulty using rules at various levels of complexity, to provide a more detailed account of how to determine the complexity of rules required in a task, to take account of the simultaneous processes of activation and inhibition, and to underscore the importance of taking intentionality seriously in the study of executive function. This revised theory is described in Chapter VI.

## *A NOTE REGARDING THE STANDARD VERSION*

In the experiments reported in this *Monograph,* the effects of various experimental manipulations were assessed by comparing 3- to 4-year-olds' performance on new versions of the DCCS to their performance on the standard version. In order to control for certain aspects of the new versions, changes were sometimes made to the values of parameters on the standard version. When a defining feature of the standard version was changed, this change was reflected in the name of the version. Otherwise, if changes were made to parameters that do not appear (on the basis of previous research) to affect performance, then the parameter settings were simply noted.

The defining features of the standard version are the following: (a) There are two target cards and two test cards. (b) Target cards and test cards both vary along two bivalent dimensions, such that the two target cards mismatch on both dimensions, as do the two test cards. (Consequently, each test card matches one target card on one dimension and the other target card on the other dimension.) (c) The same test and target cards are used throughout the task. (d) Target cards are displayed throughout the task. (e) Children are told the rules on every trial. (f) On the preswitch phase, children are provided with two demonstration trials, designed to show children how to place the test cards. (g) Test cards are sorted face down into the sorting trays. (h) Children are not given feedback on any test trials (they are simply told, "Let's do another."). (i) Children are told explicitly when to switch. (j) There are no demonstration trials on the postswitch phase. (k) Test cards are not removed from sorting trays between the pre- and postswitch phases.

The following parameters are free to vary, but default values are noted: (a) The dimensions used may include color, shape, number, size, or pattern, among others. However, most studies have used color versus shape because these two dimensions appear to be approximately equally salient. That is, children generally do not show an a priori bias to sort by one dimension versus the other. (b) Equal numbers of pre- and postswitch trials are generally used, and these numbers have ranged from 1 to 10, although the modal value is 5. (c) Test cards may be labeled either by both dimensions or by the relevant dimension only.

## *STATISTICAL ANALYSES*

For each experiment, the results section is structured as followed. First, possible effects of stimulus type, sorting dimension, order, and gender were examined, using parametric and nonparametric analyses. Second, parametric analyses (e.g., analyses of variance [ANOVAs], independent t-tests, paired samples t-tests) were used to examine differences in performance on different versions of the DCCS. Third, because scores on the postswitch phase of the DCCS are usually bimodally distributed (i.e., children are often either correct on all postswitch trials or incorrect on all postswitch trials), children were classified as passing or failing the postswitch phase, and nonparametric tests (i.e., chi-square tests) were used to examine whether the number of children passing or failing differed for different versions of the DCCS.

## II. STUDY 1: MEMORYAND EXECUTIVE FUNCTION

### *INTRODUCTION AND SUMMARY*

Three experiments explored the role of memory in children's executive function by asking whether 3- to 4-year-olds' errors on the DCCS can be attributed to age-related limitations on memory. According to several theories, the development of short-term, working, or active memory is an important constraint on the development of executive function. If 3- to 4-year-olds fail to use the postswitch rules simply because they cannot remember four rules (i.e., the 2 postswitch rules in addition to the 2 preswitch rules), or keep the postswitch rules in active memory, then they should perform poorly on any version of the DCCS task that requires the use of four rules even those that do not require the formulation of a higher order rule and do not require the same test cards to be sorted in two different ways. In contrast, according to CCC theory, children should only have difficulty in cases where the same test card must be sorted first by one dimension and then by another because it is only under these circumstances that a dimension must serve as a setting condition and children must use a higher order rule first to select the appropriate setting condition and then to select the appropriate rule. In the absence of conflict among rules, all four can be represented at the same level in a hierarchy (see Figure 5).

In Experiment 1, the performance of 3-year-old children was examined on three versions of the DCCS: the standard version, a 4-Rules (unidimensional) version, and a 2+2-Rules (unidimensional) version. The two new versions were similar to the standard version in that four rules was presented to children. However, because the rules were unidimensional, the same test card did not need to be treated differently depending on which dimension was relevant (i.e., there was no conflict among the rules). As will be seen, the large majority of children performed well on the two modified versions, even though they typically failed to switch when performing on the standard version.

Experiment 2 was designed to address the possibility that the two new versions used in Experiment 1 did not, in fact, require children to hold four rules in mind, and hence did not tax children's memory to the same extent as the standard version. It could be argued that rather than remember four rules, children really only needed to remember which dimension (shape or color) was relevant. To test this, another group of children was given a 2 + 2- Rules (bidimensional, no overlap) version, in which they were required to sort two test cards by color and two different test cards by shape.

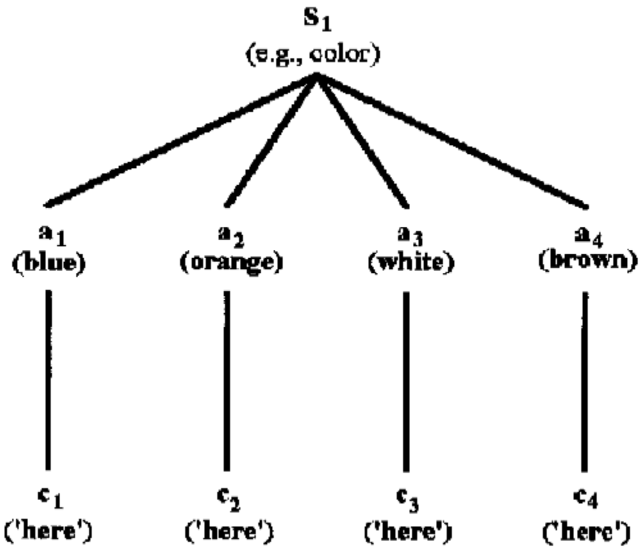

FIGURE 5.—Tree structure depicting the system of rules required in the 4-Rules and 2+2-Rules versions of the Dimensional Change Card Sort used in Experiment 1.

This version required children to remember which test cards to sort by shape and which test cards to sort by color. Moreover, as in the standard version, children were asked to switch from sorting by one dimension to sorting by the other. However, as in the 2+2-Rules (unidimensional) version, there was no conflict among the rules, so, according to CCC theory, no higher order rule was required. As predicted by CCC theory, most children performed well on this version.

Experiment 3 addressed the question of memory demand in a different way. In this experiment, children were given a new 4-Rules version, called the 4-Rules (superordinate) version, that required using four superordinate rules (described functionally: things that can walk, things one can wear, things one can ride, and things one can eat) to sort a heterogeneous series of items (e.g., a jacket, a truck, a fried egg). It was expected that the memory demand in the 4-Rules (superordinate) version would be even greater than that in the 4-Rules versions used in Experiments 1 and 2 because in the 4-Rules (superordinate) version children not only needed to keep four superordinate distinctions in mind, but they also need to determine which rule applied to each test card (i.e., there were storage plus processing demands). Nonetheless, because there was no conflict among the rules, this new version was expected to be relatively easy for 3- to 4-year-olds. As predicted, children performed better on the 4-Rules (superordinate) version than they did on the standard version of the DCCS. Clearly, children's difficulty with the standard version cannot be attributed in any straightforward way to a constraint on memory capacity. Instead, children seem to have difficulty when required to select among conflicting rules.

## EXPERIMENT 1

Experiment 1 was designed to assess the possibility that 3- to 4-year-olds fail the postswitch phase because they simply cannot keep the postswitch rules in mind. Two new versions of the DCCS were created: a 4-Rules (unidimensional) version and a 2+2-Rules (unidimensional) version (see Figure 6). The new versions were similar to the standard version in that the same number of rules was presented to children (four rules in total) but different from the standard version insofar as there was no conflict among the rules.

In the 4-Rules (unidimensional) version, children were told four rules and required to use them to sort a series of test cards by one dimension (e.g., color: "If it's blue it goes here, if it's orange it goes here, if it's white it goes here, and if it's brown it goes here."). The 2+2-Rules (unidimensional) version was identical to the 4-Rules (unidimensional) version in all respects except that, although children were told four rules, they were only required to use two at a time, as in the standard version. This feature of the procedure was designed to correspond to the fact that in the standard version children first used one pair of rules and then used another, in a serial fashion.

If children's difficulty with the standard version of the DCCS is one of limited memory capacity, then children should perform poorly on all three versions used in this experiment. However, if children's difficulty consists in using higher order rules, then they should fail only on the standard version, in which the two pairs of rules are in conflict.

### *Method*

**Participants and design.** The sample comprised forty-one 3- to 4-yearolds (*M* = 42.2 months, range: 33 to 48 months; 20 girls and 21 boys). Four additional children were tested but excluded from the final sample, either because of experimenter error (n = 1), refusal to complete the experiment (n = 2), or information from their daycare supervisor that the child was developmentally delayed (n = 1). Children were of mixed socioeconomic and ethnic backgrounds, although this information was not systematically collected.

As in all of the experiments to be described, children were recruited from local daycare centers or from a database containing the names of parents who had expressed an interest in participating in research. Parents were provided with a written description of the experiment, and they granted informed consent allowing their children to participate.

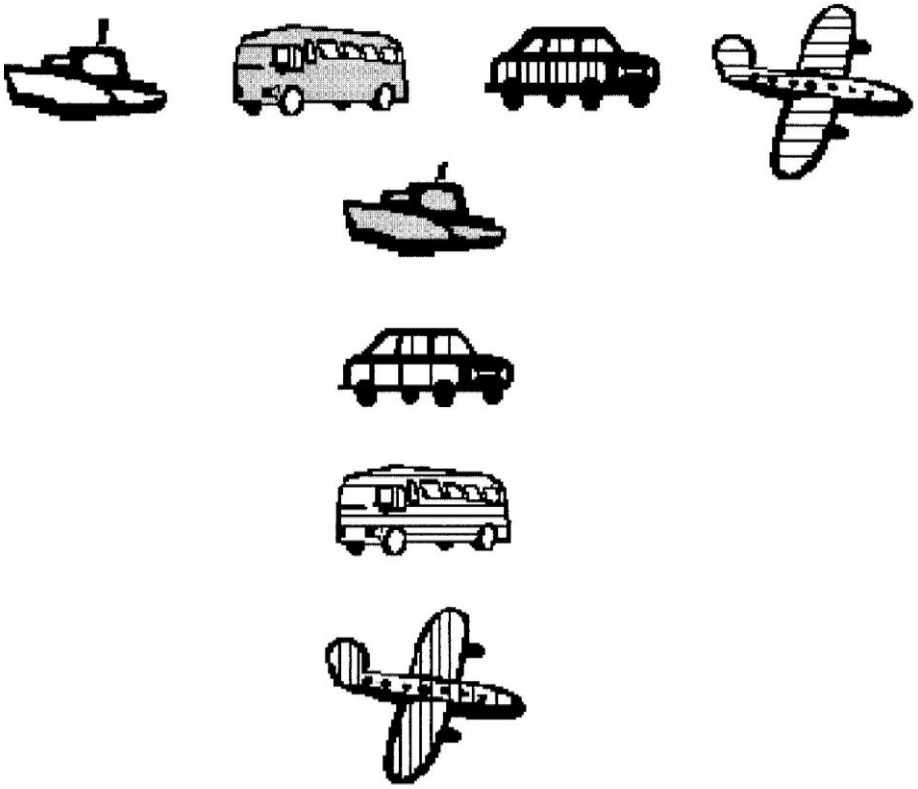

FIGURE 6.—Sample target cards (top row) and test cards in the 4-Rules (unidimensional) and 2+2-Rules (unidimensional) versions of the Dimensional Change Card Sort used in Experiment 1. Children are asked to sort test cards by one dimension (e.g., color: "If it's blue it goes here, if it's orange it goes here, if it's white it goes here, and if it's brown it goes here."). Note: white indicates blue; grey indicates orange; vertical stripes indicate white; horizontal stripes indicate brown.

All children received three versions of the DCCS in a counterbalanced order: the standard version, the 4-Rules (unidimensional) version, and the 2+2-Rules (unidimensional) version. In the standard version, children were first told rules for sorting according to one dimension (e.g., color) and then asked to switch and sort by the other dimension (e.g. shape). In the 4-Rules (unidimensional) version and the 2+2-Rules (unidimensional) version, children were only required to sort by one dimension (shape or color). Across versions, this yielded four phases (one each for the 4-Rules and 2+2-Rules versions and two for the standard version). Children were always required to sort by the alternate dimension on successive phases, with roughly half of the children starting with shape (e.g., shape, color, shape, color) and the remaining children starting with color. Thus, in the 4-Rules (unidimensional) and 2+2-Rules (unidimensional) versions, roughly half of the children were told to sort by shape and the remaining children were told to sort by color. In the standard version, roughly half of the children were first told to sort by color, and the remaining children were first told to sort by shape.

**Materials.** As in previous studies (e.g., Frye et al., 1995), the items that children sorted were 10.75 cm x 7 cm color drawings on laminated cards. There were three sets of cards (see Table 1). A different set was used for each version, and the particular card set used was counterbalanced. Card set 1 included red, lime-green, black, and purple animals (rabbit, cat, dog, and monkey). Card set 2, included blue, orange, white, and brown vehicles (boat, bus, car, and plane). Card set 3 included pink, grey, dark green, and yellow household items (telephone, stove, table, television). Colors were chosen to be clearly discriminable within a set.

Target cards were affixed to small sorting trays that were 11.5 cm long, 9.5 cm wide, and 2 cm deep. Small shelves above and behind each tray supported the target cards and allowed them to be displayed throughout the task.

**Procedure.** Testing took place in a quiet area at children's day care center or in a university laboratory, and all procedures were videotaped. All children were tested individually in one 20- to 25-minute session. Children were given 5-minute breaks between the tasks in order to minimize any interference or carryover effects. After children were seated at the table and were comfortable with the experimenter and the setting, the experimenter told the children a set of rules for separating the test cards.

In the *standard version,* two examples from a particular category (e.g., the *brown car* and the *white plane* from the vehicle category; see Table 1) were chosen as target cards and affixed to the two sorting trays. During the preswitch phase, children were first told one pair of rules (i.e., shape rules or color rules) for separating the test cards, which consisted of 10 *white cars* and 10 *brown planes.* Children who sorted by color during the preswitch phase were told: "If it's brown put it here, but if it's white put it there." In the course of explaining the game, the rules were stated repeatedly in different ways. For example, children were told, "All the ________ go here," "If it's __________ then it goes here," and "Only ____________ go here."

TABLE 1

TARGET AND TEST CARDS USED IN EXPERIMENT 1

| Card Set | Target Cards | Test Cards |
|---|---|---|
| 1. Animals | Red rabbit* | Lime-green rabbit** |
| | Lime-green cat* | Purple rabbit** |
| | Black dog | Black rabbit |
| | Purple monkey | Black cat** |
| | | Purple cat** |
| | | Red cat |
| | | Red dog** |
| | | Lime-green dogs |
| | | Purple dog |
| | | Red monkey** |
| | | Black monkey** |
| | | Lime-green monkey |
| 2. Vehicles | Blue boat | Orange boat** |
| | Orange bus | Brown boat** |
| | White car* | White boat |
| | Brown plane* | White bus** |
| | | Brown bus** |
| | | Blue bus |
| | | Blue car** |
| | | Orange car** |
| | | Brown car |
| | | Blue plane** |
| | | White plane** |
| | | Orange plane |
| 3. Household Items | Pink phone | Grey phone** |
| | Grey stove | Yellow phone** |
| | Dark green table* | Dark green phone |
| | Yellow television set* | Dark green stove** |
| | | Yellow stove** |
| | | Pink stove |
| | | Pink table** |
| | | Grey table** |
| | | Yellow table |
| | | Pink television set** |
| | | Dark green television set** |
| | | Grey television set |

*Note.*— *indicates that the card was used as a target card in the standard version. Test cards in the standard version consisted of 10 each of these cards in the alternate color. **indicates that there were two instances of this card among the 20 test cards.

The experimenter then sorted one test card face-down into each tray to illustrate what children were supposed to do. After these demonstration trials, preswitch test trials commenced. On each preswitch trial, the experimenter stated the relevant rules, randomly selected a test card, labeled the card by *both* color and shape (i.e., vehicle type; e.g., the experimenter said, "Here's a brown plane"), and asked, "Where does this go?" Children were required to place the card face-down in one of the trays. No feedback was provided; after children sorted each card, the experimenter simply said, "Let's do another one," and then proceeded to the next trial. Children sorted 10 cards in this manner.

After the preswitch trials, children were told to switch to a different pair of rules (e.g., shape rules) for separating the remaining 10 test cards. The preswitch test cards were left in the sorting trays, but the transition to the new rules was marked explicitly by saying, for example, "Now we're going to play a new game. We're not going to play the color game anymore. No way. This game is different." The experimenter then told children the postswitch rules. No demonstration trial was provided during the postswitch phase. Postswitch trials were exactly like preswitch trials except that on each trial the experimenter stated the postswitch rules instead of the preswitch rules.

The *4-Rules (unidimensional) version* was identical to the standard version except that four target cards were displayed and children were told four rules for sorting all 20 test cards. For example, children who were required to sort colored animals according shape (i.e., type of animal) were told: "If it's a rabbit it goes here, if it's a cat it goes here, if it's a dog it goes here, and if it's a monkey it goes here." Also, during the demonstration trials, the experimenter sorted one test card face-down into each of the four trays (instead of just two).

The *2+2-Rules (unidimensional) version* was identical to the 4-Rules (unidimensional) version except for the order in which test cards were presented. As in the 4-Rules (unidimensional) version, children were shown four target cards and on each trial they were told four rules for sorting the 20 test cards according to one dimension (color or shape). However, the first 10 test cards that children were required to sort all corresponded to two of the four rules. The second half of the test cards all corresponded to the remaining two rules. For example, in the household objects category, children told to sort by color might first be shown 10 pink and grey test cards, and then be shown 10 yellow and (dark) green test cards, which corresponded to the pre- and postswitch phases of the standard version. No demonstration trial was provided after the first 10 trials.

### Results

Performance on all versions was scored as the number of trials on which children sorted correctly. In contrast to the standard version, the 4-Rules (unidimensional) version and the 2+2-Rules (unidimensional) version do not have two phases. In order to compare children's performance on the different versions, separate scores were computed for the first and last 10 trials of each task. Preswitch trials of the standard version were thus included in the analysis, even though children generally perform well on those trials. By using both pre- and postswitch trials of the standard version, performance on the different tasks could be compared without imposing an arbitrary scoring criterion for the 4-Rules (unidimensional) version and the 2+2-Rules (unidimensional) version.

Separating children's performance into two halves made it possible to examine whether children's performance on the second half of the standard version was significantly worse than their performance on the second halves of the 4-Rules (unidimensional) version and the 2+2-Rules (unidimensional) version. In addition, separation of children's performance into two halves made it possible to examine practice effects and the role of fatigue in the 4-Rules (unidimensional) version and the 2+2-Rules (unidimensional) version.

***Group analyses.*** Examination of the data indicated that some of the cells created by crossing dimension order (color or shape first) with half (first vs. second half of each task) had no variance. Therefore, to assess the effect of dimension order, data were collapsed across levels of half. A two-way (Version x Dimension Order) ANOVA on number correct revealed no significant effect of order and no Version x Dimension Order interaction. Therefore, dimension order was excluded from subsequent analyses.

A three-way mixed ANOVA with sex as a between-subject variable and version and half as within-subjects variables revealed a main effect of version, F(2, 78) = 16.27, p <.0001 (effect size *f* = .65), a main effect of half, F(1, 39) = 47.47,p < .0001 (effect size *f* = 1.10), and a Version x Half interaction, F(2, 78) = 53.7, *p* <.0001. There were no other significant effects. (Note: Due to departures from homogeneity of variance, probability values were adjusted using the Greenhouse-Geisser correction.) The Version x Half interaction was analyzed by examining the simple effects of half separately for each version. As expected, the effect of half was significant for the standard version, F(1, 39) = 54.36, *p* < .0001 (effect size *f* = 1.18); children performed poorly on the second half of the task. The difference between first and second half approached significance for the 4-Rules version, F(1, 39) = 3.72, *p* <.07 (effect size *f* = .31), indicating that children performed slightly better on the second half of the task for this version. Children's mean scores and standard errors on each half of the tasks are depicted graphically in the first six bars in Figure 7.

Furthermore, a 2 x 3 ANOVA with sex as between-subjects variable, version as within-subjects variable, and performance in the second test half as dependent measure revealed a significant effect for version, F(2, 78) = 40.16, *p* < .001 (effect size *f* = 1.01). Newman-Keuls post hoc tests *(p* <.05) indicated that children performed worse on the standard version *(M* = 1. 85, *SD* = 3.66) than on both the 4-Rules version *(M* = 9.02, *SD* = 2.47), *p* <.05, and the 2+2-Rules version *(M* = 8.15, *SD* = 3.58), *p* < .05. The latter two versions did not differ from each other. A similar 2 x 3 ANOVA, with sex as a between-subjects variable, version as within-subjects variable, and performance in the first test half as dependent measure did not reveal any significant effects.

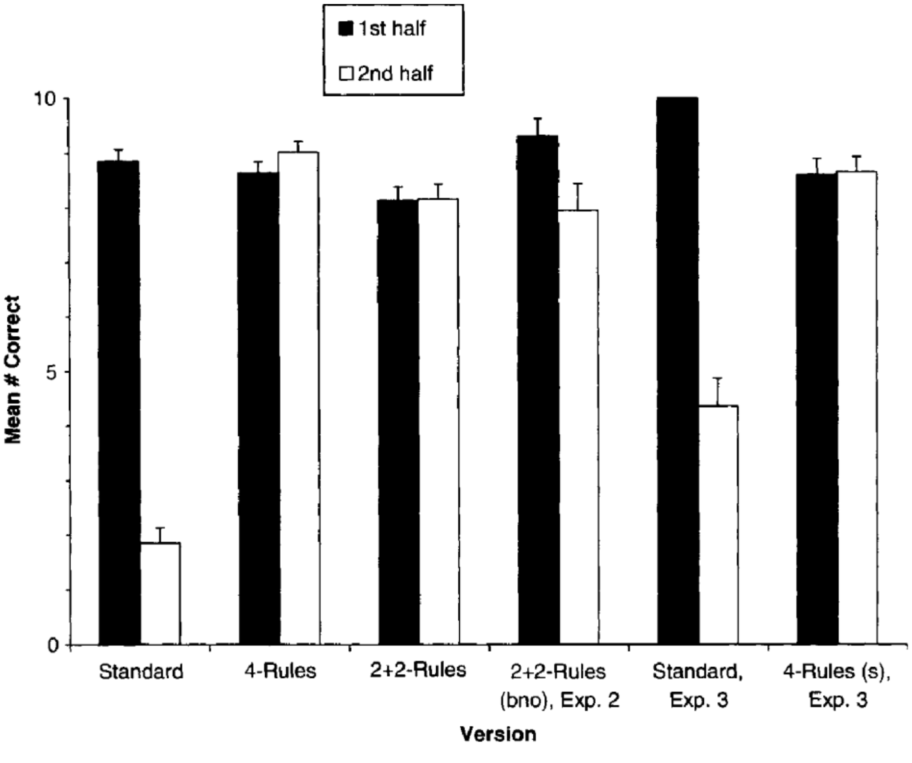

FIGURE 7.—Mean number correct (and standard error) on the Dimensional Change Card Sort, according to version and first half versus second half. 4-Rules = 4-Rules (unidimensional), 2+2-Rules = 2+2-Rules (unidimensional), 2+2-Rules (bno) = 2+2-Rules (bidimensional, no overlap), 4-Rules (s) = 4-Rules (superordinate). The standard, 4-Rules (unidimensional), and 2+2-Rules (unidimensional) versions were administered in Experiment 1 (*N* = 41). The 2+2-Rules (bidimensional, no overlap) version was administered in Experiment 2 (*N* = 16). The standard (Exp. 3) and 4-Rules (superordinate) versions were administered in Experiment 3 (*N* = 20).

Five children (out of 41; i.e., 12.2%) failed to sort at least 8 of 10 cards correctly on the preswitch phase of the standard version. Eight of 10 cards exceeds the number that would be expected based on random responding (binomial distribution, p < .05). Two of these children showed a clear bias by putting all 10 cards in one of the two boxes, the other three sorted the cards on the wrong dimension (e.g., color instead of shape). Because these children failed the preswitch phase of the standard version, their performance on the postswitch phase was difficult to interpret, and comparisons with the other two versions were compromised. When analyses were repeated excluding these five children (i.e., with $N = 36$), the same pattern of results emerged, except that there was no effect of half for the 4-Rules (unidimensional) version.

***Individual analyses.*** For children who passed the preswitch phase of the standard version, success on all versions was defined as at least 8 out of the last 10 cards sorted correctly. The probability of success based on random responding was even lower for the 4-Rules (unidimensional) and 2+2-Rules (unidimensional) versions than it was for the standard version (i.e., there was a .25 probability of sorting correctly by chance on any given trial vs. a .5 probability). Hence, the criterion of 8 provided a more conservative estimate of children's performance on these versions.

On the standard version, only two children (out of 36) performed better than would be expected based on random responding; for the 4-Rules (unidimensional) and 2+2-Rules (unidimensional) versions the numbers of children were 34 and 31, respectively. Twenty-eight of the 36 children (78%) showed a characteristic pattern of performance: They succeeded (i.e., performed better than chance) on the two modified versions and failed the standard version.

### *Discussion*

Consistent with previous findings (e.g., Frye et al., 1995; Jacques et al., 1999; Zelazo et al., 1996), the majority of 3- to 4-year-olds in this study perseverated on the preswitch rules in the standard version of the DCCS. However, these same children succeeded on two new versions in which children were told four rules simultaneously but the rules were not in conflict. These findings suggest that children's difficulty with the standard version of the DCCS cannot be attributed in a straightforward fashion to a constraint on memory capacity, and hence memory development may not be the primary determinant of the development of executive function.

Several aspects of the experiment require further explanation, however. For example, although the three versions were reasonably well matched in that all required the children to use four rules to sort a series of 20 test cards, the standard version differed from the other two versions in at least two ways. First, only the standard version contained conflicting rules. That is, in the standard version, but not the other two versions, the same test cards had to be sorted one way according to one pair of rules (e.g., the preswitch rules) and a different way according to the other pair (the postswitch rules). According to the CCC theory, this is the key difference between versions, because it is this feature of the standard version that makes it necessary to use a higher order rule (i.e., children must first select the appropriate rule pair before deciding which particular rule applies to the test card).

The standard version also differed from the other two versions in that the rules in the standard version were bidimensional (i.e., two of the rules were based on color and two were based on shape), whereas in the 4-Rules and 2+2-Rules versions the rules were unidimensional. It is possible that bidimensionality per se poses a problem for children. Moreover, because the rules were unidimensional in the two new versions, it is possible that children did not, in fact, need to keep four rules in mind on these versions. Rather, children may simply have needed to remember the relevant dimension, and then deduce what went where in a given trial.

To address this concern, two additional versions of the DCCS were created. In Experiment 2, a group of 3- to 4-year-olds was given a 2+2-Rules (bidimensional, no overlap) version of the task in which they were shown four target cards and asked to sort test cards first by two rules based on shape and then by two rules based on color. In this version, children needed to remember which cards to sort by shape and which cards to sort by color, but they still did not need to use a higher order rule because each test card was uniquely associated with a single rule. In Experiment 3, a different approach was used to increase the likelihood that children would need to keep four rules in mind. In this experiment, a group of 3- to 4-year-olds was given a 4-Rules (superordinate) version, in which they were told four relatively abstract, superordinate rules for sorting a heterogeneous series of test cards. It was expected that children would need to remember the rules and deduce on each trial which rule applied to each test card (cf. Zelazo & Reznick, 1991).

## EXPERIMENT 2

In Experiment 2, a new group of 3- to 4-year-olds was given a 2+2-Rules (bidimensional, no overlap) version of the DCCS. In this version, children were required to sort conflicting test cards according to two color rules and two shape rules, but the shape rules and color rules did not overlap. Thus, children were shown four target cards: a blue rabbit, a red boat, a green flower, and a yellow car. They were told two rules for sorting by one dimension (e.g., color) and two rules for sorting by the other (e.g., shape; see Figure 8). In particular, children were told, "If it's blue it goes there, if it's red it goes there, if it's a flower it goes there, and if it's a car it goes there." On the first 10 test trials, they were asked to sort five blue boats and five red rabbits. On the second 10 test trials, they were asked to sort five yellow flowers and five green cars. Notice that, as in the standard version, all test cards would be sorted differently if one were sorting by shape or by color. Also, children were asked to switch from sorting by one dimension to sorting by the other. However, any particular test card did not need to be treated differently depending on the game being played, so, according to CCC theory, no higher order rule was required.

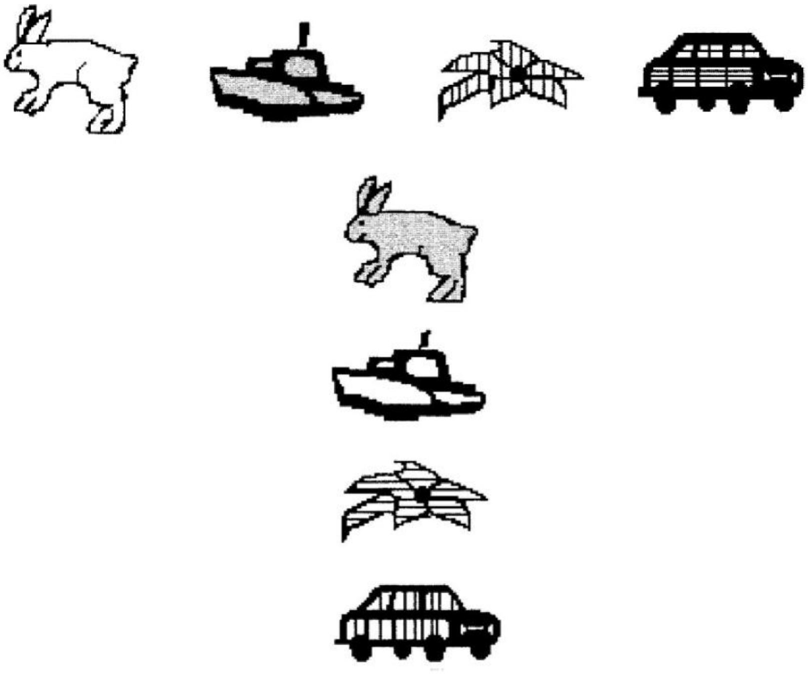

FIGURE 8.—Sample target cards (top row) and test cards in the 2+2-Rules (bidimensional, no overlap) version of the Dimensional Change Card Sort used in Experiment 2. Children are asked to sort test cards by two dimensions (e.g., color: "If it's blue it goes here; if it's red it goes there" and shape: "If it's a flower it goes there, and if it's a car it goes there."). Note: white indicates blue; grey indicates red; vertical stripes indicate green; horizontal stripes indicate yellow.

### *Method*

**Participants.** Sixteen 3- to 4-year-olds (*M* = 44.7 months; range: 37 to 50 months; 6 girls and 10 boys) were recruited in the same fashion as in Experiment 1. None of these children had participated in Experiment 1. (Indeed, there was no overlap among participants in any of the experiments to be described except as noted in the Participants section of Experiment 6).

**Procedure.** All children were administered the 2+2-Rules (bidimensional, no overlap) version of the DCCS, which was administered in the same fashion as the 2+2-Rules (unidimensional) version in Experiment 1. Children were shown four target cards (a blue rabbit, a red boat, a green flower, and a yellow car), and told, "If it's blue it goes here, if it's red it goes there, if it's a flower it goes there, and if it's a car it goes there." The experimenter then sorted one test card face-down into each tray to illustrate what the children were supposed to do. On each trial, the experimenter stated the relevant rules, selected a test card, labeled the card by both color and shape, and asked children, "Where does this go?" The first 10 test trials included five blue boats and five red rabbits, presented in a random order (with the constraint that no more than two cards of the same type be presented in succession). The second 10 test trials included five yellow flowers and five green cars, presented in a similar fashion. The total procedure took approximately 10 minutes to administer.

### *Results*

**Group analyses.** As in Experiment 1, performance was scored as the number of trials on which children sorted correctly, with separate scores for the first and last 10 trials. To assess the relative difficulty of the 2+2-Rules (bidimensional, no overlap) version, children's performance on this version was compared to children's performance on the standard version in Experiment 1. However, because the children in Experiment 2 were significantly older than the children in Experiment 1, this comparison was based only on data from the 35 children in Experiment 1 who were older than 36 months (mean age = 43.34 months, *SD* = 2.64, which did not differ from the mean age of children from Experiment 2, t(49) = 1.32, *p>.19).*

A paired sample t-test on scores from the 2+2-Rules (bidimensional, no overlap) version showed that there was no significant difference between children's performance in the first *(M*= 9.3 1, *SD*= 2.50) and second half *(M* = 7.94, *SD* = 4.01) , t(15) = 1.08, *p>.29* (see Figure 7). Next, children's performance on the 2+2-Rules (bidimensional, no overlap) version was compared with children's performance on the standard version from Experiment 1. A three-way mixed ANOVA with version (standard vs. 2+2 Rule) and sex as between-subjects variables and test half (first half vs. second half) as a within-subjects variable revealed significant effects of version, F(1, 47) = 42.21, *p*< .001 (effect size *f* = .95), and test half, F(1, 47) = 17.70, *p<.001* (effect size *f* = .61), as well as an interaction between version and test half, F(1, 47) = 7.24, *p* < .05. The interaction was due to the fact that in the first half children performed equally well on both versions (standard version: *M* = 8.69, *SD* = 2.96; 2+2-Rules [bidimensional, no overlap] version: *M*= 9.3 1, *SD* = 2.50), but in the second half, children performed poorly on the standard version *(M* = 2.17, *SD* = 3.88) and well on the 2+2-Rules (bidimensional, no overlap) version *(M* = 7.94, *SD* = 4.01).

**Individual analyses.** As in Experiment 1, success on the 2+2-Rules (bidimensional, no overlap) version was defined as 15 out of 20 cards sorted correctly. Thirteen (81%) of the 16 children in Experiment 2 succeeded on this version. All 3 children who failed sorted 10 cards correctly. Two of these children sorted by shape in both halves of the task, and the other child sorted by color in both halves.

A chi-square test comparing performance on the 2+2-Rules (bidimensional, no overlap) version to performance on the standard version in Experiment 1 showed that the numbers of children passing depended on the version, $\chi^2(1, N = 51) = 18.21$,p < .0001, with a greater proportion of children passing in the 2+2-Rules (bidimensional, no overlap) version.

### *Discussion*

In Experiment 2, the children performed well on the 2+2-Rules (bidimensional, no overlap) version of the DCCS, which required them to sort some test cards by color and some test cards by shape. Compared to the standard version of the DCCS used in Experiment 1, significantly more children passed the 2+2-Rules (bidimensional, no overlap) version.

Children's success on the 2+2-Rules (bidimensional, no overlap) version supports the suggestion that memory limitations are not a primary determinant of children's difficulty with the DCCS. Moreover, the comparison of children's performance on this version with their performance on the standard version of the DCCS in Experiment 1 helps to isolate the source of children's difficulty on the standard version. These two versions were similar in that children were told a total of four rules, two for sorting by color and two for sorting by shape. In addition, in both versions, children were asked to switch from using two rules for sorting by one dimension to using two rules for sorting by the other. However, a key difference between the versions may be that in the 2+2-Rules (bidimensional, no overlap) version, any particular test card did not need to be treated differently depending on the game being played. That is, there was no conflict among the rules. This issue is addressed further in Study 2.

## EXPERIMENT 3

In Experiments 1 and 2, the new versions all required children to sort a homogeneous series of test cards according to one dimension or another. Moreover, there were only one or two relevant dimensions (shape or color). It is possible, therefore, that these versions allowed children to chunk the information that they were required to remember, thereby reducing the demands on memory. Although it seems unlikely that the memory demands in the 2+2-Rules (bidimensional, no overlap) version were lower than those in the standard version, Experiment 3 was conducted to address the question of memory limitations further, and in a different way.

In Experiment 3, children were presented with a new version of the DCCS, the 4-Rules (superordinate) version, in which they were required to sort a relatively heterogeneous series of test cards according to four discrete superordinate categories. It was expected that the 4-Rules (superordinate) version would pose even greater memory demands than the new versions used in Experiments 1 and 2, and that children would not only need to remember the relevant rules but also make relatively difficult inferences to determine which rule was most appropriate for each test card. That is, in addition to a storage component, there was also a considerable processing component. Nonetheless, according to CCC theory, 3- to 4-year-olds should perform better on the 4- Rules (superordinate) version than on the standard version of the DCCS because only the standard version of the DCCS requires the construction of a higher order rule.

### *Method*

**Participants.** Twenty 3- to 4-year-olds (*M* = 41.5 months; range: 37 to 47 months; 9 girls and 11 boys) were recruited in the same fashion as in Experiment 1. An additional 3 children were tested but excluded from the final sample because they refused to complete the experiment *(n = 1)* or because of experimenter error *(n* = 2).

**Procedure.** Each child received the standard version of the DCCS and a 4-Rules (superordinate) version, with half the children receiving the standard version first, and half receiving the 4-Rules (superordinate) version first. The standard version was exactly like the standard version in Experiment 1, except that on each trial, the experimenter labeled each test card by the relevant dimension only (e.g., "Here's a flower"). A yellow flower and a green boat were used as target cards, and green flowers and yellow boats were used as test cards. Dimension order was counter- balanced such that roughly half of the children within each version order were first told to sort by color.

As in the 4-Rules versions used in Experiments 1 and 2, children in the 4-Rules (superordinate) version of the DCCS were shown four target cards and told four rules for sorting test cards. Target cards and test cards are shown in Table 2.

The experimenter described each target card in terms of the functional, superordinate categories cited in the rules (i.e., things that can walk, things you can wear, things you can ride, and things you can eat). Then the experimenter pointed to each target card in turn and said, "Now we're going to play a card game. In this game, we put all the things that can walk over here [points to the dog]. If it is something that can walk, put it in this box. We put all the things you can wear over here [points to the sweater]. If it is something you can wear, put it in this box. We put all the things you can ride over here [points to the bus]. If it is something you can ride, put it in this box. We put all the things you can eat over here [points to the apple]. If it is something to eat, put it in this box."

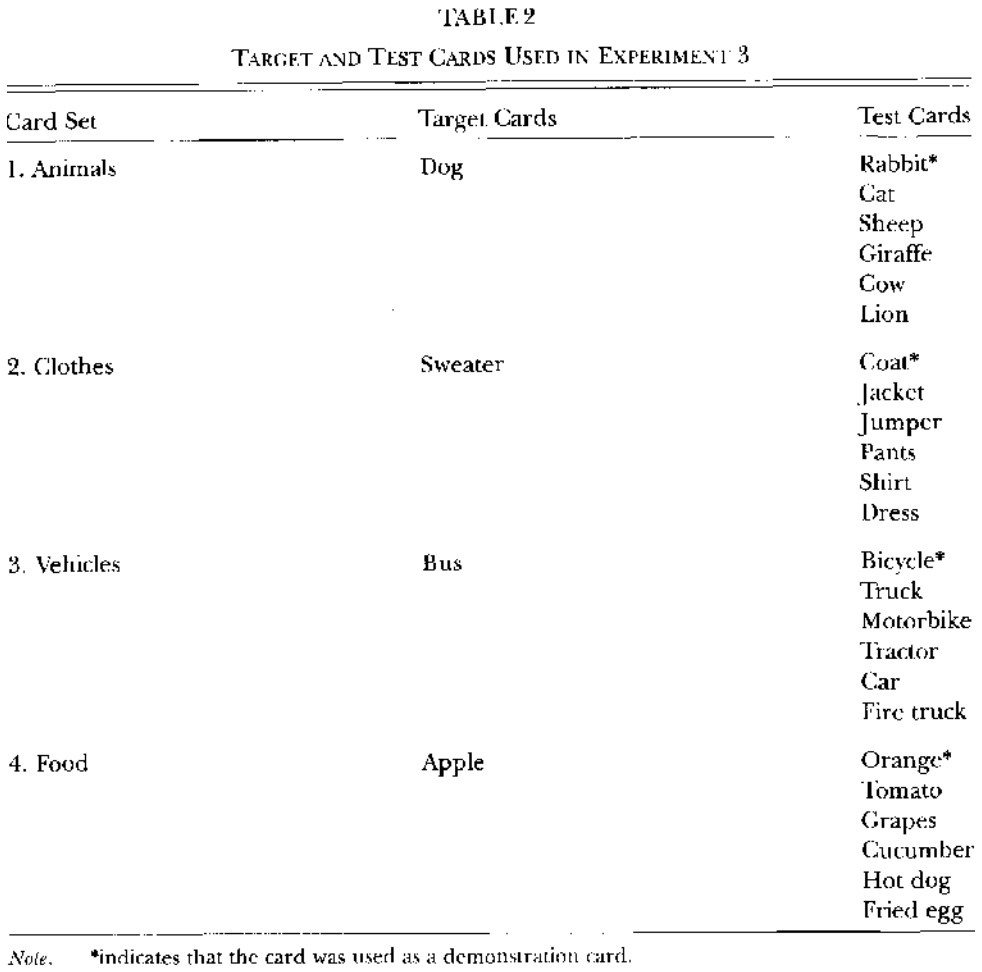

TABLE 2

TARGET AND TEST CARDS USED IN EXPERIMENT 3

| Card Set | Target Cards | Test Cards |
|---|---|---|
| 1. Animals | Dog | Rabbit*<br>Cat<br>Sheep<br>Giraffe<br>Cow<br>Lion |
| 2. Clothes | Sweater | Coat*<br>Jacket<br>Jumper<br>Pants<br>Shirt<br>Dress |
| 3. Vehicles | Bus | Bicycle*<br>Truck<br>Motorbike<br>Tractor<br>Car<br>Fire truck |
| 4. Food | Apple | Orange*<br>Tomato<br>Grapes<br>Cucumber<br>Hot dog<br>Fried egg |

*Note.* *indicates that the card was used as a demonstration card.

The experimenter then sorted one test card face-down into each tray to illustrate what children were supposed to do. After these demonstration trials, children received 20 test trials presented exactly like the 4-Rules version in Experiments 1 and 2.

The total procedure took approximately 15 minutes to administer.

### *Results*

**Group analyses.** Preliminary analyses revealed no effects of version order or dimension order, so these variables were excluded from subsequent analyses. In addition, all children performed perfectly on the first half of the standard version, so there was no variance in this cell. A two-way mixed ANOVA with sex as a between-subjects variable and version (standard vs. 4-Rules [superordinate]) as a within-subjects variable was conducted on number of correct trials (out of 20). This analysis revealed that children sorted more cards correctly in the 4-Rules (superordinate) version ($M = 17.25$, $SD = 4.98$) than in the standard version ($M = 14.3\ 5$, $SD = 4.64$), $F(1, 18) = 6.68$, $p < .05$ (effect size $f = .61$). Similar results were found when only the last 10 trials were considered: children performed better on the second half of the 4-Rules (superordinate) version ($M = 8.65$, $SD = 2.54$) than they did on the second half of the standard version ($M = 4.3\ 5$, $SD = 4.64$), $F(1, 18) = 17.22$, $p < .001$ (effect size $f = 1.05$; see Figure 7). Finally, a Pearson correlation was used to determine that postswitch performance on the standard version was significantly related to overall performance in the 4-Rules (superordinate) version ($r = .48$, $p < .05$).

**Individual analyses.** As in Experiments 1 and 2, children who sorted 15 or more cards on the standard version or the 4-Rules (superordinate) version were classified as passing. As shown in Table 3, more children failed the standard version than the 4-Rules (superordinate) version, $\chi^2(1, N = 20) = 4.09$, $p < .05$.

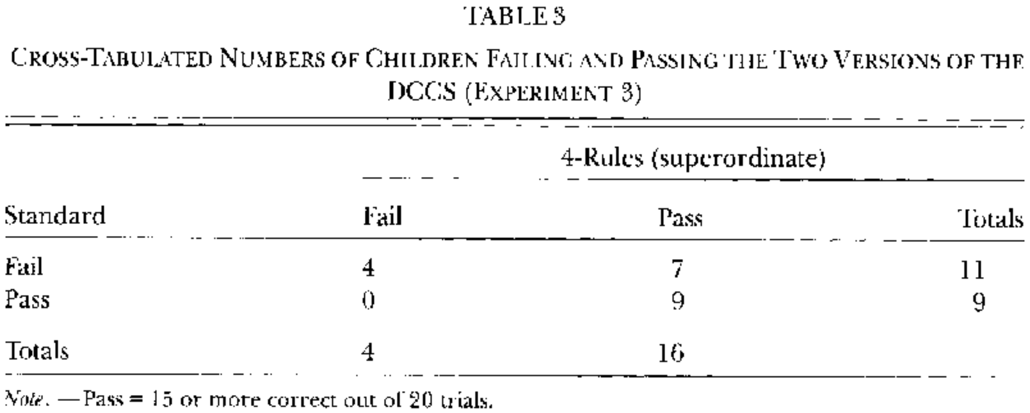

TABLE 3

CROSS-TABULATED NUMBERS OF CHILDREN FAILING AND PASSING THE TWO VERSIONS OF THE DCCS (EXPERIMENT 3)

| | 4-Rules (superordinate) | | |
|---|---|---|---|
| Standard | Fail | Pass | Totals |
| Fail | 4 | 7 | 11 |
| Pass | 0 | 9 | 9 |
| Totals | 4 | 16 | |

*Note*. —Pass = 15 or more correct out of 20 trials.

### *Discussion*

Experiment 3 explored further the possibility that memory constraints are responsible for 3-year-old children's perseveration on the DCCS by comparing children's performance on the standard version to their performance on a new 4-Rules (superordinate) version. The 4-Rules (superordinate) version likely posed even greater memory demands than the previous 4-Rules versions because the rules were relatively abstract and the test cards were heterogeneous. Despite this, children performed significantly better on the 4-Rules (superordinate) version. This finding therefore provides further evidence against the suggestion that limitations on children's memory capacity play an important role in 3- to 4-year-olds' poor performance on the DCCS.

## GENERAL DISCUSSION

Study 1 involved three experiments that examined whether 3- to 4year-olds' errors on the DCCS can be attributed to age-related limitations on memory capacity. Several theories (e.g., Case, 1985, 1992; Gathercole, 1998; Gordon & Olson, 1998; Morton & Munakata, 2002) suggest that age-related changes in short-term, active, or working memory are major determinants of children's performance on a wide variety of measures, including measures of executive function. In the DCCS, 3- to 4-year-olds may simply have difficulty keeping the postswitch rules in mind. Experiment 1 tested this memory account by comparing children's performance on the standard version of the DCCS to their performance on two new versions, the 4-Rules (unidimensional) and 2+2-Rules (unidimensional) versions, that were similar to the standard version in that they required children to sort by four rules. If memory constraints are a major determinant of children's performance, then the two new versions should be at least as difficult as the standard version and possibly more difficult because children are told the four rules simultaneously. Results showed that performance was significantly worse in the standard version; indeed, most children failed the standard version but not the other two versions.

Experiment 2 addressed the possibility that children did not really need to hold four rules in mind in order to succeed on the 4-Rules (unidimensional) and 2+2-Rules (unidimensional) versions. If children simply remembered the single relevant dimension, they could perhaps infer what went where in a given trial. In Experiment 2, children were given the 2+2-Rules (bidimensional, no overlap) version, in which they were told to sort first by two rules based on one dimension (e.g., color) and then by two rules based on the other dimension (e.g., shape). In this version, children needed to remember which cards to sort by color and which cards to sort by shape. Results revealed that 3- to 4-year-olds performed well on the 2 + 2- Rules (bidimensional, no overlap) version.

Experiment 3 presented children with the 4-Rules (superordinate) version, which likely posed even greater memory demands than the 4-Rules versions used in Experiments 1 and 2 because it involved superordinate rules and a heterogeneous series of test cards. Nonetheless, children performed significantly better on the 4-Rules (superordinate) version than on the standard version of the DCCS. Taken together, findings from the three experiments provide strong evidence against a memory account of performance on the DCCS.
The findings also help isolate what may be a crucial determinant of difficulty. In each of the modified versions of the DCCS, there was no conflict among rules and children did not have to sort the same test card in two different ways. Because each test card was uniquely associated with a different rule, children arguably did not

need to formulate and use a higher order rule for selecting among conflicting rules. The findings are thus consistent with the CCC theory, according to which it is higher order rule use and not memory that poses a problem for 3- to 4-year-olds.

In a similar vein, using the Day-Night Stroop task, Diamond and colleagues (Diamond, Kirkham, & Amso, 2002; Gerstadt et al., 1994) have also shown that it is the conflict between rules and not memory demands that creates difficulty for 3- to 4-year-olds. In the Day-Night Stroop task, children were instructed to say "day" when shown a line drawing of the moon and stars, and "night" when shown a line drawing of the sun. Gerstadt et al. found that 3-year-old children generally failed to comply with the task instructions, and that performance improved between 3.5 and 7 years (the percentage correct increased from 71 % correct to 92% correct). By contrast, 3- to 4-year-old children had few difficulties in a control condition in which children were instructed to say "day" and "night" in response to abstract line drawings; performance was already very good (91 % correct) by age 3.5 years.

Although the findings reported in Study 1 suggest that 3- to 4-year-olds' difficulty on the DCCS cannot be attributed to limitations on memory in any straightforward fashion, the findings do of course leave open the possibility that children's memory for the rules is limited in a way that permits them to succeed in some situations (i.e., those without conflict) but not others (those with conflict). Morton and Munakata's (2002) model is one such account (see also Munakata, McClelland, Johnson, & Siegler, 1997) because it attributes improvement in performance to the incremental increase in graded active memory representations. Graded memory accounts have produced evidence that conflict can increase the memory demand of a task, potentially explaining how memory limitations can impair performance only in the presence of conflict. The implications of the findings from Study 1 for graded memory accounts will be discussed further in Chapter VI.

The findings also leave open the possibility that working memory plays a necessary role in the DCCS and in other measures of executive function. In fact, this possibility is supported by the findings that the 4-Rules (superordinate) task and the standard version were significantly correlated, and that passing the 4-Rules (superordinate) task appeared to be a prerequisite for passing the DCCS. Indeed, according to CCC theory, the DCCS, like any measure of rule use, requires children to formulate explicit rules, maintain them in working memory, and then use them to guide their behavior. What the findings from Study 1 suggest is that 3- to 4-yearolds' difficulty depends more on the conflict among rules than on the simple requirement that rules be remembered. Study 2 focuses on how children resolve this conflict, and when they are required to do so.

## III. STUDY 2: RULE COMPLEXITYAND STIMULUS CHARACTERISTICS IN EXECUTIVE FUNCTION

### *INTRODUCTION AND SUMMARY*

The results from Study 1 suggest that 3- to 4-year-olds' difficulty with the DCCS cannot be attributed in a straightforward fashion to limitations on short-term or working memory (i.e., difficulty keeping the postswitch rules in mind). Children performed well on several new versions of the DCCS in which they were required to sort according to four rules. In one version, the 2+2-Rules (bidimensional, no overlap) version, children were required to sort some test cards by color and some test cards by shape. These results in particular show that neither memory nor bidimensionality per se appeared to be the source children's difficulty on the standard version.

However, one possibility is that children have difficulty on the DCCS because they cannot treat the same stimulus (i.e., test card) in two different ways in the context of a single task. For example, children who match a red rabbit to a red boat by color may have difficulty matching the very same card by shape to a blue rabbit on subsequent trials. This hypothesis follows both from inhibition accounts of the DCCS (e.g., Kirkham et al., in press; Perner & Lang, 1999) and from Perner's redescription hypothesis (Perner et al., 2002). Inhibition accounts hold that preswitch responses and/or attention to the preswitch dimension become prepotent, and 3- to 4-year-olds lack the inhibitory control to suppress them. The redescription hypothesis holds that 3- to 4-yearolds have difficulty appreciating that a single stimulus can be described in multiple ways.

In contrast, CCC theory predicts that 3- to 4-year-olds can treat a single stimulus in two different ways under some circumstances—namely, whenever doing so does not require the use of a higher order rule. According to CCC theory, a higher order rule will be required whenever rules are nested under different setting conditions in a hierarchical tree structure like that in Figure 3. Under these circumstances, children need first to consider a setting condition and then to select the appropriate rule.

Although it is sometimes supposed that higher order rules are required only when there are two pairs of conflicting rules (Perner, Lang, & Kloo, 2002), we believe that they are required whenever there is "a conflict in at least two of the outcomes that span the width of the tree" (Frye, 2000, p. 154). This specification suggests that a higher order rule will be required even for a single pair of rules when the rules are nested under different major branches of a hierarchical tree structure. For example, in many standard measures of theory of mind, such as false belief tests, only a subset of the tree structure is relevant (e.g., "If Maxi, then red cupboard; if me, then blue cupboard"), but as long as two different rules must be nested under different setting conditions, then a higher order rule is required because children must consider both the setting condition and the rule when deciding what to do. Similarly, from this perspective, it should be possible to create a "pruned tree" version of the DCCS that continues to be difficult for 3- to 4-year-olds (see Figure 9).

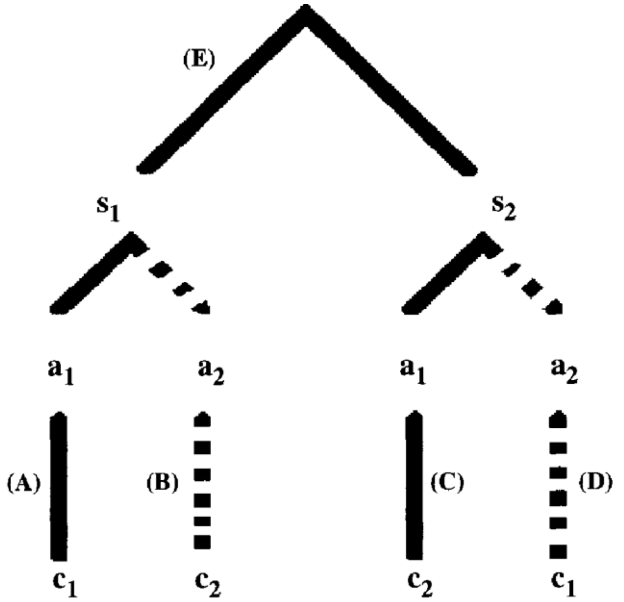

FIGURE 9.—"Pruned" hierarchical tree structure showing two rules (A and C) nested under different major branches of the tree structure. According to Cognitive Complexity and Control theory, switching between these two rules requires consideration of the setting conditions as well as the antecedent conditions. *Note.* $s_1$ and $s_2$ = setting conditions; $a_1$ and $a_2$ = antecedent conditions; $c_1$ and $c_2$ = consequences.

In Study 2, three experiments were designed to test the circumstances in which children can and cannot use rules to respond in two different ways to a single stimulus. In this study, conflict among rules was assessed both within and across dimensions. All versions in this study involved conflict among rules, but only bidimensional rules were nested under different setting conditions. This study also explored the effects of two types of stimulus characteristic (one vs. two test cards; integrated vs. separated stimuli) that might be expected to affect children's performance on the DCCS.

Experiment 4 involved a version of the DCCS in which (a) children were required to respond in two different ways to a single test card (i .e., there was conflict among the rules), (b) only a single pair of rules was required, and (c) these rules were nested under different setting conditions. In this Pruned Tree (single test card) version of the DCCS, only a subset of the four rules was used (i.e., there was one preswitch and one postswitch rule), and only one of the two possible test cards was used. Thus, for example, if the target cards were a green flower and a yellow car, then the test card might be a green car. During the preswitch phase, children were told to play the green game, and during the postswitch phase they were told to play the car game. Results suggested that when bidimensional rules are used, 3- to 4-year-olds have difficulty employing even a single pair of rules.

In Experiment 5, 3- to 4-year-olds were tested on a version in which (a) there was conflict among the rules, (b) only a single pair of rules was required, but (c) these rules were *not* nested under different setting conditions. In this Unidimensional (split stimuli) version, children were told a pair of rules that focused on only one of the dimensions (e.g., color) and they were required to use these rules to sort a single split test card (see Figure 10). Thus, for example, children might first be told to play the green game, and then be told to play the blue game. Under these circumstances 3- to 4-year-olds performed well.

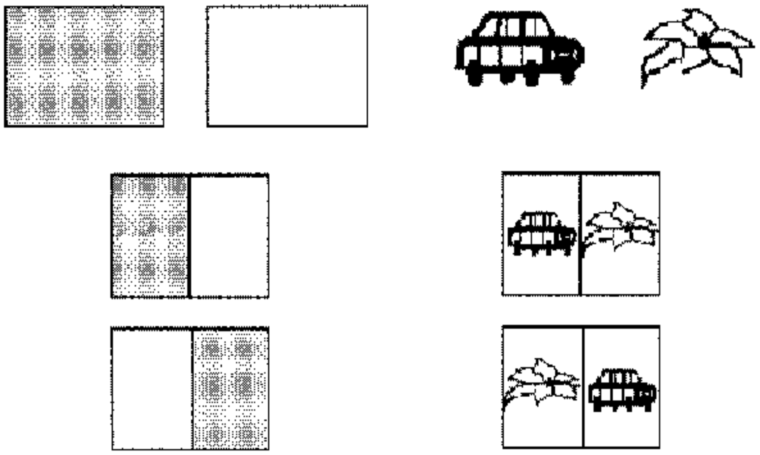

FIGURE 10.- Sample target cards (top row) and test cards in the Unidimensional (single test card) version of the Dimensional Change Card Sort used in Experiment 5. On the left, color is the relevant dimension. Children are told two rules ("If green then here, if blue then there"), asked to use one of the rules ("Play the green game"), and then asked to use the other ("Play the blue game"). On the right, shape is the relevant dimension. Children are told two rules ("If car then here, if flower then there"), asked to use one of the rules ("Play the car game"), and then asked to use the other ("Play the flower game"). Note: on the left white indicates blue; grey indicates green; on the right, white indicates unfilled.

Experiment 6 examined the effect of rule dimensionality together with a potentially important aspect of the stimuli used in Experiment 5. Rules were either bidimensional (as in Experiment 4) or unidimensional (as in Experiment 5), and the dimensions on the test cards were either integrated as in Experiment 4 or separated as in Experiment 5. As in Experiments 4 and 5, all versions involved conflict among rules, but only bidimensional rules were nested under different setting conditions. Results revealed that children were much more likely to perseverate on the bidimensional versions than they were on the unidimensional versions. However, there was no effect of whether the stimuli were integrated versus separated. Together, these findings show that 3- to 4- year-olds can treat a single stimulus in two different ways, and they further support the hypothesis that 3- to 4- year-olds' difficulty on the standard version of the DCCS can be attributed to the requirement that they use a higher order rule.

## EXPERIMENT 4

In Experiment 4, children were given the Pruned Tree (single test card) version, in which they were required to use a pair of bidimensional rules to sort a single test card. Because only a single pair of rules was used, instead of two incompatible pairs of rules, and because only a single test card was used, it might be expected that 3- to 4-year-olds should do better on the Pruned Tree (single test card) version than on the standard version of the DCCS. This follows, for example, from the memory accounts considered in Study 1. According to CCC theory, however, 3- to 4-year-olds should have difficulty with this version because two conflicting rules are nested under different major branches of a hierarchical tree structure. To test these predictions, children's performance on this version was compared to their performance on the standard version and on a modified standard version in which only one test card was used. This last version, called the standard version (single test card), was included to assess any possible effects of using only a single test card, instead of the usual two.

### *Method*

**Participants.** Forty-eight 3- to 4-year-olds (M = 41.7 months; range: 35 to 52 months; 26 girls and 22 boys) were recruited in the same fashion as in Experiment 1. An additional 6 children were excluded from the final sample because of experimental error (n = 4), parental interference (n = 1), or refusal to complete the experiment (n = 1).

Children were randomly assigned to receive one of three versions of the DCCS: the Pruned Tree (single test card) version, the standard version, or the standard version (single test card). There were two sets of cards, corresponding to two different pairs of dimensions. For set 1 (color and shape), the number of items depicted on each test card was held constant. Target cards were (one) yellow car and (one) green flower, and the test cards were (one) green car or (one) yellow flower. For set 2 (number and size), the shape of the items was held constant (all items were rabbits). Target cards were one big thing (i.e., one big rabbit) and two little things, and test cards were two big things and one little thing. Half of the children in each version received set 1 and half received set 2. Within each set, the particular dimension presented first was counterbalanced.

**Procedure.** The standard version was administered exactly as in the previous experiments, except that there were 5 preswitch trials and 5 postswitch trials. Also, on the second demonstration trial, children themselves were told to sort the test card (which was a different type of card than the card the experimenter sorted on the first demonstration trial), and children were corrected if necessary on this demonstration trial. During test trials, test cards were labeled by both dimensions.

The standard version (single test card) was identical to the standard version, except only one of the two possible test cards was used on all pre-and postswitch trials. As a result, in the demonstration trials, both the experimenter and the children sorted the same type of test card.

The Pruned Tree (single test card) version was administered like the standard version, except that children were told a pair of rules that spanned two dimensions. For example, the task was introduced, the rules were explained, and children who received the color and shape set (set 1) were shown the green car and told, "If it's the green game put it here, but if it's the car game put it here." Then children were given two demonstration trials, each illustrating one of the rules. On the first demonstration trial, the experimenter played the game that was eventually required in the postswitch phase. On the second demonstration trial, children played the game that was to be played in the preswitch phase. As in the two standard versions, there were 5 preswitch trials and 5 postswitch trials. On each trial, children were told the rules, shown a test card that was labeled by both dimensions, told, "Play the (e.g., green) game," and asked, "Where does this go?" After the 5 preswitch trials, children were told explicitly to switch to the new game. The total procedure took approximately 10 minutes to administer.

### *Results*

**Group analyses.** Performance was initially scored as the number of correct postswitch trials (out of 5). To assess the effect of the particular dimension pair used (color and shape [set 1] vs. number and size [set 2]), a two-way (Version x Dimension Pair) ANOVA was conducted. This analysis revealed no significant effects of Dimension Pair and no Version x Dimension Pair interaction. This analysis was followed by a series of one-way (Preswitch Dimension) ANOVAs that assessed whether the particular dimension (within each dimension pair) that was used in the preswitch phase was related to postswitch performance. These analyses were run separately for the children in the standard versions (who were told explicitly about both values of each dimension) and children in the Pruned Tree version (who were only told explicitly about one level of each dimension). No significant effects of preswitch dimension were revealed for either of the dimension pairs, except that children in the standard versions scored better when number rather than size was the preswitch dimension, $F(1, 14) = 13.3$, $p < .01$ (effect size $f = .25$).

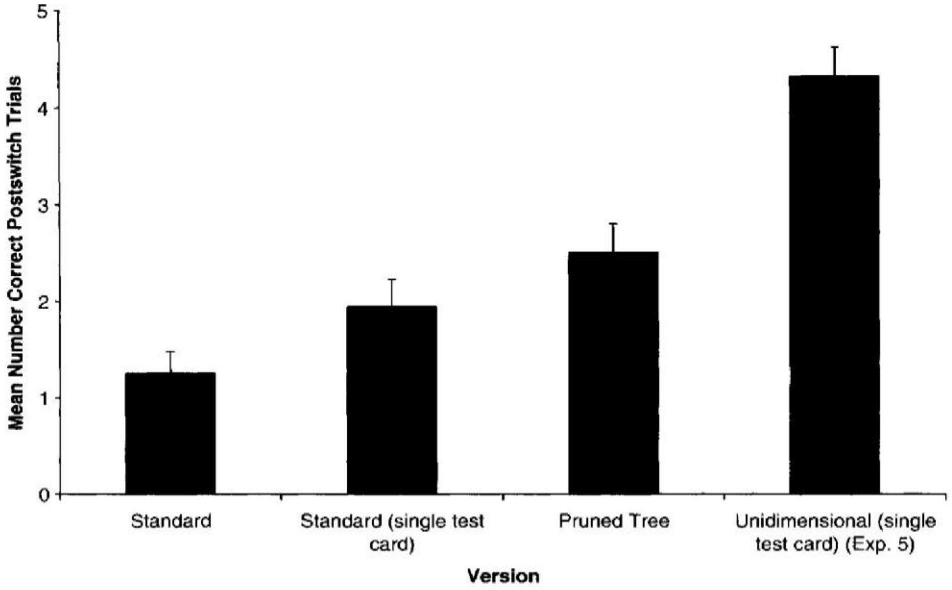

FIGURE 11.—Mean number correct (and standard error) on the postswitch trials of the Dimensional Change Card Sort, according to version. The standard, standard (single test card), and Pruned Tree versions were administered in Experiment 4 ($n = 16$ for each version). The Unidimensional (single test card) version was administered in Experiment 5 ($N = 16$).

Because all the versions were counterbalanced, we conducted the remaining analyses collapsed across dimension pairs and preswitch dimensions. A two-way (Sex x Version) ANOVA conducted on all participants failed to reveal any significant effects (see Figure 11, first three bars). The analysis was then repeated excluding those children (n = 13) who failed the preswitch phase (i.e., who scored fewer than 4 of 5 correct). Once again, no significant effects were revealed.

TABLE 4

NUMBERS (AND PERCENTAGES) OF CHILDREN FAILING AND PASSING THE POSTSWITCH PHASE OF THE DCCS BY VERSION (EXPERIMENT 4)

| | Version | | |
|---|---|---|---|
| | Standard | Standard (single) | Pruned Tree |
| Fail | 11 (100%) | 10 (71%) | 7 (70%) |
| Pass | 0 (0%) | 4 (29%) | 3 (30%) |
| Total | 11 | 14 | 10 |

*Note.* —Pass = 4 or more correct out of 5 postswitch trials (binomial, $p < .19$). Standard (single) = standard (single test card) version. Pruned Tree = Pruned Tree (single test card) version. Data are from children who passed the preswitch phase.

**Individual analyses.** Because the main goal of the individual analyses was to determine whether individual children switched sorting criteria, only children who passed the preswitch phase (4 or 5 correct) were included. Children were classified as passing the postswitch phase if they scored at least 4 out of 5 correct (see Table 4). A chi-square test revealed that success on the postswitch phase did not depend on the version of the DCCS that they received, $\chi^2(2, N = 35) = 4.02, p > .05$.

### *Discussion*

Three-year-olds in this experiment exhibited considerable difficulty using even a single pair of rules. In contrast to Experiment 2, in which children performed well when required to use four nonoverlapping bidimensional rules, the majority of 3- to 4-year-olds failed the Pruned Tree (single test card) version in Experiment 3. This finding underscores the importance of conflict among rules and is consistent with the suggestion that 3- to 4-

year-olds have difficulty whenever they are required to use rules that span major branches in a hierarchical tree structure. According to CCC theory, when children are asked to play the "red game" and then the "rabbit game" with reference to a single stimulus, they must formulate a higher order rule, select a dimension (i.e., a setting condition), and then select the appropriate rule.

## EXPERIMENT 5

Experiment 4 demonstrated that 3- to 4-year-olds failed to switch flexibly even when they were required to use a single pair of rules (as opposed to two pairs of rules in the standard DCCS). According to CCC theory, failure on the Pruned Tree (single test card) version resulted from the inability to construct a higher order rule. However, it is also possible that young children are simply incapable of sorting the same test card in two different ways within an experimental context.

Experiment 5 was designed to test this hypothesis directly by presenting 3- to 4-year-olds with a version of the DCCS in which only one dimension (e.g., color) was used: the Unidimensional (single test card) version. Although the wording of the rules in this version was identical to the wording in the Pruned Tree (single test card) version (i.e., "If it's the _______________ game put it here, but if it's the ________________ game put it here"), CCC theory predicted that 3- to 4-year-olds would perform well on this version because only one dimension, and therefore only one major branch of the tree in Figure 3, need be considered. In contrast, however, if children were unable to sort a single test card in two different ways, either because of weak inhibition or because of difficulty redescribing stimuli, then they would be expected to fail this version.

### *Method*

**Participants and design.** Sixteen 3- to 4-year-olds (M = 41.7 months; range: 38 to 47 months; 7 girls and 9 boys) were recruited in the same fashion as in Experiment 1.

All children received two instances of the Unidimensional (single test card) version, one with color rules and one with shape rules, in a counterbalanced order. In this version, the target cards were unidimensional (e.g., a blue patch vs. a green patch, or an outline of a car vs. the outline of a flower). The test card, on the other hand, displayed both values of the relevant dimension only (see Figure 10). For color rules, the test card was half green and half blue. For the shape rules, the test card displayed the outline of a flower on one lateral side and the outline of a car on the other lateral side. For each task, half of the children were required to first sort by one level of the dimension (e.g., play the green game) and then switch to the second level (e.g., play the blue game).

**Procedure.** The Unidimensional (single test card) version was administered in a similar fashion to the Pruned Tree (single test card) version in Experiment 4. On test trials, children were shown the green/ blue card and told, "If it's the green game put it here, but if it's the blue game put it here. Let's play the green (blue) game. Where does this one go?" After the first task, children were given a brief intermission (approximately 2 minutes). Then the second task was administered in an identical fashion (except with cards and rules from the other dimension). The total procedure took approximately 10 minutes to administer.

### *Results*

**Group analyses.** An initial repeated-measures ANOVA failed to detect any differences in number of correct postswitch trials on the two sorts. Thus, to simplify the analyses and to keep them comparable to Experiment 4, the results were averaged across both tasks. A one-way (Order) ANOVA was then conducted to test for possible order effects. The analysis revealed no significant effect of order, and therefore this variable was excluded from further analyses.

A one-way (Sex) ANOVA failed to reveal any effect of sex, $F(1, 14) = 0.95$, *ns.* In general, children performed very well on this task, averaging 4.2 out of 5 on the postswitch phase ($SD = 2.4$), significantly above the chance level of 2.5 out of 5, $t(15) = 5.6$, $p < 0.01$. These results remained significant even after excluding children who failed the preswitch phase (averaging fewer than 4 out of 5 correct; $n = 4$).

Mean postswitch performance on the Unidimensional (single test card version) was then compared to performance on the Pruned Tree (single test card) version used in Experiment 4, using a one-way (Version) ANOVA. Results revealed a main effect of version, $F(1, 30) = 6.72$, $p < .05$ (effect size $f = .47$), confirming superior performance on the Unidimensional (split stimuli) version (see Figure 11).

**Individual analyses.** Those children who passed the preswitch phase were also classified as either passing (averaging 4 or more out of 5 correct) or failing (averaging fewer than 4 out of 5 correct) the postswitch phase. Eleven out of these 12 children passed the postswitch phase, which is significantly greater than chance, $\chi^2$ $(1, N = 12) = 8.33, p < .01$.

### *Discussion*

The results of Experiment 5 indicate that children are capable of sorting the same stimulus card two different ways when only one dimension is considered. Although the wording of the rules was identical to the wording of the rules in the Pruned Tree (single test card) version in Experiment 4 (e.g., "If it's the _______ game it goes here and if it's the _________ game it goes here. We're playing the ___________ game. Where does it go?"), children performed much better on the Unidimensional (split stimuli) version. According to CCC theory, this is because only the Pruned Tree (single test card) version requires the use of a setting condition to bridge the two rules—because each rule corresponds to a different dimension. In contrast, no setting condition is needed by the Unidimensional (split stimuli) version because the rules correspond to levels *within* the same dimension.

The results of Experiment 5 are inconsistent with both inhibition accounts of the DCCS (e.g., Kirkham et al., in press; Perner & Lang, 2002) and Perner's redescription hypothesis (Perner et al., 2002). If 3- to 4-yearolds' difficulty on the standard version is due to an immature inhibition mechanism—producing lack of response control or representational inflexibility, then children should perform poorly on the Unidimensional (single test card) version. Similarly, they should perform poorly on this version if they have difficulty appreciating that a single stimulus can be described in multiple ways.

In contrast, CCC theory predicts that 3- to 4-year-olds can treat a single stimulus in two different ways under some circumstances—namely, whenever doing so does not require the use of a higher order rule. According to CCC theory, a higher order rule will be required whenever rules are nested under different setting conditions in the hierarchical tree structure shown in Figure 3. Under these circumstances, children need first to consider a setting condition and then to select the appropriate rule.

However, in defense of Perner et al.'s (2002) redescription theory, it could be argued that in Experiment 5, children did not treat the unidimensional stimulus as a single entity or Gestalt, but instead focused on different aspects of the stimulus in the pre- and postswitch phase. If this were the case, then perhaps children did not need to coordinate alternative perspectives in Experiment 5. Experiment 6 examined this possibility by presenting children with a bidimensional version of the DCCS that involved spatially separated dimensions. Following the logic of this defense of the redescription theory, children should also do well on this version of the DCCS because it also allows them to focus on different aspects of the test cards without requiring them to coordinate these aspects. By contrast, CCC theory would predict that children do poorly on this bidimensional separated version because it requires them to cross major branches of a tree-like structure.

## EXPERIMENT 6

Experiment 4 showed that 3- to 4-year-olds had difficulty sorting on a version of the DCCS in which they were required to sort a single test card in two different ways according to two different dimensions—the Pruned Tree (single test card) version. In Experiment 5, a group of 3- to 4-year-olds was able to sort a single test card in two different ways when doing so did not require sorting according to two dimensions. Experiment 6 was designed to test directly the prediction, made by the CCC theory, that 3- to 4-year-olds are able to treat a single stimulus in two different ways when doing so does not require crossing major branches of a tree structure like that in

Figure 3. This experiment also assessed the effect of a potentially important difference in the stimuli used in Experiment 4 versus those used in Experiment 5—whether test cards were integrated versus separated. In this manner, Experiment 6 examined the possibility, raised in defense of the redescription theory, that when presented with separated stimuli, children serially alternate between focusing on different aspects of the stimulus, without coordinating two alternative perspectives. If children simply serially alternated between different perspectives in Experiment 5, then they should do well on a bidimensional version of the DCCS that involved separated stimuli.

Shepp and colleagues (Barrett & Shepp, 1988; Shepp & Barrett, 1991; Shepp, Barrett, & Kolbet, 1987; but see Ridderinkhof, van der Molen, Band, & Bashore, 1997) have suggested that there are age-related changes in the way in which young children and adults perceive objects (e.g., colored rabbits). Whereas younger children perceive these stimuli holistically as integrated wholes, older children and adults are better at analyzing these stimuli into separate dimensions or features. Support for this suggestion comes from findings that in matching tasks, the performance of younger children (e.g., 5- to-6-year olds) is more closely related to whether the stimuli are spatially integrated or separated than is the performance of older children and adults.

According to this separability hypothesis, children's performance on the DCCS should be related to whether the dimensions of the target and test cards are presented in an integrated or separated fashion. Indeed, children's difficulty with the DCCS may be due to difficulty analyzing the stimuli into separate attributes, located on different dimensions.

In this experiment, four versions of the DCCS were created by crossing two variables, rule dimensionality (bidimensional vs. unidimensional) and whether the test cards were integrated or separated (see Figure 12). According to CCC theory, children were expected to perform well on both unidimensional versions because, although these versions involve conflicting rules, they do not require the use of rules nested under different major branches of the tree structure in Figure 3. In contrast, children were expected to perform poorly in the bidimensional versions because these versions do require the use of rules nested under different major branches. The separability hypothesis was tested by comparing children's performance on the two bidimensional versions.

### *Method*

**Participants and design.** Forty-eight 3- to 4-year-olds (M = 42.8 months; range: 37 to 49 months; 23 girls and 25 boys) were recruited in the same fashion as in Experiment 1, except that 13 of the children tested in this experiment also participated in Experiment 5. These 13 children were evenly distributed across the four experimental versions (4 children in one version, and 3 each in the other three versions), and removal of these children from the analyses did not alter the results. An additional 2 children were tested but excluded from the final sample because they refused to complete the experiment.

Twelve children were assigned randomly to each of the four conditions: unidimensional separated (US), unidimensional integrated (UI), bidimensional separated (BS), and bidimensional integrated (BI). In each condition, children received two tasks (i.e., a replication of the version used in that condition), one involving color and/or shape, and the other involving pattern and/or size. The order in which rule pairs were presented was counterbalanced across participants.

### *Materials*

Two sets of cards were used. The first set varied in color (red or blue) and shape (cars or flowers). The second set varied in size (large or small) and pattern (dots or stripes). In the unidimensional versions, separated test cards depicted the two possible response options (e.g., red and blue) adjacently on a single card, whereas the integrated test cards depicted the two aspects of a dimension in a single form, such as a red and blue rabbit. The target cards for such a version would be a red rabbit and a blue rabbit (see Figure 12). For the separated test cards, one level of the relevant dimension was presented on the left side of the card for half of the trials, and on the right side for the remaining trials.

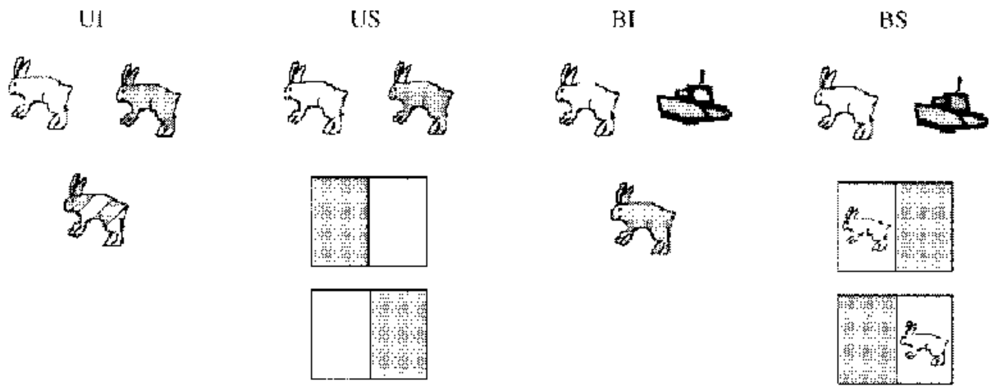

FIGURE 12.—Sample target cards (top row) and test cards in the four versions of the Dimensional Change Card Sort used in Experiment 6. UI = Unidimensional Integrated, US = Unidimensional Separated, BI = Bidimensional Integrated, BS = Bidimensional Separated. In the examples of the two unidimensional versions, color is the relevant dimension; children were told two rules ("If blue then here, if red then there"), asked to use one of the rules ("Play the blue game"), and then asked to use the other ("Play the red game"). In the examples of the two bidimensional versions, children were first told to sort by one dimension (e.g., color), and then told to sort by the other (shape). Note: white indicates blue; grey indicates red.

The bidimensional versions required sorting by two dimensions, such as size and pattern. In these versions, for the separated stimuli, both dimensions were presented adjacently on a single card (e.g., blue on one side and a rabbit on the other). The integrated stimuli consisted of both dimensions presented in a single form, such as a red rabbit. The target cards for this version consisted of a blue rabbit and a red boat (see Figure 12). For the separated test cards, one level of the relevant dimension was presented on the left side of the card for half of the trials, and on the right side for the remaining trials.

In all four versions, the same test card (but with lateral side varied for separated test cards) was presented for all five preswitch trials and all five postswitch trials.

**Procedure.** The procedure for all versions was identical to the procedure for the Unidimensional (single test card) version used in Experiment 5. However, for the bidimensional versions, children were told bidimensional rules (e.g., "if it's red it goes here, but if it's blue it goes there") on the pre- and postswitch phases. In all cases, test cards were labeled simply as "one" (e.g., "Where does this one go?"). Children were given a short break (approximately 5 minutes) between the two tasks. The total procedure took approximately 20 minutes to administer.

### *Results*

**Group analyses.** As in Experiments 4 and 5, correct responding was scored as the number of correct postswitch trials. To assess the effects of the particular rule pairs used (i.e., the red/blue pair or the stripe/dot pair for the US and UI versions; the color/shape pair or the number/size pair for the BS and BI versions) and the order in which they were used, two mixed (Rule Pair x Order) ANOVAs were conducted, one for the unidimensional versions and one for the bidimensional versions. Rule pair was a within-subject variable and order was a between-subject variable. The only significant finding was that in the unidimensional versions, children performed significantly better on the red/blue rule pair than on the stripe/dot rule pair, *F(1,* 23) = 4.5 5, p < .05 (effect size *f* = .45). These analyses were followed by a series of one-way (Preswitch Dimension) ANOVAs that assessed whether within each rule pair, the particular rule (or rules) used in the preswitch phase was related to performance. The only significant finding was that children performed better when the blue rule as opposed to the red rule was used in the preswitch phase, F(1, 22) = 5.0, p < .05 (effect size *f* = .48). Because all the versions were counterbalanced and in general there were few order effects, we conducted the remaining analyses collapsed across rule pair, order, and preswitch rule(s).

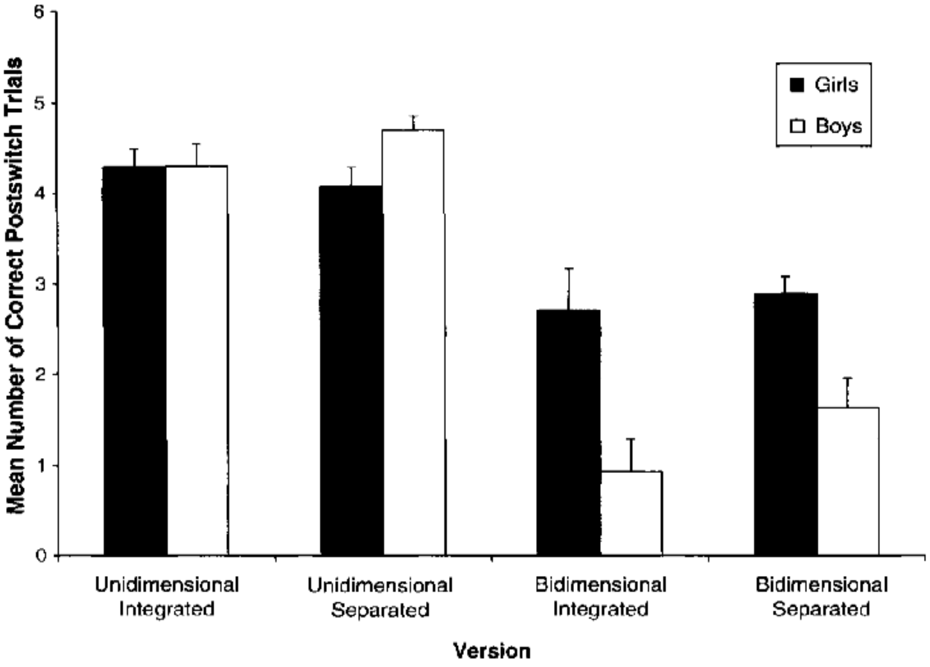

FIGURE 13.—Mean number correct (and standard error) on the postswitch trials of the Dimensional Change Card Sort, according to version and sex (Experiment 6).

An overall repeated measures ANOVA failed to detect any differences between number of correct postswitch trials for the first and second tasks that children received. Thus, to simplify the analyses and keep them compatible with the analyses of Experiments 4 and 5, the results were averaged across both tasks (see Figure 13). A three-way (Sex x Dimensionality x Separability) ANOVA revealed that children performed better on the unidimensional versions than on the bidimensional versions, F(1, 40) = 29.0, $p < .01$ (effect size $f = .78$). Also, the interaction between sex and dimensionality was significant, F(1, 40) = 4.6, $p < .05$. Tests of simple effects indicated that the effect of dimensionality was significant for both boys, F(1, 23) = 26.7, $p < .0001$ (effect size $f = 1.08$), and girls, F(1, 21) = 6.77,*p* 6.77, $p < .05$ (effect size $f = .56$), although the effect was more pronounced for boys. The results did not change when those children who failed the preswitch phase (i.e., whose average score on the preswitch phase was fewer than 4 out of 5 correct) were excluded.

**Individual analyses.** Children were classified as passing the postswitch phase if they averaged at least 4 out of 5 correct (see Table 5). Analyses revealed that for those children who passed the preswitch phase, success on the postswitch phase depended on version, $\chi^2$ (3, $N = 40$) = 14.9, $p < .01$. As can be seen in Table 5, children in the unidimensional versions tended to pass the postswitch phase, whereas children in the bidimensional versions tended to fail.

TABLE 5

NUMBERS (AND PERCENTAGES) OF CHILDREN FAILING AND PASSING THE POSTSWITCH PHASE OF THE DCCS BY VERSION (EXPERIMENT 6)

| | Version | | | |
|---|---|---|---|---|
| | UI | US | BI | BS |
| Fail | 2 (20%) | 1 (11%) | 8 (73%) | 8 (80%) |
| Pass | 8 (80%) | 8 (89%) | 3 (27%) | 2 (20%) |
| Total | 10 | 9 | 11 | 10 |

*Note.* Pass = an average score of 4 or more correct out of 5 postswitch trials (binomial, $p < .19$). UI = Unidimensional Integrated, US = Unidimensional Separated, BI = Bidimensional Integrated, BS = Bidimensional Separated. Data are from children who passed the preswitch phase.

### *Discussion*

Experiment 6 demonstrates clearly that when there is conflict among rules, 3- to 4-year-olds perform well on unidimensional versions of the DCCS but poorly on bidimensional versions. These results replicate, in a single experiment, the key findings from Experiments 4 and 5, namely that 3- to 4-year-olds can sort a single test card in two different ways when doing so only requires the use of a single dimension (and hence, does not require crossing major branches of a tree structure like that in Figure 3). Taken together, the results of these experiments provide strong evidence against both inhibition accounts of the DCCS (e.g., Kirkham et al., in press; Perner & Lang, 2002) and Perner's redescription hypothesis (Perner et al., 2002).

The results of Experiment 6 also assessed a potentially important difference in the presentation of the stimuli used in Experiment 4 versus those used in Experiment 5 -- whether test cards were integrated versus separated and showed that it had no effect. This finding suggests that children's difficulty on the standard version of the DCCS cannot be attributed to the fact that the stimuli are presented in a spatially integrated fashion.

Finally, the results revealed a Sex x Dimensionality interaction indicating that the effect of dimensionality, although significant for both boys and girls, is more pronounced for boys. Insofar as this interaction also indicates that girls perform better than boys on the more difficult bidimensional versions, it raises the possibility that the cognitive processes underlying performance on the DCCS develop more quickly in girls. This issue will be addressed further in the Discussion of Experiment 8.

## GENERAL DISCUSSION

The results of Study 2 show that 3- to 4-year-olds do not inevitably "lock in" on a single way of responding to (or representing) a specific test card. Three-year-olds are able to treat a single test card in two different ways when doing so does not require using bidimensional rules. In Experiments 5 and 6, children were shown target cards that differed only on one dimension (e.g., a blue rabbit and a red rabbit). They were then presented with a test card that could be matched to either target card (e.g., a blue-and red-striped rabbit) and were told to use one rule for sorting it (e.g., "If we're playing the red game, then put it here"). After several trials, they were told to switch and use a different, incompatible rule (e.g., "If we're playing the blue game, then put it there"). Under these circumstances, 3- to 4-year-olds effectively switched and ceased their old way of responding. In contrast, in Experiment 4, sorting by even a single pair of rules was difficult for 3- to 4-year-olds when the two rules spanned major branches in the hierarchical tree structure shown in Figure 3. Together, these findings demonstrate that perseveration is at least partly a function of rule complexity, and cannot be attributed solely to a problem with inhibitory control—either at the level of responses or at the level of representations.

The results are also inconsistent with a version of Perner's redescription hypothesis (Perner & Lang, 2002) because children should perform poorly on the unidimensional versions if they have difficulty appreciating that a single stimulus can be described in multiple ways. As predicted by CCC theory, redescription in the context of the DCCS appears to be easy or difficult depending on whether or not the rules call for sorting within or across major branches in the tree structure in Figure 3.

Finally, Experiment 6 also showed that whether stimulus dimensions are presented in a spatially integrated or separated fashion has little effect on performance. This finding contradicts the prediction derived from the separability hypothesis (Shepp & Barrett, 1991) that children may fail the DCCS because they process spatially integrated stimuli holistically and have difficulty attending selectively to particular dimensions or attributes, although further study of the effects of spatial integration versus separation in measures of children's executive function (e.g., the Stroop test; see Archibald & Kerns, 1999) is clearly warranted.

Although the spatial separation of dimensional information was not related to children's performance on the DCCS, it remains possible that understanding dimensional structure is closely related to the cognitive changes indexed by the DCC S. Indeed, according to CCC theory, the ability to formulate higher order rules is necessary for the construction of the concept of dimensions, and for subsequent analytical processing of values on those dimensions. As Zelazo and Frye (1997) suggested, it is only by distancing themselves from discriminations *within* a dimension and considering two or more dimensions in contradistinction that children are able to conceptualize dimensions qua dimensions (see also Smith, 1989). This issue will be addressed further in Chapter VI.

## IV. STUDY 3: WHAT DO CHILDREN PERSEVERATE ON WHEN THEY PERSEVERATE?

### *INTRODUCTION AND SUMMARY*

Study 1 indicated that memory per se does not appear to be the primary cause of 3- to 4-year-olds' difficulty with the DCCS. Three-year-olds can use four rules to sort a series of cards when those rules are not in conflict. In Experiment 2, this success was found even for bidimensional rules (two shape rules and two color rules), so bidimensionality per se does not appear to be the problem either. Study 2 focused on cases where there was conflict among rules, and found that 3- to 4-year-olds had difficulty using bidimensional rules even when only a single pair of rules ("if red, then here; if rabbit, then there") was required. Taken together, the results of Studies 1 and 2 support the claims of the CCC theory that 3- to 4-year-olds are able to represent and use pairs of lower-order rules, at one level in a hierarchy, but have difficulty formulating and using a higher order rule. According to CCC theory, it may be *possible* to formulate a higher order rule in many situations, but it is *necessary* to do so when a single stimulus must be responded to in terms of more than one dimension. Under these circumstances, 3- to 4-year-olds will have difficulty resolving conflict between incompatible rule pairs. Study 3 examined further what types of conflict pose problems for 3- to 4-year-olds by asking what it is that children are perseverating on when they perseverate on the standard version of the DCCS.

The CCC theory predicts that when children perseverate, they are perseverating on specific lower order rules (e.g., "If red, then here; if blue, then there") a prediction that may be referred to as the *specific rules hypothesis.* Children select and use a pair of rules during the preswitch phase, these rules become activated, and this activation persists into the postswitch phase (Marcovitch & Zelazo, 2000). In contrast, children who perseverate could be attending to stimuli solely in terms of the first dimension (i.e., the *dimension hypothesis).* This type of perseveration would seem to correspond to the attentional biases described by Zeaman and House (e.g., House, 1989; Zeaman & House, 1963), and would result in centration on a dimension regardless of the particular values of that dimension.

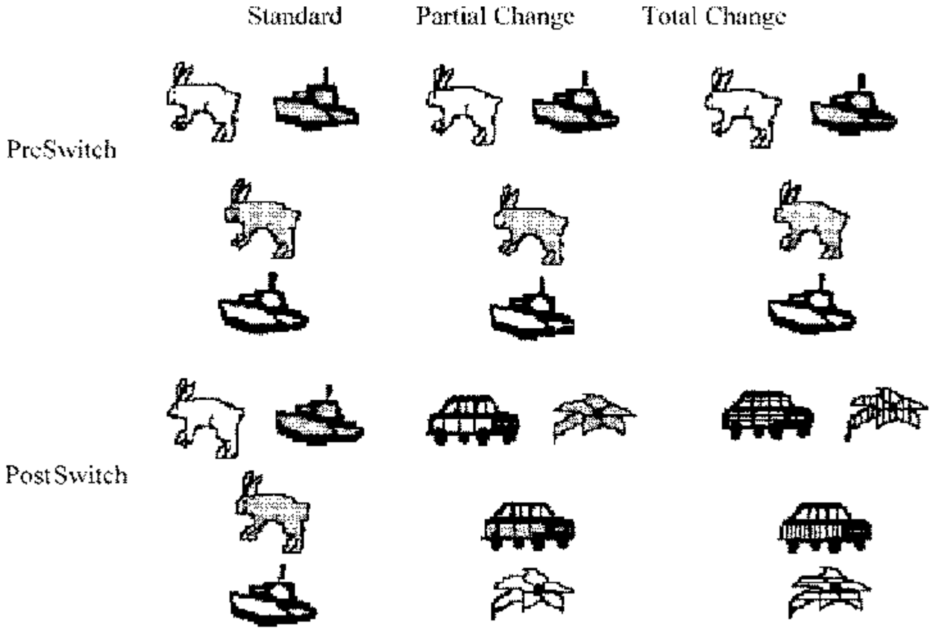

FIGURE 14.—Sample target cards (top row) and test cards in the standard, Total Change, and Partial Change versions of the Dimensional Change Card Sort used in Experiment 7. In the example of the Partial Change, color rules are presented first. Note: white indicates blue; grey indicates red; vertical stripes indicate green; horizontal stripes indicate yellow.

Single dimension centration is central to the Piagetian characterization of the preoperational child (Inhelder & Piaget, 1964), and more recent work has provided evidence for its role in a variety of contexts, ranging from discrimination learning (Caron, 1969; Medin, 1973; Odom & Mumbauer, 1971; Smiley & Weir, 1966) to conservation (Gelman, 1969) to word learning (Baldwin, 1989).

Another possibility, which might be referred to as the *specific stimuli hypothesis,* is that 3- to 4-year-olds' perseveration on the standard version of the DCCS reflects responses to unique stimulus configurations (or compounds) that are not conceptualized either as instances of dimensions or as values along dimensions (cf. Cole, Gay, Glick, & Sharp, 1971). If this were the case, then children should perseverate only in the presence of these particular stimuli.

Experiment 7 was designed to test these three hypotheses by examining 3- to 4-year-olds' performance on two new versions of the DCCS (see Figure 14). In the Total Change version, the values of the dimensions were changed between the pre- and postswitch phases (e.g., children were required to sort red and blue rabbits and boats by color during the preswitch phase, but to sort yellow and green flowers and cars by shape during the postswitch phase). If 3- to 4-year-olds fail the postswitch phase of the standard version because they continue to attend to the preswitch dimension, then they should continue to perseverate during the postswitch trials in the Total Change version. However, if they perseverate on specific stimuli or specific rules, then they should not perseverate on the Total Change version because the specific stimuli are different and the preswitch rules no longer apply.

The second new version involved a change in the specific stimuli that did not preclude the possibility of perseverating on the first pair of specific rules. In this version, called the Partial Change version, only the values of the dimension that was *irrelevant* on the preswitch trials were changed. For example, if children first sorted red and blue rabbits and boats by color during the preswitch phase, they would be required to sort red and blue flowers and cars by shape during the postswitch phase. This would still allow children to perseverate on specific rules, such as, "If it's red, then put it here, and if it's blue, then put it there," but it would prevent them from perseverating on responses to specific stimuli, such as a red boat.

In addition to these two new versions, children were also administered a modified standard version, called the standard (target cards refreshed, preswitch feedback) version. The standard version was modified to make it comparable to the two new versions. In both the Partial Change version and the Total Change version, the target cards had to be taken down and replaced between the pre- and postswitch phases. Therefore, in the standard (target cards refreshed, preswitch feedback) version, target cards were also taken down momentarily, and were then replaced as the experimenter proceeded to the postswitch phase.

One other feature of the standard version was also modified (and was consistent with the procedure for the two new versions). Because the focus of this experiment was on the level at which children perseverate when they do perseverate, we wanted to increase the likelihood that children would indeed perseverate. Therefore, in the standard (target cards refreshed, preswitch feedback) version, as in the Partial Change and Total Change versions, children were told whether or not they sorted cards correctly during the preswitch phase. Given that 3- to 4-year-olds rarely erred during the preswitch phase, this modification seems unlikely to have affected preswitch performance, although it is possible that it increased overall levels of postswitch preservation (this issue was addressed in Experiment 8, in which no feedback was provided during the preswitch phase).

The three different hypotheses regarding what it is that 3- to 4-yearolds perseverate on in the standard version make different predictions regarding how children will respond on the Partial Change and Total Change versions of the DCC S. If children perseverate in their responses to particular stimulus configurations, then they should not perseverate on either new version. If children perseverate on a dimension, then they should perseverate on both new versions. If they perseverate on rules specifying values of a dimension (e.g., red), as predicted by the CCC theory, then they should perseverate on the Partial Change versions, but not the Total Change version.

## EXPERIMENT 7

### *Method*

**Participants.** Ninety-eight 3- to 4-year-olds (M = 41.0 months; range: 33 to 48 months; 50 girls and 48 boys) were recruited in the same fashion as in Experiment 1. Three additional children were tested but not included in the final sample because color names were not known (n = 1) or because English was not the child's first language (n = 2).

**Design.** Children at each age were randomly assigned to receive one of three versions of the DCCS: the standard (target cards refreshed, preswitch feedback) version (n = 31, 16 boys and 15 girls), the Total Change version (n = 34, 16 boys and 18 girls), or the Partial Change version (n = 33, 16 boys and 17 girls). For all versions, the dimension (color or shape) that was relevant during the preswitch phase was counterbalanced and crossed with the set of cards they received. Two sets of cards were used: (set 1) red and blue rabbits and boats, and (set 2) yellow and green cars and flowers. Roughly half of the children receiving the standard (target cards refreshed, preswitch feedback) version sorted one set of cards, and the remaining children sorted the other. In the Total Change version, roughly half of the children sorted one of these sets first, and then sorted the other set. Children receiving the Partial Change version also sorted one of these two sets of cards first. However, in the postswitch phase, they sorted one of the four sets of cards that were created by crossing the two pairs of colors and shapes used in the first two sets. Thus, for example, roughly one quarter of the participants receiving the Partial Change version first sorted yellow and green cars and flowers and then sorted yellow and green rabbits and boats.

**Procedure.** All three versions of the DCCS were comprised of two phases, a preswitch and a postswitch phase. The standard (target cards refreshed, preswitch feedback) version was administered exactly like the usual standard version (see Chapter I), with the following parameter settings and modifications: (a) Test cards (for both pre- and postswitch) phases were labeled *only* by the relevant dimension. (b) In contrast to the usual procedure, children were given feedback on the preswitch trials and preswitch trials were administered until children correctly sorted 5 consecutive cards. (c) After children correctly sorted 5 consecutive preswitch cards, the target cards were taken down momentarily and were then replaced as the experimenter proceeded to the postswitch phase. (d) There were 5 postswitch trials administered without feedback. The procedures for the Total Change and Partial Change versions were identical to that for the standard (target cards refreshed, preswitch feedback) version; only the cards to be sorted differed. The total procedure took approximately 10 minutes to administer.

### *Results*

**Group analyses.** Children were given feedback during the preswitch phase, and all children reached criterion. Ninety-one children (93%) reached criterion in the minimum number of trials. A preliminary two-way (Version x Dimension Order) ANOVA on the number of correct postswitch trials indicated no effect of dimension order and no Version x Dimension Order interaction. Consequently, dimension order was dropped from subsequent analyses.

A two-way (Sex x Version) ANOVA on number of correct postswitch trials revealed only a main effect of version, F(2, 92 ) = 7.19, $p < .01$ (effect size $f = .40$). Newman Keuls post hoc tests ($p < .05$) showed that children receiving the Total Change version (M = 4.06, *SD* = 1.82) made more correct responses than children receiving the standard (target cards refreshed, preswitch feedback) version (M = 2.03, *SD* = 2.39) and the Partial Change version (M = 2.67, *SD* = 2.35), which did not differ (see Figure 15).

**Individual analyses.** On the postswitch trials, each child was classified according to whether he or she did or did not use the postswitch pair of rules (at least 4 correct out of 5). Table 6 presents the numbers of children in each response class by version.

A chi-square test revealed that the number of children who passed the postswitch phase depended on the version, $\chi^2$ (2, $N = 98$) = 10.26, $p < .01$. For the Total Change version, but not for the other versions, the number of children who used the postswitch rules exceeded 50% (based on a binomial distribution, $p < .05$).

### *Discussion*

Despite the changes made to the standard version for this experiment (target cards refreshed and preswitch feedback), the usual pattern of performance was observed: the majority of 3- to 4-year-olds perseverated on the postswitch trials. A comparison with the new versions was designed to determine whether perseveration on the DCCS reflects centration on a dimension, continued use of the preswitch rules (specifying values of a dimension), or responses to particular stimuli (e.g., blue rabbits). Children who received the Total Change version performed better than children who received the standard (target cards refreshed, preswitch feedback) version or the Partial Change version, and performance on these latter versions did not differ.

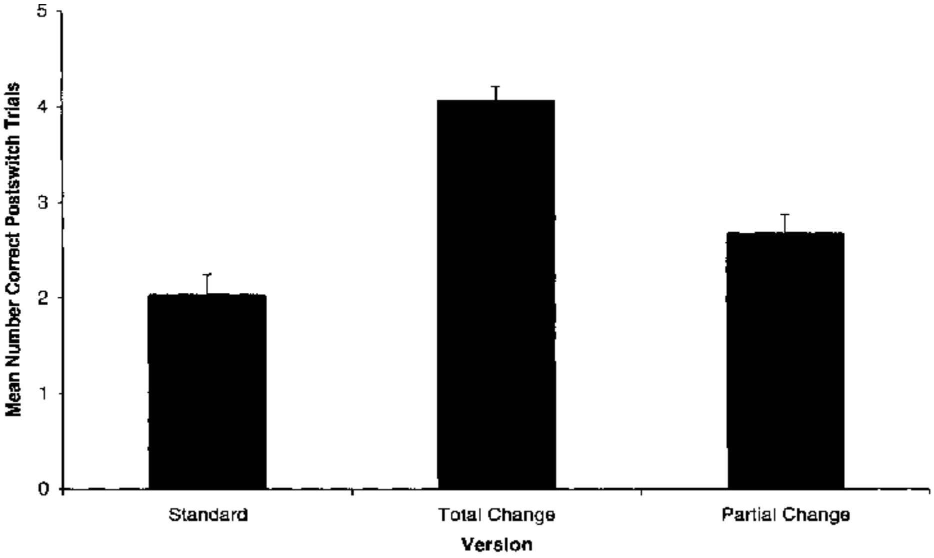

FIGURE 15.—Mean number correct (and standard error) on the postswitch trials of the Dimensional Change Card Sort, according to version (Experiment 7).

If perseveration on the standard (target cards refreshed, preswitch feedback) version were due to perseveration on a dimension, then children would have perseverated on the Total Change version in which the particular values of the dimensions were changed between the pre- and postswitch phases. However, the majority of participants who received this version used the postswitch rules successfully: Only 21% of the participants continued to sort by the preswitch dimension during the postswitch phase. Thus, when there is no continuity in the specific stimulus values between pre- and postswitch, or when children cannot use the preswitch rules during the postswitch, children do well in the DCCS. This finding makes it likely that the majority of 3- to 4-year-olds do not perseverate on a dimension. However, a more conclusive test of whether children do or do not perseverate on a dimension would consist of a change in (at least one) dimension between pre- and postswitch phase (e.g., using shape and color during preswitch, and shape and number during postswitch).

The relatively poor performance of the children who received the Partial Change version indicates that these children were continuing to use a single pair of rules (viz., the preswitch rules) during the postswitch phase. Children who received the Partial Change version often perseveratively applied the preswitch rules (e.g., "If it's red it goes here") to stimuli (standards and test cards) that they had never seen before. If children who failed the DCCS were simply perseverating on learned responses to particular stimuli, then children would not have perseverated in this version. Children's perseveration on the Partial Change version also confirms that a change in stimulus conditions per se cannot account for children's success on the Total Change version (e.g., by disrupting their set).

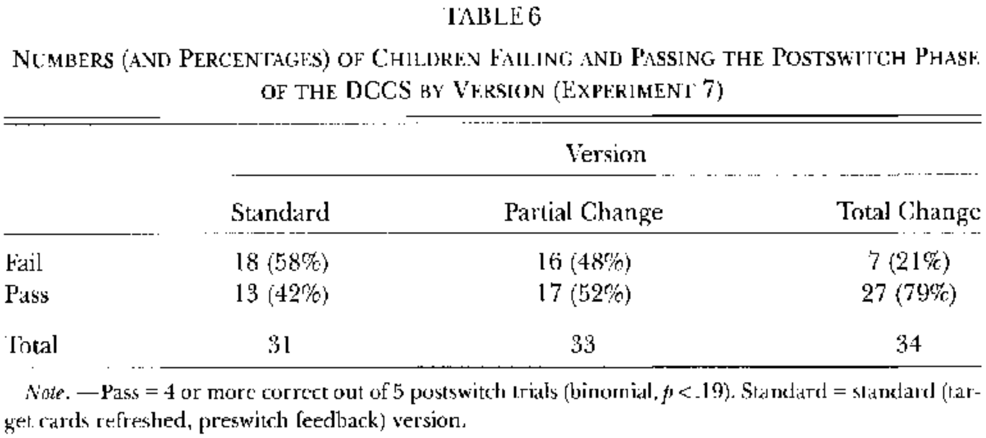

TABLE 6

NUMBERS (AND PERCENTAGES) OF CHILDREN FAILING AND PASSING THE POSTSWITCH PHASE OF THE DCCS BY VERSION (EXPERIMENT 7)

| | Version | | |
|---|---|---|---|
| | Standard | Partial Change | Total Change |
| Fail | 18 (58%) | 16 (48%) | 7 (21%) |
| Pass | 13 (42%) | 17 (52%) | 27 (79%) |
| Total | 31 | 33 | 34 |

*Note.* —Pass = 4 or more correct out of 5 postswitch trials (binomial, $p < .19$). Standard = standard (target cards refreshed, preswitch feedback) version.

Taken together, the results of Study 3 support the CCC theory insofar as they indicate that the conflict that poses a problem for 3- to 4-year-olds is conflict at the level of specific rules. Three-year-olds perseverate on the preswitch rules during the postswitch phase, consistent with the suggestion that the selection and/or use of rules during the preswitch phase strengthens the activation of these rules, thereby increasing the probability that they will be selected in the future (Marcovitch & Zelazo, 2000).

The findings might also generally be consistent with inhibition accounts. For example, attentional inertia theory (Kirkham et al., in press) suggests that 3-year-old children fail the DCCS because they cannot inhibit attention to the aspect of the stimulus that was relevant during the preswitch phase. Unfortunately, this theory is not specific about whether "aspect of the stimulus" refers to specific stimulus attributes, rules, or dimensions. However, if "aspect of the stimulus" refers to the specific values of the dimension that is relevant during the preswitch phase, then attentional inertia theory predicts that children should do poorly on the standard version and the Partial Change version, and that they should do well on the Total Change version. The role of inhibition in the DCCS will be examined further in Study 4.

## V. STUDY 4: NEGATIVE PRIMING AND EXECUTIVE FUNCTION

### *INTRODUCTION AND SUMMARY*

Study 3 showed that although children often perseverated on the Partial Change version, they generally did not perseverate on the Total Change version. These findings are consistent with the hypothesis that children perseverate on a particular pair of rules (e.g., "If it's red it goes here") rather than on a dimension or on a specific stimulus configuration. In other words, these findings indicate that the rules selected and used during the preswitch phase are also selected and used during the postswitch phase. This characterization of children's perseveration is consistent with CCC theory, according to which activation of the preswitch rules persists into the postswitch phase (Marcovitch & Zelazo, 2000). To select the postswitch rules in contrast to activated preswitch rules would seem to require some type of higher order process that operates on these rules. CCC theory suggests one such process: reflection and the formulation and use of a higher order rule.

Another possibility, which is not necessarily incompatible with the processes postulated by CCC theory, is that an inhibition mechanism could be used to help children disengage from the activated preswitch rules. Kirkham et al. (in press) have explicitly attributed perseveration in the DCCS to the failure to disengage attention from the preswitch dimension and shift attention to the postswitch dimension. They characterize this failure as a problem of "attentional inertia" and suggest that this inertia is eventually overcome by the development of the ability to inhibit attention to the aspect of the stimulus (e.g., redness) that was relevant during the preswitch phase. As they put it, "Having focused their attention on a particular dimension, their attention gets stuck, and they have extreme difficulty redirecting it" (Kirkham et al., p. 4).

The results of Study 3 disconfirm this claim by showing that it is not attention to a dimension per se (e.g., color) that children get stuck on. Nonetheless, it is possible that children do get stuck in attending to the preswitch rules, or to the particular values of the preswitch dimension cited in the preswitch rules (e.g., red and blue). An alternative possibility, however, is that instead of difficulty inhibiting activated preswitch rules during the postswitch phase, children have difficulty activating the postswitch rules because these rules had been ignored during the preswitch phase. This possibility may be referred to as the *negative priming hypothesis.*

A standard experimental paradigm used to examine negative priming consists of a two-part, prime-probe test. In the prime trial, a participant must respond to one stimulus (or aspect of a stimulus) and ignore another stimulus (or aspect). The subsequent probe trial requires the participant to respond to the previously ignored stimulus. Negative priming occurs when responding is slower than it would otherwise be to the previously ignored stimulus. Several different theoretical interpretations of negative priming have been offered (for reviews and discussions, see Fox, 1995; May, Kane, & Hasher, 1995; Milliken, Joordens, Merikle, & Seiffert, 1998; Tipper, 2001).

One possible explanation for negative priming is that ignoring a distractor stimulus involves inhibiting or suppressing attention to that stimulus, and that this inhibition persists into the probe trial (e.g., Houghton & Tipper, 1994; Tipper, 1985). A second possible explanation for negative priming is that the ignored stimulus is given an "ignore this stimulus" tag during the prime trial (e.g., Neill & Valdes, 1992). Then, during the probe trial, the previous processing episode (i.e., the prime display) is automatically retrieved. If there is a conflict in that an item that was coded as irrelevant during the prime trial is now coded as relevant during the probe trial, slower reaction times will occur. These slower reactions times are assumed to occur because of the mismatch between processing episodes, and not because the irrelevant stimulus was inhibited during the prime trial.

Both the inhibition account and the episodic retrieval account of negative priming are largely consistent with empirical evidence (e.g., see Fox, 1995; Tipper, 2001). However, neurophysiological evidence supports the inhibition account because single cell recording in the visual cortex has shown that cells increase their firing rate when a particular type of stimulus falls within their receptive field, but that the firing rate is suppressed when the same stimulus appears as an ignored distractor (Duncan, Humphreys, & Ward, 1997). According to Tipper (2001), the inhibition account and the episodic retrieval account of negative priming are not incompatible. Tipper (2001) proposed an integrative model in which selective inhibition and episodic retrieval are the product of forward and backward processes of the same mechanism: "[T]he observation of inhibition via negative priming is by necessity a bi-directional process involving initial inhibitory processing in which a target is selected from a distractor, and consequent retrieval processes activated while interacting with the probe, in which previous prime processing is reinstated/retrieved" (Tipper, 2001, p. 323).

Very few studies have explored negative priming in children. In one study by Tipper, Bourque, Anderson, and Brehaut (1989), 7-year-olds and adults received a Stroop test (Stroop, 1935) under one of four conditions: (a) in the standard Stroop condition, participants were presented with a list of color words written in a conflicting color but there was no relation between successive items in a list, (b) in a neutral condition, participants were presented with colored X's, (c) in a Repeated Ignored condition, the distractor stimulus was always the same throughout (e.g., the word "blue" written in different colors), and (d) in the Ignored Repetition condition, the distractor on one trial became the target on the subsequent trial (e.g., the word "blue" written in yellow was followed by the word "orange" written in blue). Slowed reaction times in the Ignored Repetition condition could be attributed to negative priming because the distractor that needed to be inhibited on a previous trial became the target on a subsequent trial. Results showed that the amount of negative priming was substantially larger in adults than in children (and indeed, there was generally no evidence of negative priming in children), suggesting that negative priming develops, perhaps due to growth of prefrontal cortex (Stuss et al., 1999). A subsequent study by Tipper and MacLaren (1990), however, found that negative priming can be demonstrated in younger children using less complicated tasks. Thus, the presence or absence of negative priming appears to depend on the complexity of the task used to assess it.

Negative priming in children has also been explored in Piagetian conservation tasks by Houde and Guichart (2001; see also Perret, Paour, & Blaye, 2003). Piagetian conservation involves the understanding that a change in the appearance of an object or group of objects (e.g., the length of a row of objects) does not necessarily signal a change in the quantitative value of the object or group (e.g., the number of objects in that row). Houde and Guichart had 9-year-olds judge the numerical equivalence of two rows of shapes when the use of a primed Piagetian length-equals-number strategy was either congruent or incongruent with the correct response. The authors found that children who were required to ignore the strategy that length is indicative of number subsequently took longer to use that strategy when it was required for the correct response.

Perner and Lang (2002) discussed the possibility that negative priming (in the sense of persistent inhibition) may occur in the DCCS. That is, sorting by the preswitch rules may require children to inhibit the irrelevant pair of rules, and this inhibition may persist or be reinstated in the postswitch trials, decreasing the probability that these rules will be selected in the future (i.e., during the postswitch phase, when they become relevant). Negative priming in this sense may also explain results they obtained with modified versions of the DCCS. These authors found that when the target cards varied on only one dimension or when no target cards were used at all, 3- to 4-year-olds' performance improved. In both cases, they suggest, there was no need to inhibit the irrelevant rules during the preswitch phase. However, their results are also consistent with other hypotheses. For example, the lack of target cards could have made the preswitch rules less salient and therefore easier to forget when the rules changed (Perner & Lang, 2002, p. 101). Consequently, children may not have needed to construct a higher order rule to switch between rule pairs; they may simply have sorted according to two rule pairs in succession, without coordinating them.

Although it is possible that negative priming contributes to children's difficulty on the DCCS, it cannot account for this difficulty completely. If negative priming alone were operative in the DCCS, then children should have performed well on the Partial Change version in Experiment 7, in which the values of the dimension that was irrelevant during the preswitch phase were replaced by new values. Because these values were replaced, performance on this version cannot reflect negative priming, only persistent activation of the preswitch rules (or some other process).

Curiously, although negative priming may be a problem that children need to overcome (Perner & Lang, 2002), it is usually conceptualized as evidence of a developing ability that allows successful selective attention (e.g., Dempster, 1995; Houde & Guichart, 2001; Tipper et al., 1989). For this reason, the negative priming hypothesis is incompatible with inhibition accounts such as that proposed by Kirkham and colleagues (in press). Whereas inhibition accounts suggest that children fail to inhibit during the postswitch phase, the negative priming hypothesis suggests that children fail to disinhibit during this phase. Put differently, inhibition accounts suggest that children perform poorly on the DCCS because of *too little* inhibition, whereas the negative priming hypothesis suggests that children perform poorly because of *too much* inhibition. Perhaps for this reason, Kirkham et al. explicitly state that negative priming would not occur in the DCCS. They write that "children should be able to succeed if the previously-relevant values on the now irrelevant dimension are no longer present in the stimuli (and they do)" (p. 5). To our knowledge, however, this claim has not actually been tested.

Experiment 8 was designed to test directly the role of negative priming in relation to other possible sources of difficulty on the DCCS. Children were given one of six versions of the DCCS: the standard version, the Total Change version, the Partial Change version, and three new versions (see Figure 16). In the Negative Priming version, the values of the dimension that was relevant during the preswitch phase were removed during the postswitch phase. This version should provide a pure measure of negative priming (vs. persistent activation of the preswitch rules) because performance on the postswitch phase would be sensitive to negative priming, but not to persistent activation.

In the Partial-Partial Change (test cards) version, the values of the *irrelevant* dimension during the preswitch phase were removed from the *test* cards during the preswitch phase. For example, as shown in Figure 16, when the preswitch sorting dimension was color and target cards included a blue rabbit and a red boat, test cards were blue squares and red squares. However, in the postswitch phase, test cards were replaced by red rabbits and blue boats (i.e., the standard, cross-matched test cards were used). In contrast, in the Partial-Partial Change (target cards) version, the values of the irrelevant dimension during the preswitch phase were removed from the *target* cards during the preswitch phase (but not the postswitch phase).

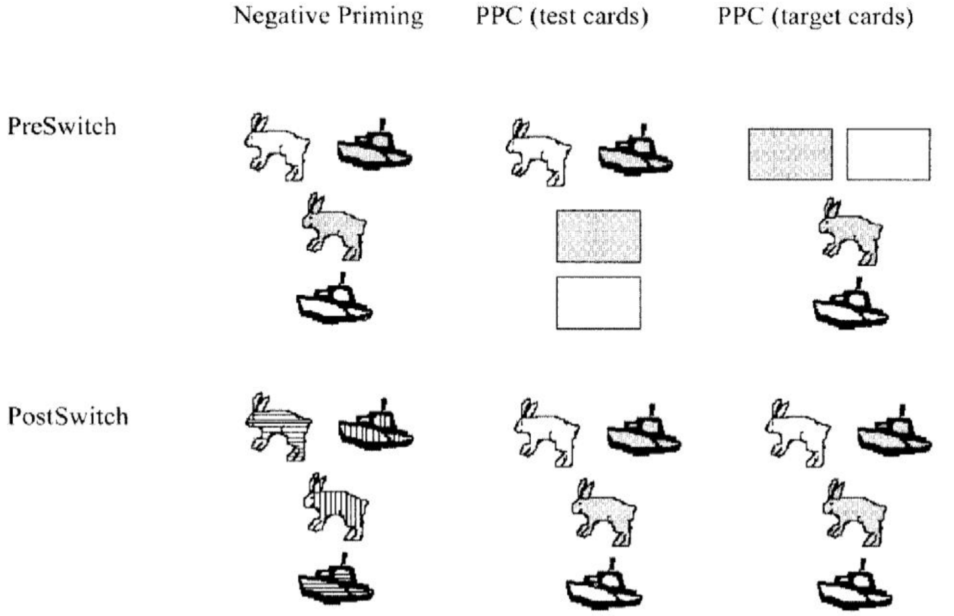

FIGURE 16.—Sample target cards (top row) and test cards in the Negative Priming, Partial-Partial Change (test cards), and Partial-Partial Change (target cards) versions of the Dimensional Change Card Sort used in Experiment 8. PPC = Partial-Partial Change. In these examples, children are first told to sort by color. Note: white indicates blue; grey indicates red; vertical stripes indicate green; horizontal stripes indicate yellow.

The Partial-Partial Change versions were designed to explore the circumstances in which persistent activation of preswitch rules interferes with postswitch performance. The primary prediction regarding these versions follows from CCC theory: 3- to 4-year-olds should perseverate in these versions because it is possible to persist in applying the (now-activated) preswitch rules. The versions differ from the Partial Change version, however, in that it was not actually possible to sort by the competing dimension during the preswitch phase because the values of either the target cards or the test cards were missing for that dimension. Therefore, if activation of the preswitch rules depends on the selection of those rules against a competing alternative, then these versions should be relatively easy for children. That is, persistent activation should be attenuated or eliminated. It should be noted, however, that these versions did not provide a pure test of this hypothesis because the values of the competing dimension were only *partially* removed during the preswitch phase. Under these circumstances, children may nonetheless need to attend selectively to the relevant values against the irrelevant values. The difference between the two Partial-Partial Change versions was included simply to explore both ways of partially removing values from the competing dimension during the preswitch phase.

Negative priming was not expected to influence postswitch performance in the Partial-Partial Change versions because (a) there was no requirement that children select one pair of rules against an alternative pair, and (b) the values of the to-be-ignored dimension were missing either from the target cards or from the test cards during the preswitch phase.

Results revealed that children performed well on the Total Change version, moderately well on the three Partial Change versions (including the two Partial-Partial Change versions), and poorly on the standard and Negative Priming versions. Indeed, these latter two versions were equally difficult, as would be predicted if the competing rules are inhibited during the preswitch phase. Clearly, an adequate explanation of performance on the DCCS needs to take account of both activation and negative priming.

Given that Experiment 8 revealed a role for negative priming in performance on the DCCS, Experiment 9 sought to determine more precisely the circumstances in which negative priming occurs. One possibility is that negative priming only occurs when children actively select one pair of rules against a competing alternative. If this were the case, then only *mismatching* (i.e., cross-matched) target and test cards would elicit negative priming (Perner & Lang, 2002). On the other hand, it is possible that negative priming in the DCCS does not depend on the selection of one pair of rules against a competing alternative. In this case, even irrelevant cues from dimensions that do not conflict with the relevant dimension may be negatively primed.

Experiment 9 aimed to investigate these two possibilities using a new version of the DCCS (see Figure 17). In this version, the Negative Priming (redundant preswitch) version, the test cards are identical to the target cards during the preswitch phase, and the values of the formerly relevant dimension are replaced during the postswitch phase, as in the Negative Priming version. As in the Negative Priming version, persistent activation of the preswitch rules would not affect postswitch performance. Unlike in the Negative Priming version, however, children do not need to select the preswitch rules against a competing alternative during the preswitch phase. Thus, if negative priming occurs when responses to mismatching cues must be selected against (and hence, actively inhibited), this new version of the task would not elicit negative priming, and performance on this version should be good. On the other hand, if attending to cues from one dimension (i.e., the relevant dimension) causes all unattended cues to be negatively primed, then the Negative Priming (redundant preswitch) version should be just as difficult as the standard version.

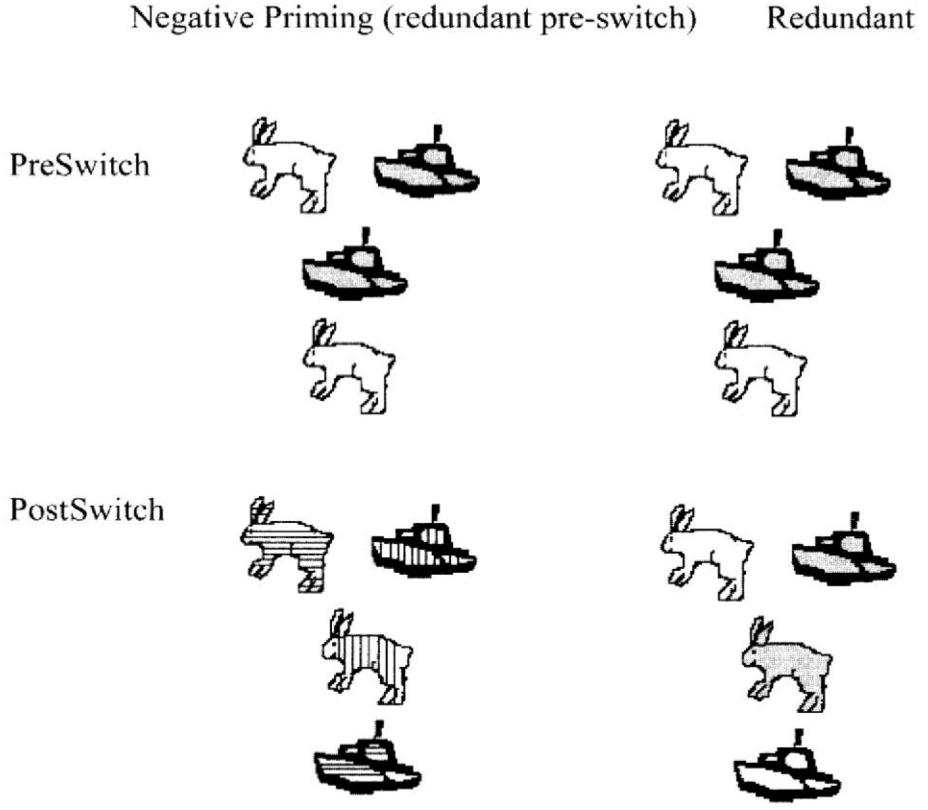

FIGURE 17.—Sample target cards (top row) and test cards in the Negative Priming (redundant preswitch) and Redundant versions of the Dimensional Change Card Sort used in Experiment 9. In these examples, children are first told to sort cards by color. Note: white indicates blue; grey indicates red; vertical stripes indicate green; horizontal stripes indicate yellow.

Performance was also assessed on a Redundant version of the DCCS in which the test cards matched the target cards on both dimensions during the preswitch phase but standard, conflicting test cards were used during the postswitch phase. Performance on this version could be affected both by persistent activation of the preswitch rules and by negative priming, so this version allowed further assessment of whether both processes depend on the active selection of one pair of rules against a competing alternative. If both activation and negative priming depend on selecting against a competing alternative, then performance on this version should be good. In an unpublished master's thesis, Jacques (1995) found that 3- to 4-yearolds perseverated on this version. Jacques's finding needs to be replicated, but poor performance on this version would seem to indicate that activation and/or negative priming can occur even in the absence of direct interference from a competing alternative.

## EXPERIMENT 8

According to CCC theory, 3- to 4-year-olds perform poorly on the postswitch phase of the DCCS because, in the absence of higher order rules, they have difficulty selecting the postswitch rules against competing rules that were activated during the preswitch phase. The circumstances in which difficulty occurs remain to be explored further. Moreover, another possible contribution to children's difficulty on the DCCS is negative priming: children may have difficulty attending to the postswitch rules because these same rules were ignored during the preswitch phase.

Experiment 8 was designed to test these possibilities by comparing performance on the Negative Priming version, the Partial-Partial Change (test cards) version, the Partial-Partial Change (target cards), and the three versions used in Experiment 7. In contrast to Experiment 7, however, the standard, Partial Change, and Total Change versions, like the other versions used in Experiment 8, were administered without feedback during the preswitch phase (i.e., the procedure was modified to be more like the standard version used in most studies). Participants in Experiment 8 were, on average, somewhat younger than participants in other experiments. Children from a younger age range were selected in order to be able to detect possible differences between the Partial Change versions and the Negative Priming version. Because these versions were expected to be easier than the standard version, it seemed likely any differences would be best detected using a younger sample. For the same reason, a larger number of pre- and postswitch trials were administered than in Experiment 7. Use of a younger sample increased the likelihood that performance on the standard version would be poorer than in Experiment 7.

### *Method*

**Participants.** One hundred and five children (*M* = 38.34 months; range: 36 to 43 months; 46 girls and 59 boys) were recruited in the same fashion as in Experiment 1. Ten additional children were excluded from the final sample either because of experimenter error (n = 5), because they refused to complete the experiment (n = 4), or because they did not appear to understand English (n = 1).

**Design.** Children at each age were randomly assigned to receive one of six versions of the DCCS: the standard (target cards refreshed) version, the Total Change (no preswitch feedback) version, the Partial Change (no preswitch feedback) version, the Negative Priming version, the Partial-Partial Change (test cards) version, and the Partial-Partial Change (target cards) version. For all versions, the dimension (color or shape) that was relevant during the preswitch phase was counterbalanced. Card sets were the same as in Experiment 7, and they were counterbalanced in the same fashion as in Experiment 7.

**Procedure.** The procedure for all versions was identical; only the cards to be sorted differed. The general procedure was the same as that used in Experiment 7, except for two changes: (a) there were 8 preswitch and 8 postswitch trials, and (b) children were not given feedback on the preswitch trials. Other than these changes, the Total Change (no pre-switch feedback) and Partial Change (no preswitch feedback) versions were the same as in Experiment 7. The Negative Priming version was essentially the reverse of the Partial Change (no preswitch feedback) version: the values of the dimension that was relevant during the preswitch phase (and irrelevant during the postswitch phase) were changed between the pre- and postswitch phases. In the Partial-Partial Change (test cards) version, the values of the dimension that was relevant during the postswitch phase were missing from the *test* cards during the preswitch phase. If children were required to sort by color during the preswitch phase, then the test cards during the preswitch phase consisted of color squares (see Figure 16). On the other hand, if the preswitch dimension was shape, then the test cards consisted of colorless outlines (e.g., outlines of rabbits and boats). During the postswitch phase, however, the standard test cards were used. Moreover, in this version, the same target cards were used in the pre- and postswitch phases.

In the Partial-Partial Change (test cards) version, the values of the dimension that was relevant during the postswitch phase were missing from the *target* cards during the preswitch phase. For example, for children who were asked to sort red and blue rabbits and boats (standard test cards) by shape during the preswitch phase, the target cards during the preswitch phase were outlines of a rabbit and a boat. For children who were asked to sort red and blue rabbits and boats by color during the preswitch phase, the target cards during the preswitch phase were a red square and a blue square. During the postswitch phase, standard target cards were used and the test cards remained the same.

The total procedure took approximately 10 minutes to administer.

### *Results*

**Group analyses.** A preliminary two-way (Version x Dimension Order) ANOVA on number of correct postswitch trials indicated that there was no effect of dimension order and no Version x Dimension Order interaction. Consequently, dimension order was dropped from subsequent analyses. A two-way (Sex x Version) ANOVA on number of correct postswitch responses revealed significant effects of sex, *F(1,* 93) = 5.32,p < .05 (effect size *f* = .24), and version, F(5, 93) = 3.19,p 3.19,p<.05 (effect size *f* = .41). The effect of sex was due to the fact that girls *(M* = 5.23, *SD* = 3.28) performed better in this experiment than boys *(M* = 3.76, *SD* = 3.39). Newman-Keuls post hoc tests (p <.05) indicated that the standard version was significantly more difficult than the Total Change version, the Partial Change version, and the Partial-Partial Change (test cards) version (see Figure 18). There were no other significant differences among tasks. These results did not change after excluding children who failed the preswitch phase (fewer than 7 out of 8 correct).

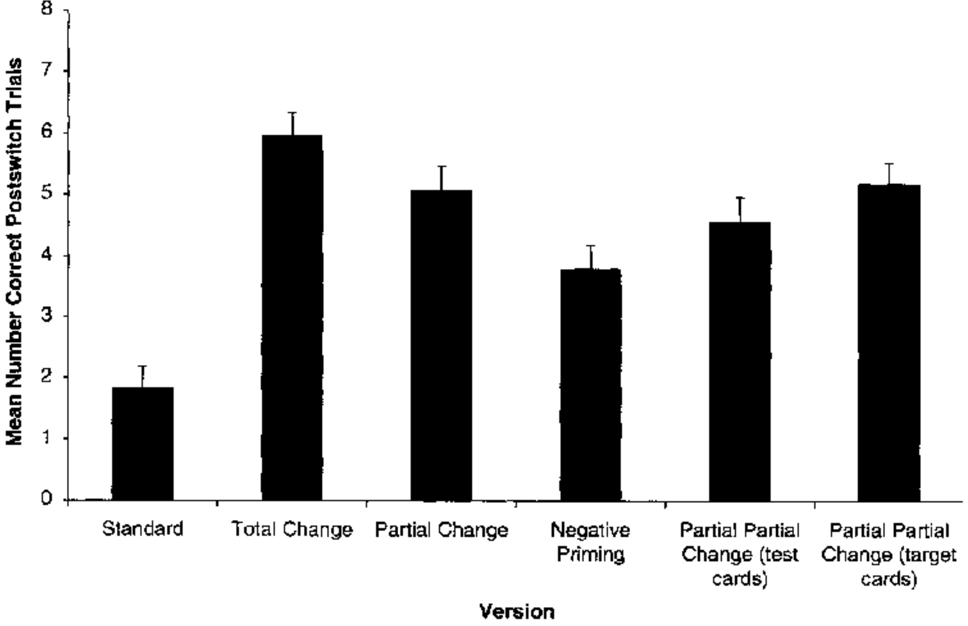

FIGURE 18.—Mean number correct (and standard error) on the postswitch trials of the Dimensional Change Card Sort, according to version (Experiment 8).

When performance on the different version was compared to chance performance (i.e., 4 out of 8 postswitch trials correct), children's performance on the standard version was significantly worse than chance, t(16) = 2.89, p <.05, and their performance on the Total Change version was significantly better than chance, t(16) = 2.51, p < .05. However, performance on the other versions did not differ significantly from chance.

**Individual analyses.** Eight children (2 in each of the Partial Partial Change version, and 1 each in the standard, the three Partial Change, the Total Change, and the Negative Priming versions) failed the preswitch phase (fewer than 7 out of 8 correct), and were excluded from further analyses. The remaining children were classified as passing the postswitch phase using the same criterion as in the preswitch phase. Table 7 displays the numbers (and percentages) of children who passed and failed the postswitch phase in each version. As can be seen, more than two-thirds of the children in the standard and Negative Priming versions failed. However, only about one third of the children in the Total Change version failed. The Partial Change and the two Partial-Partial Change versions were of intermediate difficulty, and performance on these three versions did not differ. Performance on the standard version was significantly worse than performance on the Total Change $\chi^2$ (1, $N$ = 32) = 6.35, p < .05. There was also a trend for the Partial Change version and the Partial-Partial Change (target cards) version to be easier than the standard version, $\chi^2$ (1, $N$= 32) = 3.46, p < .07 (in each case), and for the Total Change version to be easier than the Negative Priming version, $\Pi^2$ (1, $N$ = 33) = 3.64, p < .06. Twelve children (75%) perseverated (7 or 8 incorrect) in the standard version, 6 (38%) in the Negative Priming version, 5 (31%) in the Partial-Partial Change (test cards) version, 4 (25%) in the Partial Change version, 3 (19%) in the Total Change version, and 2 (13%) in the Partial-Partial Change (target cards) version.

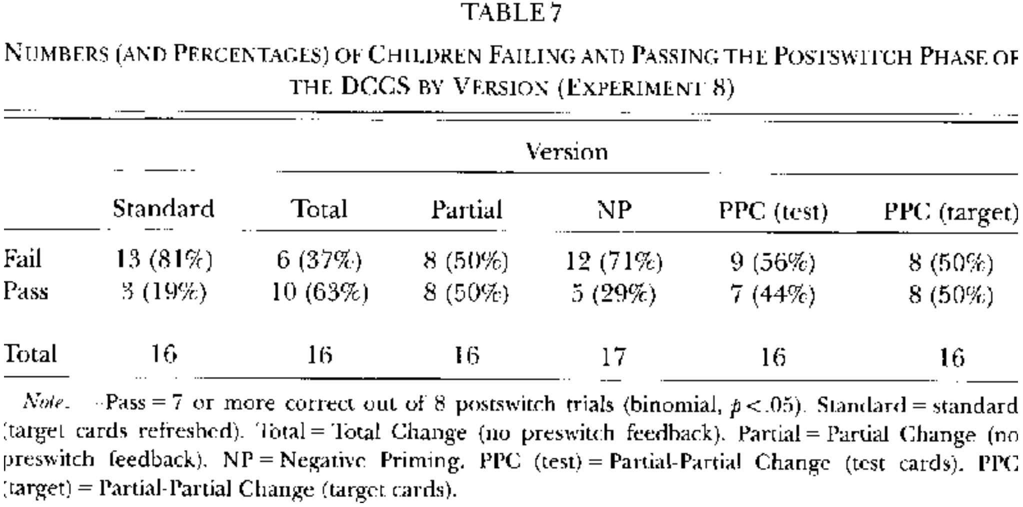

TABLE 7

NUMBERS (AND PERCENTAGES) OF CHILDREN FAILING AND PASSING THE POSTSWITCH PHASE OF THE DCCS BY VERSION (EXPERIMENT 8)

| | Version | | | | | |
|---|---|---|---|---|---|---|
| | Standard | Total | Partial | NP | PPC (test) | PPC (target) |
| Fail | 13 (81%) | 6 (37%) | 8 (50%) | 12 (71%) | 9 (56%) | 8 (50%) |
| Pass | 3 (19%) | 10 (63%) | 8 (50%) | 5 (29%) | 7 (44%) | 8 (50%) |
| Total | 16 | 16 | 16 | 17 | 16 | 16 |

*Note.* Pass = 7 or more correct out of 8 postswitch trials (binomial, $p < .05$). Standard = standard (target cards refreshed). Total = Total Change (no preswitch feedback). Partial = Partial Change (no preswitch feedback). NP = Negative Priming. PPC (test) = Partial-Partial Change (test cards). PPC (target) = Partial-Partial Change (target cards).

## *Discussion*

The results of Experiment 8 indicate that as in Experiment 7, most children passed the Total Change (no preswitch feedback) version, providing further evidence that children usually do not perseverate on dimensions per se. The results for the Partial Change (no preswitch feedback) version also resemble the findings from Experiment 7 (50% passing in Exp. 8 vs. 52% in Exp. 7), and these results support the hypothesis, derived from CCC theory, that children perseverate on activated rules specifying values of a dimension. Perseveration on the Partial Change (no preswitch feedback) version cannot be accounted for by negative priming because the dimension values that were irrelevant (and possibly negatively primed) in the preswitch phase were removed during the postswitch phase. However, in contrast to Experiment 7, the Partial Change version in Experiment 8 was significantly easier than the standard version. This discrepancy between Experiment 7 and Experiment 8 could be due to procedural changes (feedback vs. no feedback during preswitch) or due to the fact that participants in Experiment 7 (mean age = 41 months) were younger than the participants in Experiment 8 (mean age = 38 months). Further explanations for the pattern of findings with respect to the Partial Change version and the standard version are discussed in the final chapter.

In the Partial-Partial Change versions, persistent activation was possible, but the values of either the target cards or test cards were partially absent during the preswitch phase (potentially attenuating the need to select the preswitch rules against a competing alternative). The finding that performance was nearly identical (about 50% passing) on both Partial-Partial Change versions and on the Partial Change (no preswitch feedback) version suggests that performance on all three versions may have reflected comparable amounts of persistent activation of the preswitch rules. Activation may not depend on selecting against a competing alternative, although this possibility needs to be assessed further because irrelevant values were only *partially* removed during the preswitch phase. Under these circumstances, children may, nonetheless, attend selectively to the relevant values against the irrelevant values.

The main new finding from Experiment 8 is that 3- to 4-year-olds exhibited considerable difficulty on the Negative Priming version. Although the findings from the Total Change (no preswitch feedback) and Partial Change (no preswitch feedback) versions lend support to CCC theory and the idea that children persist in applying activated preswitch rules (rather than perseverating on a dimension per se), CCC theory cannot explain why children perseverated on the Negative Priming version. Persistent activation would not interfere with performance on the Negative Priming version.

Surprisingly, this experiment revealed a main effect of sex: girls performed better than boys across versions (there was no interaction). An effect of sex on the DCCS has also been reported by Carlson and Moses (2001; see also Bjorklund & Kipp, 1996), but was not found in any of the other experiments described in this *Monograph* (although there was a Sex x Version interaction in Experiment 6 reflecting the fact that girls performed better than boys on the more difficult versions). Therefore, it is possible that the effect is simply a Type I error. Alternatively, however, it may reflect a genuine difference. The effect size associated with the effect was $f = .23$, which is considered a medium effect size (Cohen, 1988).

A genuine sex difference favoring girls would not be entirely unexpected on this task insofar as it relies heavily on language and is likely to be heavily dependent on dorsolateral prefrontal cortex. Considerable evidence suggests that various aspects of language acquisition proceed more rapidly in girls (see Kimura, 1999, for a review), and these differences may (at least eventually) be reflected in patterns of functional neuroanatomical organization within prefrontal cortex (cf. Shaywitz, Shaywitz, Pugh, et al., 1995).

There is no direct evidence for more rapid development of dorsolateral prefrontal cortex in girls. However, there is evidence for reciprocal suppression between dorsolateral prefrontal cortex and orbitofrontal cortex (Drevets & Raichle, 1998), consistent with the view that dorsolateral prefrontal cortex stands in a hierarchical relation to orbitofrontal cortex and regulates it (Zelazo & Muller, 2002b). Moreover, there is evidence from monkeys (e.g., Clark & Goldman-Rakic, 1989) and from toddlers (Overman, Bachevalier, Schuhmann, & Ryan, 1996) that orbitofrontal cortex develops more rapidly in males than in females, and that this sex difference is under the control of gonadal hormones (Clark & Goldman-Rakic; Goldman, Crawford, Stokes, Galkin, & Rosvold, 1974). Together these findings prompt the speculation that whereas orbitofrontal cortex develops more rapidly in boys, perhaps dorsolateral prefrontal cortex develops more rapidly in girls. Clearly, however, this is no more than an intriguing possibility, and further work remains to be done simply to determine whether the sex difference in DCCS performance, however small in size, is a reliable effect. Pending such work, the effect of sex observed in Experiment 8 will not be discussed further.

## EXPERIMENT 9

Experiment 8 revealed evidence of negative priming in the DCCS. In the Negative Priming version, performance during the postswitch phase could not depend on persistent activation of the specific preswitch rules because these rules could not be applied during the postswitch phase. Moreover, children's good performance on the Total Change version provides evidence that children are unlikely perseverate on a dimension per se. Taken together, these findings indicate that the rules that are irrelevant during the preswitch phase are negatively primed. Indeed, the finding that the Negative Priming version was not significantly easier than the standard version suggests that negative priming may make a major contribution to 3- to 4-year-olds' difficulty on the DCCS. However, the Negative Priming version did not significantly differ from the Partial Change versions, and it was only marginally different from the Total Change version, raising the possibility that the finding from Experiment 8 is not reliable and/or that the role of negative priming is relatively minor.

Experiment 9 was designed to replicate the finding with respect to the negative priming version and to explore further the circumstances in which negative priming is elicited in the DCCS. One possibility is that negative priming is only seen when children are required to select the preswitch pair of rules against a competing alternative (Perner & Lang, 2002; cf. Houghton & Tipper, 1994). On the other hand, it is also possible that whenever children attend to the values from one dimension, everything else is negatively primed (or, alternatively, habituated to) in an automatic and relatively passive fashion. In this case, even irrelevant cues from dimensions that do not conflict with the relevant dimension may be negatively primed. Negative priming may be an emergent consequence of a discrimination process inherent in memory retrieval (Milliken et al., 1998) or a consequence of episodic retrieval (Neill & Valdes, 1992).

Experiment 9 aimed to investigate these two possibilities using two new versions of the DCCS (see Figure 17), the Negative Priming (redundant preswitch) version and the Redundant version ( Jacques, 1995). In the Negative Priming (redundant preswitch) version, target and test cards were identical during the preswitch phase, and the values of the formerly relevant dimension were replaced during the postswitch phase, as in the Negative Priming version. In the Redundant version, target and test cards were identical during the preswitch phase, and conflicting target and test cards were introduced during the postswitch phase.

If negative priming depends on active selection against a competing alternative, then performance on the Negative Priming (redundant preswitch) version should be good. If it does not, then performance on this version should be poor.

Errors on the postswitch phase of the Redundant version could reflect both negative priming and persistent activation, and this version was included to explore further the circumstances in which these potential influences occur. If negative priming depends on active selection against a competing alternative, then no negative priming should be observed on the Redundant version. Predictions regarding activation were less clear. In Experiment 8, errors were observed in the Partial-Partial Change versions even though it was not possible during the preswitch rules to sort by the alternative rules. This may indicate that activation occurs even in the absence of competing alternative rules. In the Redundant version, it was possible to sort by alternative rules during the preswitch phase, but the alternative rules prescribed the same responses as the preswitch rules (and hence, were not "competing"). Additionally, unlike in the Partial-Partial Change versions, in the Redundant version there was no conflict between target and test cards during the preswitch phase. If some mismatch between target and test cards is required to elicit activation of selected rules, then no persistent activation should be observed on the Redundant version.

In addition to the Redundant version, performance on the Negative Priming (redundant preswitch) version was compared to performance on the standard (target cards refreshed) version, the Total Change (no preswitch feedback) version, and the Negative Priming version.

### *Method*

**Participants.** Eighty-seven 3- to 4-year-olds (*M* = 41.4, range: 36 months to 48 months; 44 girls and 43 boys) were recruited in the same fashion as in Experiment 1. Six additional children were excluded from the final sample because of experimenter error (n = 5) or for admitting to tricking the experimenter (n = 1).

**Design.** Children at each age were randomly assigned to receive one of five versions of the DCCS: the standard (target cards refreshed) version, the Total Change (no preswitch feedback) version, the Negative Priming version, the Negative Priming (redundant preswitch) version, or the Redundant version. For all versions, the dimension (color or shape) that was relevant during the preswitch phase was counterbalanced. Card sets were the same as in Experiments 7 and 8, and they were counterbalanced in the same fashion as in these experiments.

**Procedure.** The standard (target cards refreshed), Total Change (no preswitch feedback), and Negative Priming versions were the same as in Experiment 8. The procedure for the remaining two versions was identical to that of the other versions except for the cards used. In the Negative Priming (redundant preswitch) version, the target cards and test cards were identical during the preswitch phase, and the values of the dimension that was relevant during the preswitch phase were replaced during the postswitch phase. In the Redundant version, the target cards and test cards were identical during the preswitch phase; standard test cards were used during the postswitch phase. The total procedure took approximately 10 minutes to administer.

### *Results*

**Group analyses.** A preliminary two-way (Version x Dimension Order) ANOVA on number of correct postswitch trials indicated that there was no effect of dimension order and no Version x Dimension Order interaction. Consequently, dimension order was dropped from subsequent analyses. A two-way (Sex x Version) ANOVA on number of correct postswitch responses revealed only a significant effect of version, $F(4, 77) = 2.74$, $p < .05$ (effect size $f = .38$), and no effect of sex, $F(1, 77) = .01$. The Newman-Keuls post hoc test ($p < .05$) indicated that the Negative Priming version was significantly more difficult than the Redundant version, the Total Change (no preswitch feedback) version, and the Negative Priming (redundant preswitch) version (see Figure 19). These results did not change after excluding children who failed the preswitch phase (fewer than 7 out of 8 correct; $n = 7$).

Comparison of children's performance on the different versions to chance performance revealed that children performed significantly better than chance on the Redundant version, $t(16) = 3.77$,$p < .0 1$, the Negative Priming (redundant preswitch) version, $t(16) = 2.6 1$, $p < .05$, and the Total Change version, $t(16) = 2.82$, $p<$ .05. Children's performance on the standard version and on the Negative Priming version did not differ significantly from chance.

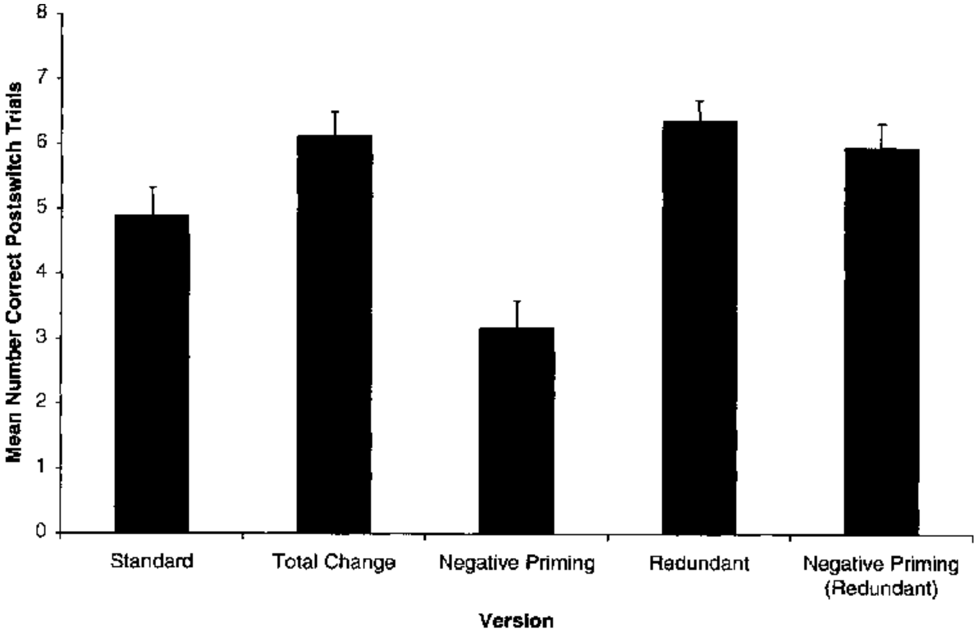

FIGURE 19. · Mean number correct (and standard error) on the postswitch trials of the Dimensional Change Card Sort, according to version (Experiment 9).

**Individual analyses.** Seven children (2 in the standard version, 2 in the Negative Priming version, and 1 each in the Total Change, the Redundant, and the Negative Priming [redundant preswitch] versions) failed the preswitch phase, using the same criterion as in Experiment 8 (i.e., at least 7 out of 8 correct, $p < .05$, binomial distribution). Children who passed the preswitch phase were classified as passing the postswitch phase by the same criterion (see Table 8). As can be seen, performance on the Negative Priming version was significantly worse than on the Redundant version $\chi^2(1, N = 32) = 6.15$, $p < .05$, on the Negative Priming (redundant preswitch) version, $\chi^2(1, N= 32) = 6.15$, $p < .05$, and on the Total Change version, $\chi^2(1, N= 32) = 6.15$, $p < .05$. There was also a trend for the Negative Priming version to be more difficult than the standard version, $\chi^2(1, N = 33) = 3.24$, $p <.08$. Nine children (53%) perseverated (7 or 8 incorrect) in the Negative Priming version, 6 (38%) in the standard version, 3 (19%) in the Negative Priming (redundant preswitch) version, 2 (13%) in the Redundant version, and 2 (13%) in the Total Change version.

### *Discussion*

Experiment 9 replicated the finding from Experiment 8 that 3- to 4year-olds performed poorly on the Negative Priming version of the DCCS, in which persistent activation of the preswitch rules could not affect postswitch performance. Children performed significantly worse on the Negative Priming version than on the Total Change (no preswitch feedback) version, the Redundant version, and the Negative Priming (redundant preswitch) version. Surprisingly, the Negative Priming version was also marginally more difficult than the standard version, and the standard version did not differ from the Total Change (no preswitch feedback) version. It should be noted, however, that for unknown reasons (possibly sampling error) children's performance on the standard (target cards refreshed) version was slightly better than is usually observed.

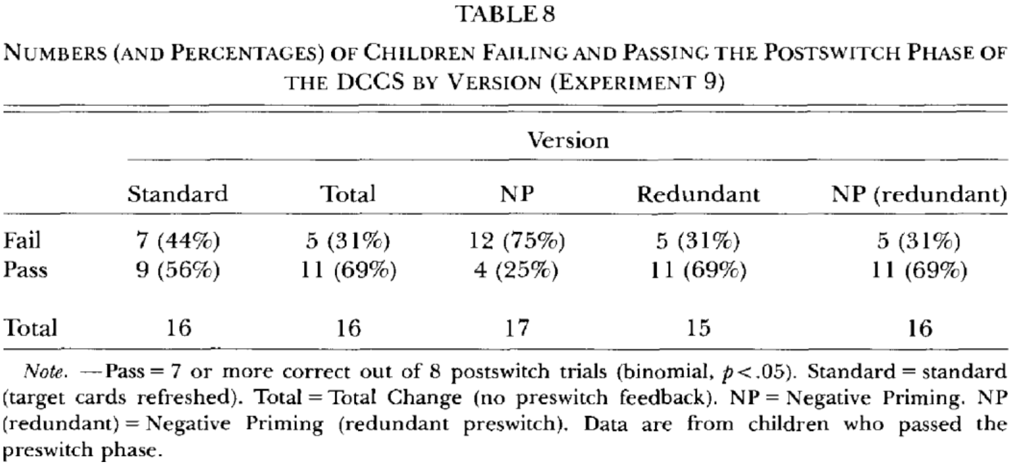

TABLE 8

NUMBERS (AND PERCENTAGES) OF CHILDREN FAILING AND PASSING THE POSTSWITCH PHASE OF THE DCCS BY VERSION (EXPERIMENT 9)

| | Version | | | | |
|---|---|---|---|---|---|
| | Standard | Total | NP | Redundant | NP (redundant) |
| Fail | 7 (44%) | 5 (31%) | 12 (75%) | 5 (31%) | 5 (31%) |
| Pass | 9 (56%) | 11 (69%) | 4 (25%) | 11 (69%) | 11 (69%) |
| Total | 16 | 16 | 17 | 15 | 16 |

*Note.* —Pass = 7 or more correct out of 8 postswitch trials (binomial, $p < .05$). Standard = standard (target cards refreshed). Total = Total Change (no preswitch feedback). NP = Negative Priming. NP (redundant) = Negative Priming (redundant preswitch). Data are from children who passed the preswitch phase.

These results further document and clarify the role of negative priming in the DCCS. In the DCCS, negative priming occurs when there is a conflicting mismatch between target and test cards during the preswitch condition. Under these circumstances, children need to attend to one dimension and ignore the alternative. In selectively attending to the values of the relevant dimension, children evidently need to inhibit the values of the interfering distractors from the irrelevant dimension. As a result, these values are suppressed and this suppression seems to persist into the post-switch phase, making it difficult for children to select and use the postswitch rules. When there is no conflicting mismatch between target and test cards during the preswitch phase, as in the Negative Priming (redundant preswitch) version, children perform significantly better.

These findings suggest that negative priming is due to an inhibitory selection mechanism that is only invoked when children are confronted with stimuli that can be sorted in two different ways. The findings argue against the position that negative priming will be operative even when conflicting stimuli are absent (Milliken et al., 1998; Neill & Valdes, 1992) because if that were the case then children should have performed poorly on the Negative Priming (redundant preswitch) and Redundant versions. Similarly, the findings argue against the suggestion that negative priming can be accounted for by habituation of attention to irrelevant values. At the same time, however, it remains possible that habituation of attention plays a role children's performance on the DCCS. Any beneficial effect of introducing novel stimuli during the postswitch phase could perhaps be attributed to dishabituation. This possibility will be discussed further in Chapter VI.

The Redundant version was included in an exploratory fashion to examine further the circumstances in which negative priming and persistent activation influence postswitch performance. In contrast to the 3- to 4-year-olds in Jacques's (1995) study, the children in Experiment 9 performed well on the Redundant version: whereas about 2/3 of the children failed the Redundant version in Jacques's study, about 2/3 passed this version in Experiment 9. The reason for this discrepancy is unclear: The mean age of the 3- to 4-year-olds in Jacques's study was 43.1 months (*SD* = 1.71), versus 41.4 in Experiment 9, and the procedure was similar to the one used in Experiment 9. However, test cards were labeled by both dimensions in Jacques's study, and children received preswitch trials (with no feedback) until they reached a criterion of 5 consecutive correct trials (maximum 20 trials). Although one must be cautious in interpreting the findings of the Redundant version until further research confirms whether this version is easy or difficult for 3- to 4-year-olds, the good performance observed in this experiment provides converging evidence that negative priming is only observed when there is a conflicting mismatch between target and test cards during the preswitch phase, and, hence, when children must select against a competing alternative.

Interpretation in terms of activation is less straightforward, and several possible interpretations exist. One possibility is that activation of selected preswitch rules only occurs when there is conflict between target and test cards during the preswitch phase. In Experiment 8, errors were observed in the Partial-Partial Change versions. Although it was not possible during the preswitch phase to sort by the alternative rules (because values of the alternative dimension were missing either for the target cards or the test cards), there was conflict between target and test cards in the sense that target and test cards did not match. Another possibility is that values of the irrelevant dimension were actually positively primed (i.e., more strongly activated) rather than negatively primed. Positive priming of unattended values has been observed in some circumstances in the adult literature on negative priming (e.g., Fox, 1995). These possibilities, along with others, will need to be explored further.

## GENERAL DISCUSSION

Experiment 8 replicated and extended the findings from Experiment 7 in the absence of feedback during the preswitch trials. Whereas about half of the 3- to 4-year-olds perseverated in the Partial Change (no preswitch feedback) version, nearly two-thirds passed the Total Change (no preswitch feedback) version. Experiment 8 also revealed that negative priming plays an important role in the DCCS. In the Negative Priming version, the values of the dimension that was relevant during the preswitch phase were replaced by different values. According to CCC theory and one reading of Kirkham et al.'s (in press) attentional inertia account, children should have no difficulty with this version of the DCCS. However, 3- to 4-year-olds performed as poorly in the Negative Priming version as they did in the standard version. Finally, in the Partial-Partial Change versions, the values of the irrelevant dimension were removed during the preswitch phase on either the target cards or the test cards. Performance on the Partial-Partial Change versions was nearly identical to performance on the Partial Change version, raising the possibility that activation of the preswitch rules occurs even when it is not actually possible to sort by an alternative rule.

Experiment 9 confirmed that 3- to 4-year-olds perform poorly on the Negative Priming version, and also clarified the conditions under which negative priming occurs. Evidence indicates that negative priming occurs only under conditions of conflict when it is possible to sort by values of another dimension. Negative priming was not observed in the Negative Priming (redundant preswitch) version or the Redundant version, in both of which target cards and test cards were identical during the preswitch phase. Both versions were significantly easier than the Negative Priming version.

Experiments 8 and 9 suggest, therefore, that there must be a conflicting mismatch between target and test cards during the preswitch phase in order for negative priming to occur in the DCCS. Under these circumstances, suppression of the values of the interfering dimension persists into the postswitch trials, making it more difficult to switch to sorting by the previously irrelevant dimension. These findings support the hypothesis that negative priming occurs in the DCCS only when children must actively select the preswitch pair of rules against a competing alternative.

Negative priming alone, however, does not suffice to explain 3- to 4-year-olds' performance on the DCCS. If negative priming alone were operative, the children would have no difficulty with the Partial Change version, in which the values of the dimension that was irrelevant during the preswitch phase were replaced by new values. However, in both Experiments 7 and 8, about half of the children failed the Partial Change version, and performance did not differ from the standard version in Experiment 7.
Thus, neither the negative priming hypothesis nor CCC theory can fully explain the pattern of findings. Whereas the findings from the Partial Change version are consistent with CCC theory, the findings from the

Negative Priming version are not. By contrast, the findings from the Negative Priming version are consistent with the negative priming hypothesis, but the findings from the Partial Change are not. In order to capture the full pattern of empirical findings, an alternative account is needed that includes both processes of activation and processes of inhibition. This alternative is described in Chapter VI.

## VI. THE DEVELOPMENT OF EXECUTIVE FUNCTION: COGNITIVE COMPLEXITYAND CONTROL-REVISED

### *SUMMARY OF RESULTS ACROSS STUDIES*

The current *Monograph* consisted of four studies (9 experiments) designed to explore the development of children's executive function, as revealed by their performance on the DCCS. The DCCS is a widely used measure of rule use, and, as such, it provides a relatively well-defined window on the development of executive function during the preschool years. Executive function in general, and as assessed by the DCCS in particular, has been implicated in children's behavior in a variety of domains and in a variety of subject groups, including bilingual children, children with autism, and children with Down's syndrome.

By experimentally manipulating features of the DCCS paradigm, we tested hypotheses about the cognitive mechanisms underlying executive function and its development. Results of this research have the potential to shed light not only on children's development in a variety of domains, but also on dorsolateral prefrontal cortical function especially during the preschool years. Performance on the DCCS almost certainly relies on neural systems involving prefrontal cortex. In particular, dorsolateral regions of prefrontal cortex have been implicated in a number of tasks quite similar to the DCCS (see Nagahama et al., 2001; Rogers, Andrews, Grasby, Brooks, & Robbins, 2000, for research using functional magnetic resonance imaging [fMRI] and positron-emission tomography [PET], respectively).

Study 1 examined whether 3- to 4-year-olds' errors on the DCCS can be attributed to capacity limitations on memory. Three experiments showed that 3- to 4-year-olds performed well on four versions of the DCCS in which children were required to use four nonoverlapping rules (i.e., children were not required to treat the same test card differently depending on the relevant dimension). In Experiment 1, the two new versions were unidimensional. In Experiment 2, children were given the 2+2-Rules (bidimensional, no overlap) version, in which they were shown four target cards and asked to sort test cards first by two rules based on one dimension (e.g., color) and then by two rules based on the other dimension (e.g., shape). Although children needed to remember which cards to sort by color and which cards to sort by shape, there was no conflict among rules because each test card was uniquely associated with a single rule. Children performed well on this version, showing that bidimensionality per se does not cause children's difficulty on the DCCS.

In Experiment 3, children performed well on the 4-Rules (super-ordinate) version, which likely posed even greater memory demands than the 4-Rules versions used in Experiments 1 and 2 because it involved superordinate rules and a heterogeneous series of test cards. Not only did children need to keep four superordinate distinctions in mind, but they also need to determine which rule applied to each test card (i.e., there were storage plus processing demands). Nonetheless, children performed significantly better on the 4-Rules (superordinate) version than on the standard version of the DCCS. Taken together, findings from the three experiments provide strong evidence against most memory capacity accounts of performance on the DCCS, and they point to the importance of conflict among rules.

Study 2 was designed to explore further the role of conflict among rules by determining more precisely the circumstances in which children can and cannot treat a single test card in two different ways. Three experiments assessed the effects of rule dimensionality (bidimensional vs. unidimensional rules) and two types of stimulus characteristic (1 vs. 2 test cards; integrated vs. separable stimuli). Here, unlike Study 1, bidimensional rule sets always involved conflict among rules whereas unidimensional rule sets did not. Results revealed effects of rule dimensionality but no effects of stimulus characteristics. Sorting by even a single pair of rules was difficult for 3- to 4-year-olds when the two rules spanned major branches of the hierarchical tree structure shown in Figure

3. When the rules did not span major branches, however, even 3- to 4-year-olds were able to treat the same stimulus in two different ways. That is, under these circumstances, 3- to 4year-olds effectively redescribed the test card and inhibited their old way of responding.

The third experiment in Study 2 (i.e., Experiment 6) replicated these findings in a single test, while also assessing whether the separated stimuli used in the unidimensional version in Experiment 5 might have accounted for children's success. According to Shepp and Barrett (1991), as well as work with adults (see MacLeod, 1991), the use of spatially separated stimuli may facilitate analysis of the stimuli into dimensions or attributes. The findings from Experiment 6, however, clearly indicate that conflict among rules, but not spatial separation of the stimuli, determines performance on the DCCS.

Taken together, the results of Study 2 show that conflict among rules is a key determinant of difficulty, but that conflict interacts with dimensionality.

Perseveration is, therefore, at least partly a function of rule complexity, and cannot be attributed to a general problem with inhibitory control—either at the level of responses or at the level of representations. Similarly, it cannot be explained by a general difficulty redescribing stimuli. The redescription hypothesis cannot account for the finding in Experiment 6 that children performed significantly better on the Unidimensional Separated version than they did on the Bidimensional Separated version. These two versions should be equally likely to alert children to the need to redescribe the test cards. From the perspective of CCC theory, however, a difference between these versions would be expected because only the Bidimensional Separated version requires children to use rules nested under different major branches of the tree structure in Figure 3. CCC theory holds that 3- to 4-year-olds fail to resolve conflict at a particular level of complexity at the level of specific rules—because they have difficulty formulating a higher order rule for selecting between dimensions.

Study 3 examined further what types of conflict in typical executive function problems pose difficulties for 3- to 4-year-olds by asking whether children who perseverate on the DCCS perseverate on specific rules as opposed to dimensions per se or particular stimuli. Although children perseverated on the Partial Change version (in which the values of the dimension that was relevant on the preswitch phase were retained during the postswitch phase), they performed well when the values of both dimensions were changed (Total Change version). These findings suggest that children perseverate on specific rules (e.g., "If red, then there"), consistent with CCC theory, according to which the selection and use of preswitch rules increases the activation level of those rules (Marcovitch & Zelazo, 2000) .

Study 4 was designed to replicate Study 3 and also to examine the possible role of negative priming on the DCCS in relation to other possible sources of difficulty. In the Negative Priming version of the DCCS, the values of the dimension that was relevant during the preswitch phase were removed during the postswitch phase. Results indicated that this version was as difficult as the standard version, as would be predicted if the competing rules are negatively primed and thus inhibited during the preswitch phase. Further work suggested that negative priming depends on the active selection of one pair of rules against a competing alternative. In Experiment 9, children performed well on the Negative Priming (redundant preswitch) version, in which test cards were identical to the target cards during the preswitch phase so children did not need actively to select against competing rules. Children also performed well in the Redundant version, suggesting that persistent activation may also depend on attending selectively to the preswitch rules.

## IMPLICATIONS FOR ALTERNATIVE ACCOUNTS OF THE DEVELOPMENT OF EXECUTIVE FUNCTION

### *Memory Accounts*

Several influential accounts of development during the preschool years suggest that age-related changes in executive function will be limited by the development of children's memory (e.g., Case, 1992, 1995; Gordon & Olson, 1998; Olson, 1991; Pascual-Leone, 1970). It is possible that the growth of memory, perhaps particularly working memory, constrains the number of rules that children can use in the DCCS. For example, 3-year-old children may represent and remember the first two rules but then be unable to hold the second pair of rules in mind due to limited available processing space.

In the standard version of the DCCS, children are told the postswitch rules on every trial, so prima facie it seems unlikely that an inability to remember the rules can account for 3- to 4-year-olds' failure to use them. Similarly, children correctly answer questions about the postswitch rules (Zelazo et al., 1996), suggesting that they have not forgotten these rules. Finally, some manipulations that might be expected to increase memory demands (e.g., removing target cards; Towse et al., 2000) actually appear to improve performance.
On the other hand, it could be argued that capacity constraints and/or proactive interference (Keppel & Underwood, 1962) prevent children from keeping the postswitch rules in mind long enough to control responding. Also, Morton and Munakata (2002) were able to model performance on the DCCS in terms of competition between active and latent memory.

The results of Study 1 showed that 3- to 4-year-olds performed well on versions of the DCCS in which children were required to use four rules but not required to respond in two different ways to the same test card. These findings clearly suggest that errors on the DCCS cannot be attributed in any straightforward way to limitations on memory. However, the findings from Study 1 leave open the possibility that 3- to 4-year-olds' memory for the rules is limited in a way that permits them to succeed in some situations (i.e., those without conflict) but not others (those with conflict), as suggested by Morton and Munakata (2002), and they leave open the possibility that memory plays a critical role in performance on the DCCS and in other measures of executive function. Indeed, according to CCC theory, children formulate explicit rules in self-directed speech, maintain them in working memory, and then use them to guide their behavior. What the findings from Study 1 suggest is simply that 3- to 4-year-olds' difficulty on the DCCS depends more on the conflict among rules than on the requirement that rules be remembered. It seems unlikely that age-related increases in memory capacity alone can explain age-related increases in performance on the DCCS.

### *Inhibition Accounts*

Several accounts suggest that children perform poorly on measures of executive function because of poor inhibitory control (e.g., Carlson & Moses, 2001; Carlson et al., 1998; Dempster, 1993, 1995; Diamond & Gilbert, 1989; Harnishfeger & Bjorklund, 1993; Luria, 1961; Perner et al., 1999; White, 1965). Perseveration seems to implicate inhibition by definition behavior is exhibited that should have been inhibited. In the DCCS, for example, children are not supposed to sort by the preswitch rules during the postswitch phase, and when they do this, they may reasonably be described as failing to inhibit sorting by the preswitch rules. But this is simply a description of their behavior, not an explanation of why they fail to inhibit sorting by the preswitch rules.

An inhibitory control account of the DCCS gains leverage, however, when it implies that 3- to 4-year-olds understand everything they need to understand in order to perform correctly. On this type of account, 3- to 4-year-olds know perfectly well what to do during the postswitch phase of the DCCS, and even try to do it, but cannot inhibit a prepotent tendency acquired during the preswitch phase. Even when conceptualized in this way, inhibition accounts are problematic for a number of reasons (Zelazo & Muller, 2002b). One limitation of these accounts is their inability to support predictions regarding the specific situations that will pose problems for children at different ages. For example, they generally fail to explain in a noncircular way why children at a particular age perseverate in particular situations but not others (e.g., why 3- to 4-year-olds perseverate in the standard DCCS but not the standard A-not-B task). A second limitation of inhibition accounts is that the construct of inhibition fails to address how one decides what is to be inhibited, and when (Rapport, Chung, Shore, & Isaacs, 2001). A third limitation is that inhibition accounts do not explain how children acquire new levels of conceptual understanding: "Inhibitory-based accounts ... cannot explain knowledge level transitions per se" (Perret et al., 2003, p. 287).

Do 3- to 4-year-olds understand everything there is to know regarding the DCCS? Do they try to sort by the postswitch rules but fail? Considerable evidence suggests that they do not. One finding (Zelazo et al., 1996, Exp. 2) suggests that 3- to 4-year-olds perseverate in the DCCS even after a single preswitch trial. In other words, sorting a card even once by one dimension prevents the majority of 3- to 4-year-olds from switching to the other dimension, so perseveration in this situation cannot be due to failure to inhibit an overlearned response. The findings by Jacques et al . (1999) that 3- to 4-year-olds judge a puppet's perseveration on the DCCS to be correct makes this point even more strongly. If 3- to 4-year-olds know what should be done in the task and are not required to make the response themselves, why is it still as difficult for them to evaluate another's performance? Taken together, these results show that 3- to 4-year-olds' have difficulty formulating what should be done and not just difficulty doing it (cf. Frye et al., 1996; Zelazo et al., 1995).

It remains possible, however, that 3- to 4-year-olds have difficulty inhibiting attention to particular aspects of the target cards (Kirkham et al ., in press). CCC theory agrees with Kirkham et al. that inhibition and refocusing are required in the DCCS. That is, both accounts agree that, in the context of this task, 3- to 4-year-olds have difficulty inhibiting attention to a previously useful aspect of the stimulus, and refocusing on another conflicting aspect of the same stimulus. However, CCC theory attempts to explain how inhibition and refocusing occur, why failures of inhibition and refocusing occur in some situations and not others, and why there are particular age-related changes in inhibition and refocusing. According to CCC theory, inhibition and refocusing are made possible by (a) reflection on rules and (b) formulation of a higher order rule for selecting the appropriate setting condition. In the absence of reflection and the formulation of a more complex rule system, children cannot properly be said to understand what to do on the DCCS. Although they know the relevant rules, these rules remain unintegrated and children cannot appreciate the relation among them.

The findings from Study 2 show that children are indeed capable of inhibition and refocusing when pre- and postswitch rules are not nested under different major branches of the hierarchical tree structure in Figure 3. This finding was expected based on CCC theory, but it is unclear how it could be accounted for in terms of Kirkham et al.'s (in press) approach. Further, unlike CCC theory, Kirkham et al. do not differentiate between persistent attention to a dimension and persistent activation of specific rules. The results of Experiment 7, which showed that children were more likely to perseverate on the preswitch sorting *rules* than the preswitch sorting *dimension,* clearly favor CCC theory in this regard. Finally, Experiments 8 and 9 show that 3- to 4-year-olds have difficulty disinhibiting the postswitch rules, a finding that is at odds with the suggestion that children fail the DCCS because of too little inhibition.

It could be argued, however, that the combination of inhibition and working memory can account for the findings presented in this *Monograph.* In fact, working memory plus inhibition accounts have been proposed by a variety of researchers (e.g., Diamond, 2002; H ala et al., 2003; Roberts & Pennington, 1996) . A working memory plus inhibition account would predict that children will only encounter difficulties in versions of the DCCS that involve conflict because conflict pits a prepotent but incorrect response against a weaker but correct response. The joint development of working memory and inhibition would then be responsible for children's eventual success on versions of the DCCS that involve conflict. Thus, for example, on this account, the finding that children performed well on unidimensional versions and 4-Rule versions of the DCCS may be attributed to the lack of conflict in these versions.

Although clearly both working memory and inhibition play a role in the DCCS, a working memory plus inhibition account by itself encounters some of the same problems that undermine the appeal of simple inhibition or working memory accounts. That is, children encounter conflict at many different levels, and they fail tasks that involve conflict at different ages. A working memory plus inhibition account lacks a clear metric that can be used to order these different tasks in an a priori fashion. For example, the 4-Rule and 2+2-Rule version used in Study 1 likely do involve conflict in the sense that children must inhibit a motor tendency to put the test card into the same tray on trial n+1 that they put it into on trial n —a perseverative pattern exhibited by children under the age of 3 years (Zelazo et al., 1995). Clearly, the a priori specification of different kinds and degrees of conflict remains a major task for working memory plus inhibition accounts.

In a sense, the neural network model by Morton and Munakata (2002) can also be considered a working memory plus inhibition model, although the inhibition component is seen to be a consequence of increases in the strength of active memory. Because the strength of active memory increases gradually, the model can explain why children are more likely to succeed on versions of the DCCS with less conflict. In addition, because the model incorporates lateral inhibitory connections among units within the prefrontal cortex, hidden, and output layers, the model might be able to simulate children's performance on the Negative Priming version (although this needs to be established). Thus, a major advantage of the model by Morton and Munakata is that it captures the dynamic interplay between activation and inhibition, which has been demonstrated in the DCCS and is probably also characteristic of other measures of executive function.

It might be noted, however, that it is unclear how the Morton and Munakata (2002) model would account for the earlier finding that 3- to 4year-olds perseverate even after a single preswitch trial (Zelazo et al., 1996). In addition, one wonders whether Morton and Munakata's model provides a satisfactory account of development and developmental mechanisms: The setting conditions and the differentiation between setting conditions are simply built into the prefrontal component of the model. In contrast to CCC theory (e.g., see Marcovitch & Zelazo, 2000), therefore, this model does not explain, but rather simply stipulates, older children's ability to differentiate between setting conditions.

### *Redescription Accounts*

The redescription hypothesis (Perner et al., 2002) predicts that 3- to 4year-olds will have difficulty appreciating that a single thing can be labeled in multiple ways. According to Perner and colleagues, this difficulty, which has been noted in the context of research on word learning (e.g., in terms of the mutual exclusivity constraint; Markman, 1989) and theory of mind (e.g., Flavell, 1988), derives from an inability to appreciate multiple perspectives on an object, and this difficulty is not overcome until children acquire the concept of perspectives.

In support of their redescription approach, Perner and colleagues propose that task manipulations that improve children's performance on the DCCS (e.g., asking children to label the test cards; Kirkham et al., in press; Towse et al., 2000, Exp. 4; or demonstrating correct sorting in the postswitch phase; Towse et al., Exp. 1) help children to understand that test cards can be redescribed. They also refer to independent evidence that 3- to 4-year-olds have difficulty with redescription. For example, in work by Doherty and Perner (199 8) using the say-something-different task, children are told a name for something (e.g., rabbit) and then asked to generate an alternative description (e.g., bunny). Three-year-olds have difficulty with this task whereas 4-year-olds do well.

Perner et al. (2002) offer a test to specify when using two labels will be particularly difficult for children. Basically, if two descriptions can be joined by "and," as for example when the descriptions "dog" and "beautifully spotted" can be combined into "beautifully spotted and a dog," then young children will be able, in principle, to use both descriptions. However, if two descriptions cannot be joined by "and" without producing an apparent conflict, then young children will accept only one description. For example, when one person sees "object A in front of object B" and another person from the other side sees "object B in front of object A," joining these two descriptions yields "object A is in front of object B and behind object B." Resolving the apparent discrepancy requires understanding the concept of perspectives.

Of course, Perner et al.'s (2002) "and" test predicts that 3- to 4-year-olds should be able to pass the standard version of the DCCS because the test cards can be easily described as "green and a car." However, as Perner and Lang (2002) note, even if 3- to 4-year-olds can, in principle, understand alternative descriptions in the DCCS, they become much more likely to do so at around 4 years of age, when they discover the concept of perspectives. Therefore, this account can be applied to the DCCS in a straightforward fashion. For example, in the preswitch phase of the DCCS, when sorting by color, children may describe a red rabbit as a *red one*. Then, in the postswitch phase, they may need to describe that same stimulus as a *rabbit*. If 3- to 4-year-olds fail to understand that it is possible to provide multiple descriptions of a single stimulus, then they will persist in describing the test cards in terms of the preswitch dimension, as suggested by Zelazo and Frye (1997) and Frye (1999).

As Zelazo and Frye (1997, p. 145) noted, "Higher order rules allow children to understand that the shape rules and the color rules both apply to a single task under different descriptions (or setting conditions)." Using a higher order rule to select a particular setting condition in effect determines how to describe a single thing for the purpose of deciding how to respond to it. In the DCCS, children may first have to describe a test card in terms of its color and then in terms of its shape. Although 3- to 4-year-olds are capable of either description, they have difficulty switching flexibly between them. Therefore, despite disagreement about the mechanisms underlying age-related changes in children's flexibility, CCC theory is similar in many respects to Perner's redescription account, and it makes many of the same predictions.

However, CCC theory also differs from Perner's account in important ways. For example, CCC theory predicts that redescription in the context of the DCCS will be easy or difficult depending on whether or not switching between rules requires appeal to a setting condition. As the results of Study 2 establish, children can treat a single test card in two different ways whenever rules are not nested under different setting conditions in the hierarchical tree structure in Figure 3. According to CCC theory, a higher order rule will be required when children need first to consider a setting condition and then to select the appropriate rule. Thus, CCC theory can account for the results of Study 2 in a straightforward fashion, whereas Perner's redescription hypothesis cannot.

## IMPLICATIONS FOR COMPLEXITY THEORIES

### *Circumstances in Which 3- to 4-Year-Olds Perseverate*

The results reported in this *Monograph* add to our understanding of the conditions in which 3- to 4-year-olds exhibit difficulty on the DCCS. As these results show, the key conditions appear to be that (a) there is conflict among at least two rules such that children are required to respond in two different ways to the same stimulus and (b) the conflicting rules are nested under different major branches in the hierarchical tree structure depicted in Figure 3. These conditions apparently must occur jointly for perseveration to be observed; when either (a) or (b) occurs alone, children perform well. Together, these conditions imply that conflict occurs at the level of specific rules, not at the level of dimensions per se or at the level of specific stimulus configurations.

Difficulty under conditions (a) and (b) appears to derive both from activation of rules selected during the preswitch phase and from inhibition of the rules selected against during the preswitch phase. Inhibition seems to depend on the presence of competing alternative rules during the preswitch phase, and activation may depend on the presence of some degree of mismatch between test and target cards during the preswitch phase.

In addition to these conditions, it is likely that interference between pre-and postswitch phases is context dependent to some extent. For example, 3- to 4-year-olds may be able to sort by either pre- or postswitch rules in the standard version when these rules are presented in very different contexts (e.g., on different days), although the limits of this likely context dependency remain to be determined.

### *Criteria for Determining When a Higher Order Rule Is Required*

The conditions outlined above help to clarify the criteria for determining when a higher order rule is required. CCC theory provides guidelines for determining the rule complexity—the number of degrees of rule embedding—required in any particular situation. The basic strategy is to calculate the simplest possible rule structure, or structures, necessary to control variations in responding to a stimulus or set of stimuli (these rule structures being formulated in an ad hoc fashion in order to solve the problem). A new degree of embedding is only *required* (although it may be allowed) in cases where at least two rules apply to a single stimulus with respect to different dimensions (e.g., in the Pruned Tree [single test card] version of the DCCS, both the red rule and the rabbit rule apply to the red rabbit, in different dimensions, viz., *color* and *shape).* When this happens, a dimension must serve as a setting condition in order to permit selection of, first, the appropriate setting condition and then of the appropriate rule.

This approach predicts that 3 - to 4-year-olds will have difficulty whenever they are required to formulate a single rule system that spans major branches in a hierarchical tree structure like that depicted in Figure 3. A higher order rule will not be required, although it may be allowed, when switching between specific rules that are not in conflict (e.g., within a dimension or between nonoverlapping rules) and when using conflicting rules in different contexts.

Color and shape are paradigmatic instances of dimensions, but they are not the only possibilities. A dimension, on this view, corresponds to any relatively abstract, superordinate category of variation, in contrast to a more direct, concrete representation of a stimulus. Recall Vygotsky's (1929) description of a "primitive" boy (i.e., one who lacks formal education) who is asked to reflect on knowledge that he represents:

> Another example: a primitive boy is asked, "What is the difference between a tree and a log?" He answers, "I have not seen a tree, nor do I know of any tree, upon my word." Yet there is a lime-tree growing just opposite his window. When you ask him, "And what is this?" he will answer, "This is a lime-tree." (Vygotsky, 1929, p. 417)

From the perspective of the CCC theory, the concept of *tree* is an abstract, superordinate concept, and this boy has not coordinated his knowledge of a lime-tree into a general dimensional system that captures his knowledge of trees; he has not reflected on *trees* per se. Reasoning about a tree in this example involves reasoning about a dimension because the concept of tree corresponds to a category of variation that has to be considered as such. Zelazo and Frye (1997) suggested that it is only by distancing themselves from discriminations *within* a dimension and considering two or more dimensions in contradistinction that children are able to conceptualize dimensions qua dimensions (see also Smith, 1989).

Other examples include different personal perspectives (Frye et al., 1995; Zelazo & Frye, 1997), as in tests assessing understanding of false belief. In these tests, for example in judging the identity of an ambiguous object that only the child has seen, the reasoning required may be as follows: "If you're asking me, then the answer is it's a sponge not a rock, but if you're asking my friend, then the answer is that it's a rock and not a sponge." That is, children may be required to formulate and use a higher order rule. Similarly, as discussed by Zelazo and Sommerville (2001), children must consider temporal perspectives as such (i.e., as distinct from objective time: before vs. later) when they are asked to reason about their own past false beliefs. For example, 3-year-olds typically fail Gopnik and Astington's (1988) representational change task, where they must appreciate that they themselves changed from thinking Smarties to thinking sticks, even while the contents of the box did not change. According to CCC theory, they fail this task because the task requires them to differentiate between *the history of the self* (one category of variation) and *the history of the world* (another category of variation). Instead, children assimilate the subjective series to the objective series and reason within a single dimension. Notice that when similar tasks only require reasoning within a single dimension, 3-year-olds perform well. For example, in a control task used by Gopnik and Astington (Exp. 1), most 3-year-olds were able to judge that *now* there is a doll in a closed toy house but *before* there was an apple.

The notion of higher order rule use bears some resemblance to the construct of mediation, as it was used in research on discrimination learning. A variety of neobehaviorist approaches explored the possibility that, with age, children acquire the ability to make covert responses to stimuli that mediate between environmental stimuli and overt responding (e.g., H. H. Kendler & T. S. Kendler, 1962). Regardless of whether the mediational responses were hypothesized to be verbal or attentional (e.g., Zeaman & House, 1963), it was argued on the basis of research on discrimination learning that children under about 6 years of age fail to mediate their responses to environmental stimuli. Discrimination-learning research was directed mainly at the question of when children conceptualize specific stimuli (or cues such as "red") to be values of a general dimension (e.g., color). Dimensional responding was taken to reflect mediation and was inferred from the relative ease of intradimensional (and reversal) versus extradimensional (and nonreversal) shifts in rule learning (as opposed to rule use) tasks, and from the results of optional shift studies (T. S. Kendler & H. H. Kendler, 1966).

The results of this research are far from straightforward (see Esposito, 1975, for a review), and mediation theory (T. S. Kendler, 1979) is not directed toward explaining changes in rule use in the preschool period because it maintains that children in this age range cannot represent and use rules (which is a form of mediation). It is now well established that 3year-olds can use rules (Zelazo & Reznick, 1991). However, results from the DCCS suggest that in the absence of a higher-order rule for selecting between dimensions, 3- to 4-year-olds cannot be said to understand a dimension qua dimension. Although 3- to 4-year-olds do use rules for sorting by a dimension, such as color, it is not until children can reflect on these rules and contrast them with rules for sorting according to a different dimension, such as shape, that the dimension itself becomes an object of consideration for children. Being able to reflect on color rules *as* color rules that contrast with shape rules (or rules from any other dimension) would seem to be required to comprehend the way in which different colors form a coherent category of variation (i.e., a dimension).

### *Activation and Inhibition Processes*

The results reported in this *Monograph* clearly indicate that both activation and inhibition play roles in performance on the DCCS. This outcome suggests the following account of performance on the standard version of the DCCS. During the preswitch phase, the preswitch rules are selected against competing alternative rules, which are ignored. For example, based on the experimenter's instructions, children may select two specific shape rules against two specific color rules. Then, in terms of this example, the activation level of the shape rules is increased whereas the color rules are inhibited. Performance during the postswitch phase requires that children overcome the inhibition of the values of the formerly irrelevant dimension and, at the same time, deactivate the values of the formerly reinforced dimension.

The Negative Priming version is slightly (but not significantly) more difficult than the Partial Change version, and to the extent that these versions provide pure measures of inhibition and activation, respectively, this may indicate that the ignored rules are inhibited to a greater extent than the selected rules are activated. However, there are good reasons to believe that these are not pure measures. New values are introduced in the postswitch phase and these are likely to attract attention because attention to novelty appears to be a basic design feature of the human attentional system (e.g., Desimone & Duncan, 1995). Attention to novel values would undermine switching in the Negative Priming version because the new values introduced in the postswitch phase need to be ignored. In contrast, attention to novel values would facilitate switching in the Partial Change version because the new values are precisely those to which children need to attend. This difference may explain why the Negative Priming version is more difficult than the Partial Change version. However, further empirical research will be required to assess the relative influences of inhibition, activation, and novelty, and whether these influences change with age. Further research will also be required to map out whether these influences interact, and, if so, how.

Experiments 8 and 9 also raise a number of important questions about the processes underlying negative priming. The findings from Experiment 9 suggest that negative priming in the DCCS is only operative when children must select a pair of rules against a competing alternative. Negative priming thus appears to reflect mechanisms that play an instrumental, inhibitory role in the selection of relevant rules in the presence of competing distractors (see also Levy & Anderson, 2002). It is possible that in other tasks and/or at different ages negative priming may occur in the absence of conflicting information (see Milliken et al., 1998), but this does not appear to be the case for 3- to 4-year-olds in the DCCS. Certainly, further investigation is warranted regarding the question of whether negative priming is a unitary process or whether different mechanisms underlie negative priming in different tasks and at different ages.

Negative priming has rarely been investigated from a developmental perspective. However, Tipper and colleagues (1989) have shown that, compared to adults, evidence of negative priming is weak in 7-year-olds in a Stroop task. How can negative priming play such an important role in the DCCS if it is difficult to observe even in middle childhood? One possible answer to this question is that the influence of negative priming is dependent on task complexity; it may be observed first in less complex tasks and later in more complex tasks (see Tipper & McLaren, 1990; Stuss et al., 1999, for related arguments). Another possibility is that children failed to exhibit negative priming in previous studies simply because they failed to attend selectively during the prime phase. Clearly, however, these questions need to be addressed empirically.

Future research might also explore more fully the variables that are related to negative priming on the DCCS (e.g., see Fox, 1995; May et al., 1995, for reviews). For example, the spatial separation of target and distractor has been found to be related to the magnitude of negative priming in adults. In order to examine the effect of spatial separation on negative priming in the DCCS, the Negative Priming version could be administered with spatially separated stimulus values (analogous to Experiment 6). Similarly, research on negative priming in adults shows that when more distractors have to be ignored, any single one of them is less strongly inhibited (Fox, 1995). In the DCCS, the effect of number of distractors could be tested by adding dimensions to the stimuli. Further, the adult literature on negative priming suggests that negative priming can be long lasting and persist despite intervening trials (Allport & Wylie, 2000; Fox, 1995). It is unknown whether and under what circumstances negative priming is persistent in 3- to 4-year-olds in the DCCS. The time course of negative priming during the preswitch phase is also unknown. We assume that negative priming builds up gradually in the course of the preswitch. However, it is possible that negative priming reaches maximum strength even after a single preswitch trial. In order to examine this question, the number of preswitch trials could be manipulated in the Negative Priming version, as was done in the standard version by Zelazo et al. (1996), who found that 3-year-old children perseverated after one preswitch trial.

Future studies could also examine the role of negative priming in other measures of executive function, such as the Wisconsin Card Sorting Test (Chelune & Baer, 1986), the Flexible Item Selection Task ( Jacques & Zelazo, 2001), and the Day-Night-Stroop task (Diamond et al., 2002; Gerstadt et al., 1994). For example, in the Day-Night Stroop task, children are instructed to say the word "day" when shown a picture of the moon and stars, and "night" when shown a picture of the sun. Three- to 4-year-old children's difficulties in the Day-Night Stroop task are commonly attributed to their lack of inhibitory control (Diamond et al., 2002). Specifically, it is argued that these children have a difficult time inhibiting a word (e.g., "night" when shown the picture of the moon) that is semantically related to the word they are supposed to say (e.g., "sun"). However, it is also possible that children have difficulty overcoming the negative priming that occurs when they respond correctly. Using various measures of executive function should allow researchers to track the development of negative priming across a wide range of ages. This research could also be extended to include phenomena such as retrieval-induced forgetting (Anderson & Bell, 2001; Levy & Anderson, 2002), understanding homonyms (Gernsbacher & Robertson, 1995), and task switching (e.g., Allport & Wylie, 2002).

Finally, it should be noted that this account points to a reconceptualization of the concept of negative priming and its development. Negative priming is often conceptualized as evidence of an inhibition mechanism that allows successful selective attention (e.g., Dempster, 1995; Houde & Guichart, 2001; Tipper et al., 1989). However, the approach outlined here suggests that the suppression of attention resulting in negative priming may also be a problem to be overcome in the course of development. This characterization contrast sharply with most inhibition accounts of executive function (e.g., Carlson & Moses, 2001; Kirkham et al., in press; Luria, 1961; Perner et al., 1999; White, 1965). Whereas inhibition accounts suggest that children perform poorly on the DCCS because of *too little* inhibition, the current account suggests that children perform poorly in part because of *too much* inhibition. In the Negative Priming version of the DCCS, children evidently have difficulty disinhibiting the postswitch rules.

The task dynamics of increasing activation and inhibition explain why 3-year-old children fail in the DCCS, but they do not explain why children pass. According to the CCC theory children pass the DCCS because the development of reflection and higher order rule use allows them to control their behavior in a relatively top-down fashion, so that this behavior is not determined associatively by task dynamics and the relative activation levels of pre- and postswitch rules. Higher order rules allow children to select inhibited postswitch rules against activated preswitch rules, just as an adult would switch flexibly on the DCCS even after (say) 100 preswitch trials (although there may well be a cost in reaction time). Higher order rules are likely represented in a linguistic format (e.g., Emerson & Miyake, 2003; Goschke, 2000; Luria, 1961; Vygotsky, 1962), and this emphasis on higher order rule use underscores the important role that language plays in the flexible, top-down control of behavior. Research with brain-injured adults also suggests that language plays an important role in flexible task switching (Mecklinger, von-Cramon, Springer, & Matthes-von Cramon, 1999). Furthermore, there is evidence of significant correlations between performance on the DCCS and verbal ability (Lang & Perner, 2002; Perner, Lang, & Kloo, 2002). Clearly, however, the precise role of language in the development of executive function deserves more empirical attention.

### *Taking Intentionality Seriously*

The CCC theory suggests that (a) executive function corresponds to goal-directed problem solving (i.e., it is a function, not a mechanism), (b) children accomplish executive function by formulating rules in potentially silent self-directed speech, and (c) there are age-related constraints on the complexity of the rules that children are able to formulate and use. This approach makes specific, testable hypotheses regarding the psychological structures that underlie children's behavior in different situations and at different ages, and makes specific predictions about the circumstances in which children at different ages will exhibit failures of executive function.

An important implication of CCC theory, with its emphasis on goal-directed processing and the way in which children construe particular problems, is that executive function is closely tied to intentionality (Frye, 1999; Frye & Zelazo, 2003). Intentionality is a complex concept that is often traced back to Brentano's (1973) book, *Psychology from an Empirical Standpoint* (published in German in 1874)although its history is longer still. Brentano used the notion of intentionality to mark the difference between mind (which he considered to be coextensive with consciousness) and matter. For Brentano, "intentionality," from the Latin *intendere* (meaning "to stretch," as in an archer's bow), or "mental in-existence" captured the fact that any conscious experience, no matter how minimal, is an experience of something it has content existing in it, and it aims at or is directed toward that content, whether that content is simple pain or pleasure, or something more complex, such as a desire or a belief. The same cannot be said of things that are merely physical. Brentano's intentionality can thus be viewed as a ground-level characteristic of consciousness, which any adequate psychological theory or philosophy of mind will need to address.

In contrast to this philosophical sense, the term "intentionality" is also used in an everyday sense to mean "purposeful" or "goal-directed." We talk about doing something intentionally, and we mean doing it in a goal-directed fashion, doing it purposefully, or doing it deliberately. The everyday sense of intentionality is closely related to Brentano's sense, both etymologically and conceptually, because intentional actions are directed at goals in the same way that mental states are directed at their objects (i.e., what they are of; see Crane, 1998, for a discussion of common misunderstandings of Brentano's notion of intentionality). Moreover, the two senses are definitionally dependent because, for many authors, intentional action is goal-directed behavior that is accompanied by (or motivated by) a particular type of intentional statenamely, an intention (e.g., Adams, 1986).

Research on executive function is properly concerned with intentionality not only in Brentano's (1874/1973) sense, but also in the everyday sense. Executive function is simply goal-directed problem solving, and in understanding the psychological processes that underlie executive function and bring it about, one needs to take account of the content and directedness of an agent's intentional states (e.g., beliefs, desires, goals, intentions). Although approaches to executive function and related phenomena have long recognized a distinction between effortful, controlled processes, on the one hand, and automatic, stimulus-driven processes, on the other (e.g., Hasher & Zacks, 1984; Logan, 1988; Norman & Shallice, 1986; Ponser & Snyder, 1975; Shiffrin & Schneider, 1977), it is only recently that researchers have begun to address controlled processes in terms of broader conceptions of intentionality. Examples can be seen in the adult literature on task switching (Allport & Wylie, 2000; Goschke, 2000). In the task switching paradigm, participants alternate between performing one task (e.g., naming the color in which a word is printed, as in a Stroop task) and performing a second task that requires competing responses to the same stimuli (e.g., reading the color word; see Allport & Wylie, 2000). A common finding is that reaction times increase in the trial following the switch (i.e., there is a switch cost). To explain these switch costs, researchers have suggested that intentional, goal-directed processes formed on the basis of an experimenter's instructions interact with automatic, involuntary response tendencies to produce goal-directed behavior. For example, Goschke has presented a number of empirical findings that suggest switch costs are influenced by intentional processes (e.g., active preparatory processes) and proposes that "intentions modulate or 'configure' automatic processes for voluntary action, whereas the selection of responses, though dependent on prior intentions, is influenced by various forms of involuntary processing" (p. 350).

In a similar vein, Hommel (2000, pp. 266) suggested that response selection occurs automatically once a goal has been set: "Once a task set is implemented (and automatic routes enabled) ... the whole system is prepared to act in an automatic fashion and this may sometimes produce undesirable side effects." Despite these unwanted side effects, intentions usually accomplish their goal, so Hommel (p. 267) concluded on a positive note, stating that "with sufficient time, no subject in a Stroop task would ever name the color word."

Switch costs and involuntary side effects are also characteristic of preschoolers' performance on the DCCS. In this sense, Kirkham et al. (in press) are correct in drawing parallels between adults' performance on task switching and preschoolers' performance on the DCCS. However, the qualitative difference between these cases is that children, unlike adults, do *not* give the correct response, even when given sufficient time. Even though preschoolers are not subjected to any time constraints in the DCCS, they fail to sort the postswitch cards correctly.

What differs between children and adults is the ability to form more complex intentional representations (Frye & Zelazo, 2003). Three-year-old children adopt the correct goal representation and select the appropriate rules for acting when doing so does not require them to bridge major branches in a tree structure like that in Figure 3. For example, 3- to 4-yearolds can switch flexibly between lower order rules during the preswitch phase of the DCCS (e.g., they first sort a red card and then sort a green card). Three-year-olds fail to switch, however, when the instructions call for the use of a higher order rule to select a setting condition. CCC theory suggests that there are age-related improvements in the complexity and scope of children's intentional, top-down processes. With the construction of higher order rule systems, children's intentional representations become more complex. These intentional representations structure children's reasoning and behavior, and affect what kind of meaning children will make of a situation (Overton, 1994, 1998, 2003).

One implication of this intentionalistic approach to executive function is that the representation of a problem is necessarily subjective, and differs with developmental level. Which stimuli are relevant and what they mean is determined by a motivated agent in a particular context. The relevant context, in turn, is also subjectively defined. Constraints on complexity such as those identified by CCC theory operate on rules formulated in an ad hoc fashion in response to particular problems and always in light of children's own goals. Rules can be characterized objectively in the context of a well-defined paradigm such as the DCCS, but the rule systems that children formulate and use in their everyday behavior will be much more difficult to interpret. And as Deak

(2000) pointed out, even in the DCCS children need to understand the experimenter's intention to signal that the rules have changed.

To date, theories of executive function have focused almost exclusively on the processing of information defined objectively from a third-person perspective. Eventually, however, if we are to take seriously the suggestion that executive function corresponds to consciously controlled behavior, we must attempt to reconcile our third-person descriptions of cognition and behavior with first-person, intentional characterizations of *meaningful* thought. Although this objective has largely been lost since the days of Baldwin (1897) and Piaget (1963), it is increasingly being rediscovered, both in developmental psychology (e.g., Barresi & Moore, 1996; Bloom & Tinker, 2001; Deak, 2000; Overton, 2003) and in other areas of psychology (e.g., Thompson & Varela, 2001; Varela, 1996).

## REVISED CCC THEORY

The findings from this *Monograph* support a revision of the CCC theory in which the key claims of CCC theory are retained. These claims include the following: (a) Executive function is best viewed functionally, as an outcome, not an explanatory construct. (b) Children's plans are assumed to correspond literally to rules, formulated in potentially silent self-directed speech. (c) In response to particular problems, children formulate rule systems in an ad hoc fashion and use these rules systems to regulate their inferences and action, and select particular pieces of information for maintainence in working memory. (d) There are several age-related increases in the highest possible complexity of children's rule systems, and these increases can be observed in many domains of behavior. (e) Complexity is measured by the number of levels of embedding in children's rule systems. (f) Age-related changes in complexity are made possible by age-related changes in reflection that in turn might be dependent on the experience-dependent maturation of prefrontal cortex. Based on evidence from animal studies (e.g., see Huttenlocher, 2002), it is very likely that the maturation of prefrontal cortex is influenced by environmental stimulation. Moreover, there is evidence that parents' verbal scaffolding of children's play is related to their executive function skills (Landry, Miller-Loncar, Smith, & Swank, 2002), and training studies designed to improve children's executive function have been successful (e.g., Dowsett & Livesey, 2000; Kloo & Perner, in press). Clearly, the role of the environment in general, and parent-child interaction in particular, on the development of executive function needs to be examined in more detail.

The revised CCC theory (the CCC-r) adds to the original theory in several ways. It specifies more clearly the circumstances in which children will have difficulty using rules at various levels of complexity, and it provides a more detailed account of how to determine the complexity of rules required in a task. It takes account not only of the activation of rules as a function of experience but also the inhibition of rules. Finally, insofar as the CCCr theory takes intentionality seriously, it represents an integration of the CCC theory with the Levels of Consciousness (LOG) Model (e.g., Zelazo, 1999, 2000; P. R. Zelazo & P. D. Zelazo, 1998). CCC theory shows how age-related changes in executive function—considered as a functional construct are due to age-related changes in the maximum complexity of the rules that children can formulate and use when solving problems. The LOC model shows how these age-related changes in maximum rule complexity are, in turn, made possible by age-related increases in the degree to which children can consciously reflect on the rules they represent (i.e., age-related increases in children's highest *level of consciousness;* Zelazo, 1999, 2000, in press). Together, the CCC theory and the LOC model provide a framework for an intentionalistic, but still scientifically tractable, account of executive function (Frye & Zelazo, 2003).

The LOG model is an information-processing model designed to capture the development of consciousness and explain its role in executive function. As an information processing model, it traces the flow of information through a functional system—in this case, illustrating the way in which intentional objects (i .e., representations) are operated on as they come to figure in the conscious control of behavior. As a developmental model, the LOC model depicts the way in which this functional system changes in the course of ontogeny, and shows the consequences of these changes for executive function. According to this model, higher levels of consciousness are brought about by a functional process of reflection or reentrant signaling that allows subjective experiences at one level to become objects of reflection at a higher level (cf. reflective abstraction; Muller, Sokol, & Overton, 1998; Piaget; 2001; psychological distancing; DeLoache, 1993; Dewey, 1931/1985; Sigel, 1993). Each degree of reflection has specifiable consequences for the quality of experience, the potential for recall, the complexity of explicit knowledge structures, and the possibility of cognitive control (e.g., Zelazo, in press).

## REMAINING QUESTIONS AND CHALLENGES

We believe that CCC theory, and especially CCC-r theory, provides a comprehensive account of current research on the DCCS. However several researchers (e.g., Kirkham et al., in press; Munakata & Yerys, 2001; Perner et al., 1999; Towse et al., 2000) have challenged various aspects of the theory. It may be useful to consider the most common challenges in turn, as many of them are based on misconceptions regarding what it is that CCC theory claims.

### *How Could Children Learn the Rules the CCC Theory Claims Children Use?*

Perner (2000; see also Perner et al., 1999) criticized the application of CCC theory to theory of mind tasks, suggesting that the rules identified by CCC theory "cannot be the rules that children bring to bear on the task, because these rules could only be known after a practice run or as a result of the child having figured out the problem" (p. 382). According to CCC theory, however, it is not that children must learn rules, but rather that they must formulate rules in an ad hoc fashion basically, they need to talk their way through the problem in a way that allows them to access the appropriate piece of knowledge at the moment of responding. For example, in a false belief task, children must say to themselves something along the lines of, "There are sticks in the box, not crayons, but I'm being asked about my friend, so the answer is crayons, not sticks." Developmental constraints on the complexity of one's rule formulations determine task difficulty.

### *CCC Theory Analyzes Task Complexity in an Arbitrary Way*

Another objection to CCC theory concerns the apparently arbitrary way in which task complexity is analyzed. To illustrate this objection, Perner (2000) provided an alternative analysis of the false belief task according to which it requires a simple pair of rules, rather than a higher order rule for integrating two incompatible pairs of rules. It should be noted, however, that CCC theory does not attempt to provide a logically necessary analysis of the false belief task or any other task. Instead, it generates empirical hypotheses regarding the rules children formulate and use when solving a particular problem such as the DCCS. Any given two-choice discrimination, including the false belief task (i.e., false belief response vs. reality response), is amenable to analysis in terms of a simple pair of rules. However, the CCC theory holds that the psychological perspectives identified in this task (i.e., the child's correct perspective vs. the other person's false perspective) serve naturally as setting conditions for a higher order rule. Thus, the empirical claim is that, when solving the task, one first determines from which perspective to reason, and then determines which judgment to make from that perspective. This claim receives empirical support from the current findings together with previous research showing that performance on the DCCS is correlated with performance on false belief (e.g., see Perner & Lang, 2001), although further work on this topic is clearly required.

### *The Abulic Dissociations Predicted by CCC Theory Are Only Apparent*

According to the CCC theory, there are several age-related increases in the complexity of the rules children are capable of formulating and maintaining in working memory. Each increase permits children to exercise a new degree of control over their environment and behavior, but children are subject to limitations that cannot be overcome until yet another level of complexity is achieved. Abulic dissociations occur (under certain conditions, such as when there is conflict among rules) until incompatible pieces of knowledge are integrated into a single, more complex rule system via another degree of reflection. In the absence of integration, the particular piece of conscious knowledge that controls behavior is determined by relatively local associations (e.g., the rules that are selected, stored, and used may depend on what children have done previously in that situation).

Munakata and Yerys (2001) have suggested that these abulic dissociations are only apparent. These authors found that when the knowledge questions are made more complex (e.g., "Where do the blue flowers go in the shape game?"), so that they, like the postswitch sorting questions, require a higher order rule for selecting a setting condition, 3- to 4-yearolds often have difficulty with the knowledge questions too. Although Munakata and Yerys described their findings as if they were incompatible with CCC theory, the findings arguably provide support for it. That is, the findings arguably show that it is the complexity of the inferences required that is important, not the verbal versus manual modality of the questions (see also Zelazo et al., 1996, Exp. 4). Moreover, the fact remains that when the simpler (unidimensional) knowledge questions are used, an abulic dissociation is revealed between answers to those questions (correct) versus answers to the standard sorting questions (incorrect).

### CCC *Theory Cannot Account for Task Manipulations That Improve Children's Performance*

It has also been suggested that CCC theory cannot account for the effects of various task manipulations that lead to improved performance. For example, Kirkham et al. (in press) suggested that both the beneficial effect of having children label test cards on DCCS and the detrimental effect of leaving already sorted test cards "face up" favor an inhibitory account, as opposed to CCC theory.

Happaney and Zelazo (in press) addressed these points as follows. With respect to labeling, one should first note that the labeling effects are not completely consistent. In Towse et al. (2000, Exp. 4), children who failed the postswitch phase were encouraged (one way or another) to label correctly. However, two-thirds of these children then proceeded to sort the cards incorrectly. In any case, more generally, positive effects of labeling simply show that labeling helps children to refocus their attention perhaps by forcing them to use a different pair of rules. The results do not show that children now understand how the two dimensions are related, or that higher order rules are not important for this understanding, and they do not show that the typical development of this ability is *not* brought about by increases in self-reflection that allow children to better use higher order rules. For example, it is quite possible that labeling exerts its influence simply by changing children's bias without inducing the use of a higher order rule. If this is the case, children would exhibit "attentional inertia" on sorting by the postswitch dimension, and if asked to switch back to the preswitch rules, they may fail to do so.

Unfortunately, Kirkham et al. (in press) did not assess whether improvements in performance generalized in this way, so the issue has yet to be resolved. However, it is also possible that labeling does, in fact, provide children with a more sophisticated conceptual structure. Labeling makes information explicit, and may well induce reflection on that information ( Jacques & Zelazo, in press). Finally, CCC theory claims that, in the normal course of development, switching is brought about by age-related increases in reflection and higher order rule use, but if labeling improved performance in some other way, this would not undermine CCC theory. There may be multiple ways to improve performance on the DCCS, and demonstrating that one way suffices has no bearing on whether there are others, and, most important, it does not reveal which ways are typically operative in producing age-related changes.

The finding that leaving test cards face up in the trays impairs children's performance also fails to provide a substantive challenge to CCC theory. This finding only demonstrates that it is possible to increase the salience of one of two pairs of rules. The key issue, which remains to be assessed, is how children eventually are able to "resist the pull" of the conflicting dimension.

***Even Adults Have Difficulty With Task Switching and Surely They Can Use Higher Order Rules*** Kirkham et al. (in press) cited evidence that adults have difficulty with the DCCS and related tasks (such as measures of task switching; e.g., Allport & Wylie, 2000). They suggested that because adults are capable of using higher order rules, difficulty using higher order rules cannot explain the costs associated with task switching, and hence cannot explain children's performance either. However, although CCC theory proposes that adults are *capable* of using high-order rules, it does not state that they always will. Indeed, just as inhibition can be expected to be effortful and have a cost in increased latencies, so reflection and higher order rule use is effortful and has a cost associated with it (Zelazo, Craik, & Booth, in press).

### *Children Only Have Difficulty on the DCCS When There Is Conflict Between Rules*

Kirkham et al. (in press) claimed that children only have difficulty on the DCCS when they are required to shift their attentional focus from one dimension to another that conflicts with the first, and they suggested that this undermines the claim that children normally require a higher order rule to succeed. However, according to CCC theory, it is only when children must switch between incompatible rule pairs nested under different major branches in a hierarchical tree structure that a higher order rule is required.

Another example of this same general criticism has been offered by Towse and colleagues (2000) and Perner and Lang (2002), who noted that target cards seem to be required to elicit 3- to 4-year-olds' errors on the DCCS. However, on the CCC account, it is only when there is conflict, as when there are target cards, that a higher order rule is going to be required in order to overcome the conflict. Otherwise no higher order rule is required by children in order to change their behavior. Simply using one pair of lower order rules and then another (i.e., in succession, without any need to reconcile them) will suffice.

## FUTURE DIRECTIONS

The results of the research described in this *Monograph* answer several questions, but they also leave many questions unanswered. For example, theoretical questions remain regarding relations between CCC-r and other approaches to the development of executive function, such as Perner's redescription theory and accounts emphasizing the development of both working memory and inhibitory control. There are also many empirical questions. For example, future work should assess more directly some of the fundamental processes (e.g., the use of self-directed speech) postulated by CCC-r theory, and it would be worthwhile to do so using a variety of different measures of executive function, not just the DCCS. In this section, however, we describe in more detail just two of the ways in which future research might usefully continue to examine the development of executive function.

### *Development of Executive Function in Older Children*

The research reported in this *Monograph* involved 3- to 4-year-old children, and inferences were made about age-related changes occurring between the ages of 3 and 5 years. However, it will be important in future studies to examine directly the *development* of performance on some of the new versions of the DCCS introduced here, especially given the possibility that age-related changes on some of these versions may be nonmonotonic. For example, it is possible that performance on the Total Change version actually *declines* as children begin to construe the stimuli in terms of dimension. Similarly, although CCC-r theory predicts that performance on the Negative Priming version will improve between the ages of 3 and 5 years, the fact that Tipper et al. (19 89) failed to find evidence of negative priming in 7-year-olds raises the possibility negative priming is a U-shaped function of age in early childhood.

Development should also be assessed beyond the preschool years. Indeed, several studies suggest that the development of executive function follows a protracted course, and performance on executive function tasks such as the WCST (Chelune & Baer, 1986), the Tower of Hanoi (Welsh, 1991), and a variety of working memory measures (Luciana & Nelson, 1998) continues to improve at least until adolescence. For example, Welsh, Pennington, and Groisser (199 1) used a battery of relatively global measures of executive function tasks and found that children passed different tasks at a range of different ages. Interpretation of these results is difficult, however, because global measures of executive function depend on many different underlying processes (i.e., there are no process-pure measures) and because some sort of framework is required for making systematic comparisons across tasks that differ in difficulty in addition to which aspects of executive function they assess. Certainly it is problematic to compare performance on an easy measure of planning and a difficult measure of rule use and then conclude that planning develops before rule use. CCC-r theory provides a framework for making such comparisons that can be extended to account for age-related changes beyond the preschool years (e.g., through the emergence of higher levels of consciousness and the ability to formulate increasingly higher order rules; Zelazo et al., in press).

In any case, however, in order to capture executive function at different ages in more detail, complex executive function tasks need to be broken down into more molecular processes and these processes need to be studied experimentally, as was done with the DCCS in the current *Monograph*.

### *Development of "Hot" Executive Function*

A second direction for future research is to explore the relatively "hot" affective aspects of executive function associated with orbitofrontal cortex in addition to the more purely cognitive, "cool" aspects associated with dorsolateral prefrontal cortex (Zelazo & Muller, 2002b). Whereas cool executive function is more likely to be elicited by relatively abstract, decontextualized problems, hot executive function is required for problems that involve the regulation of affect and motivation (i.e., regulation of basic limbic system functions).

This characterization of hot executive function in contradistinction to cool executive function is consistent with several recent proposals regarding the function of orbitofrontal cortex (e.g., Damasio, 1994; Rolls, 1999). For example, based on single-cell recordings of neurons in orbitofrontal cortex together with neuroimaging data and evidence that damage to orbitofrontal cortex impairs performance on simple tests of object reversal and extinction, Rolls (e.g., 1999) suggested that orbitofrontal cortex is required for the flexible representation of the reinforcement value of stimuli. A rather different theory has been proposed by Damasio (e.g., 1994). According to this theory, the somatic marker theory, orbitofrontal cortex is required for processing learned associations between affective reactions and specific scenarios, and this processing plays a crucial but often overlooked role in decision making. Despite their differences, however, both approaches capture the fact that the control of thought and action depends on different cortical systems, depending on whether or not it occurs in motivationally significant contexts.

Traditionally, research on executive function in human beings has focused almost exclusively on cool executive function, using measures such as the Wisconsin Card Sorting Test. Recently, however, there has been growing interest in hot executive function as well, and in particular in what might be called affective decision making, or decision making about events that have emotionally significant consequences (i.e., meaningful rewards and/or losses). The hot aspect of executive function appears to be involved, for example, in theory of mind (Zelazo & Muller, 2002b), delay of gratification (Mischel, Shoda, & Rodriguez, 1989), and affective decision making (Damasio, 1994). It is currently unclear whether the development of hot executive function can be conceptualized in terms of a hierarchical model like CCC-r theory, and it remains to be seen whether and how the development of hot and cool aspects of executive function are related (for a discussion, see Zelazo & Muller, 2002b). An experimental approach to hot executive function using tasks such as delay of gratification or the children's gambling task (Kerr & Zelazo, in press) might usefully address this gap in the literature.

## CONCLUSION

Considerable research has shown that most 3- to 4-year-olds perseverate during the postswitch phase of the DCCS, whereas most 4-year-olds switch flexibly. The DCCS provides a window on the development of executive function, and this *Monograph* described four studies that used variants of the DCCS to experimentally test hypotheses derived from different theoretical perspectives on executive function. Among the most important findings are the following: (a) Three-year-old children can use four rules to sort cards, showing that memory limitations per se do not constrain children's executive function on the DCCS. (b) Children can use bidimensional rules when these rules are not in conflict, indicating that switching between dimensions per se is not the problem either. (c) Children have difficulty using even a single pair of rules when these rules are in conflict but can use conflicting rules when doing so does not require switching between dimensions. This highlights the importance of rule conflict and supports the hypothesis that children have difficulty formulating and using a higher order rule for selecting between setting conditions and resolving the conflict. (d) Stimulus separation among test cards does not seem to be related to performance, indicating that the findings from the DCCS cannot be attributed to holistic versus analytic perceptual processing. (f) Children perform well on Total Change versions of the DCCS, suggesting that conflict at the level of dimensions does not pose a problem for most children. (g) Many children perform poorly in Partial Change versions, suggesting first that children do not perseverate in making particular responses to specific test cards, second that conflict at the level of specific rules does indeed pose a problem for children, and third that this conflict is due to persisting activation of the preswitch rules. (h) Many children perform poorly in the Negative Priming version, but well in the Negative Priming (redundant preswitch) version. This suggests that selecting the preswitch rules against a competing alternative results in inhibition of the competing rules that persists into the postswitch phase and makes it difficult for children to select those rules when required to do so.

Considered together, the results of these studies provided the basis for revision of CCC theory to CCC-r, which (a) specifies more clearly the circumstances in which children will have difficulty using rules at various levels of complexity, (b) provides a more detailed account of how to determine the complexity of rules required in a task, (c) takes account of both the activation and inhibition of rules as a function of experience, and (d) highlights the importance of considering intentionality in the study of executive function.

## APPENDIX

# SUMMARY OF VERSIONS OF THE DIMENSIONAL CHANGE CARD SORT USED

| Experiment/ Version | Mean Age (months) | Task Description | Percentage of Children Passing |
|---|---|---|---|
| Experiment 1 | 42.2 | | |
| Standard | | Same two mismatched test and target cards during pre- and postswitch; preswitch sorting according to values of one dimension (e.g., color); postswitch sorting according to values of the other dimension (e.g., shape) | 5% |
| 4-Rules (unidimensional) | | Four target cards, 4 types of test card; 4 rules pertaining to one dimension | 83% |
| 2+2 Rules (unidimensional) | | Four target cards, 4 types of test card; 4 rules pertaining to one dimension; first sorting test cards according to 2 rules; then sorting test cards according to the other 2 rules | 76% |
| Experiment 2 | 44.7 | | |
| 2+2 Rules (bidimensional, no overlap) | | Four target cards; 4 types of mismatching test cards; first sorting 2 types of test card according to one dimension (e.g., color; red vs. blue), then sorting 2 other types of test card according to the other dimension (e.g., shape; car vs. flower); no overlap between pre- and postswitch rules | 81% |
| Experiment 3 | 41.5 | | |
| Standard | | Same as Experiment 1 | 45% |
| 4-Rules (superordinate) | | Four target cards depicting exemplars of 4 different functionally | 80% |

| Experiment/ Version | Mean Age (months) | Task Description | Percentage of Children Passing |
|---|---|---|---|
| | | defined categories; no perceptual match between test and target cards | |
| Experiment 4 | 41.7 | | |
| Standard | | Same as Experiment 1 | 0% |
| Standard (single test card) | | Same as standard, except there is a single mismatched test card during pre- and postswitch phases | 29% |
| Pruned Tree (single test card) | | Two target cards; a single mismatched test card; rules refer to only *one* value of pre- and postswitch dimensions (e.g., first sort by green, then sort by car). | 30% |
| Experiment 5 | 41.7 | | |
| Unidimensional (single test card) | | Two unidimensional target cards (e.g., a blue color patch, a green color patch); 1 split test card (e.g., half red and half blue); preswitch sorting according to one value (e.g., red), postswitch sorting according to the other value (e.g., blue) | 92% |
| Experiment 6 | 42.8 | | |
| Unidimensional Integrated | | Two target cards (e.g., a blue rabbit, one red rabbit), 1 split test card (e.g., half red and half blue rabbit); preswitch sorting according to one value (e.g., red), postswitch sorting according to the other value | 80% |
| Unidimensional Separated | | Two target cards (e.g., a blue rabbit, a red rabbit), 1 split test card depicting a blue and a red color patch adjacently; preswitch sorting according to one value (e.g., red), postswitch sorting according to the other value (e.g., blue) | 89% |
| Bidimensional Integrated | | Same as standard (single test card version) in Experiment 4 | 27% |
| Bidimensional Separated | | Two integrated target cards; a single mismatched split test card depicting the values of both dimensions adjacently (e.g., red color patch, outline of a rabbit); preswitch sorting according to the value of one dimension (e.g., color); postswitch sorting | 20% |

| Experiment/ Version | Mean Age (months) | Task Description | Percentage of Children Passing |
|---|---|---|---|
| | | according to the value of the other dimension (e.g., shape) | |
| Experiment 7 | 41.0 | | |
| Standard (target cards refreshed, preswitch feedback) | | Same as standard version in Experiment 1 except that test cards are taken down between pre- and postphases and then replaced; feedback on the preswitch phase | 42% |
| Partial Change | | Mismatched test and target cards during pre- and postswitch; values of the dimension that was *irrelevant* during the preswitch phase are changed between pre- and postswitch phases; preswitch sorting according to one dimension, postswitch sorting according to the other dimension; feedback on the preswitch phase | 52% |
| Total Change | | Mismatched test and target cards; values of both dimensions are changed between pre- and postswitch phases; preswitch sorting according to one dimension, postswitch sorting according to the other dimension; feedback on the preswitch phase | 79% |
| Experiment 8 | 38.3 | | |
| Standard (target cards refreshed) | | Same as Experiment 7 except no feedback on the preswitch phase | 19% |
| Total Change (no preswitch feedback) | | Same as Experiment 7 except no feedback on the preswitch phase | 63% |
| Partial Change (no preswitch feedback) | | Same as Experiment 7 except no feedback on the preswitch phase | 50% |
| Negative Priming | | Mismatched test and target cards during pre- and postswitch; values of the dimension that was *relevant* during the preswitch phase are changed between pre- and postswitch phases; preswitch sorting according to one dimension, postswitch sorting according to the other dimension; no feedback on the | 29% |

| Experiment/ Version | Mean Age (months) | Task Description | Percentage of Children Passing |
|---|---|---|---|
| | | preswitch phase | |
| Partial Partial Change (test cards) | | No mismatch between test and target cards during preswitch phase (*test* cards show only value of one dimension); mismatching test and target cards during postswitch; preswitch sorting according to one dimension, postswitch sorting according to the other dimension | 44% |
| Partial Partial Change (target cards) | | No mismatch between test and target cards during preswitch phase (*target* cards show only value of one dimension); mismatching test and target cards during postswitch; preswitch sorting according to one dimension, postswitch sorting according to the other dimension | 50% |
| Experiment 9 | 41.4 | | |
| Standard (target cards refreshed) | | Same as Experiment 8 | 56% |
| Total Change (no preswitch feedback) | | Same as Experiment 8 | 69% |
| Negative Priming | | Same as Experiment 8 | 25% |
| Redundant | | Matched test and target cards during preswitch; mismatched test and target cards during postswitch; preswitch sorting according to one dimension, postswitch sorting according to the other dimension | 69% |
| Negative Priming (redundant preswitch) | | Matched test and target cards during preswitch; mismatched test and target cards during postswitch; values of the dimension that was relevant during the preswitch phase are changed between pre- and postswitch phases; preswitch sorting according to one dimension, postswitch sorting according to the other dimension | 69% |

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