Journal of Experimental Child Psychology 108 (2011) 211–219

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Brief Report

Automatic shifts of attention in the Dimensional Change Card Sort task: Subtle changes in task materials lead to flexible switching

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ARTICLE INFO

Article history:
Received 8 April 2010
Revised 1 July 2010
Available online 3 August 2010

Keywords:
Attentional flexibility
Dimensional Change Card Sort
Cue saliency
Attentional weights
Task switching
Asymmetric switching

ABSTRACT

Two experiments tested a hypothesis that reducing demands on executive control in a Dimensional Change Card Sort task will lead to improved performance in 3-year-olds. In Experiment 1, the shape dimension was represented by two dissimilar values (*stars* and *flowers*), and the color dimension was represented by two similar values (*red* and *pink*). This configuration of stimuli rendered shape more salient than color. In Experiment 2, attentional weights of each dimension value were manipulated by using two versus four values to represent the dimensions of shape and color. The results indicated that increasing saliency of the postswitch dimension (Experiment 1) and reducing attentional weights of individual dimension values (Experiment 2) lead to a marked improvement in the postswitch sorting accuracy in 3-year-olds.

Introduction

There is a large body of evidence suggesting that young children have difficulty in shifting their attention among multiple object dimensions. This phenomenon has been widely investigated using a Dimensional Change Card Sort (DCCS) task. In the DCCS, children are presented with cards depicting objects that differ on two dimensions such as color and shape (e.g., red and blue flowers, red and blue boats). Children are first asked to sort cards by one dimension (e.g., shape, in which case they need to group blue flowers with red flowers). Next, children are asked to sort the same cards by the other dimension (e.g., color, in which case they need to group red boats with red flowers). Despite

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doi:10.1016/j.jecp.2010.07.001

understanding the instructions and receiving reminders about the sorting rule on every trial, 3-year-olds typically succeed during the first phase but tend to perseverate in sorting by the initially relevant dimension during the second phase of the task (for a review, see Zelazo, Müller, Frye, & Marcovitch, 2003). Importantly, children are equally likely to perseverate whether the initially relevant dimension is shape or color.

There is no consensus on why 3-year-olds perseverate in the DCCS task, and several theories have been proposed to explain this phenomenon. There is, however, an agreement that successful performance on this task requires sufficiently developed executive control—"the ability to orchestrate thought and action in accordance with internal goals" (Miller & Cohen, 2001, p. 167). Different theories of task switching emphasize the importance of different components of executive control for success in the DCCS, namely inhibition (Kirkham, Cruess, & Diamond, 2003), working memory (Yerys & Munakata, 2006), and integrating multiple sets of rules (Zelazo et al., 2003). Indeed, the DCCS was developed as a child-appropriate analog of the Wisconsin Card Sort Test (WCST) (Berg, 1948), which has long been used as a clinical tool in diagnosing impairments of executive control in school-age children and adults (Milner, 1963).

Difficulties in performing tasks requiring executive control have been attributed to the immaturity of the prefrontal cortex (PFC), which is one of the last brain areas to mature (Miller & Cohen, 2001). Patients with PFC damage exhibit deficits on the WCST similar to those of healthy 3-year-olds on the DCCS task; they can readily discover the rule for initial sorting but are unable to flexibly adjust their responses when the sorting rule changes. Similarly, monkeys with PFC lesions are impaired on the analog of this task. Miller and Cohen (2001) argued that "the PFC is not critical for performing simple automatic behaviors" but is critical "when behavior must be guided by internal states or intentions" (p. 168).

Development of automatic and controlled attention

Humans exhibit both visual and auditory preferences from birth (for reviews, see Bornstein, 1990; Colombo, 2001). These preferences are typically characterized as stimulus driven—determined by the properties of the stimulus. In the visual domain, infants' attention to various stimuli is driven largely by their brightness, intensity, and novelty rather than by their intentions (Ruff & Rothbart, 1996). For instance, once a stimulus "grabs" their attention, many 1-month-olds find it difficult to voluntarily disengage their attention. Unlimited exposure to such an attention-grabbing stimulus may result in prolonged looking that ends in considerable distress, a phenomenon known as *obligatory looking* (Stechler & Latz, 1966).

Obligatory looking diminishes after 2 months of age, suggesting development of some degree of control over disengagement of attention. Similarly, control over engagement of attention develops during the first months of life. It has been demonstrated that, unlike 4-month-olds, 6-month-olds are capable not only of reactionary saccades (in response to an appearing target) but also of anticipatory saccades (to the anticipated location of a yet invisible target) (Johnson, Amso, & Slemmer, 2003). Research suggests that development of controlled attention is gradual and continues through adolescence (for a review, see Luna, 2009).

Overall, *automatic attention* is typically characterized as stimulus driven, involuntary, effortless, and bottom-up; *controlled attention* is characterized as participant driven, voluntary, effortful, and top-down (Kastner & Ungerleider, 2000; Miller & Cohen, 2001; Norman & Shallice, 1986; Schneider & Chein, 2003). If perseveration errors in the DCCS task indeed stem from the immaturity of controlled attention, children should be able to perform the task when demands on executive control are reduced.

There is indirect evidence to support this hypothesis given that certain modifications to the DCCS task lead to marked improvement in performance. For example, 3-year-olds are more likely to succeed if previously relevant dimension values are removed from the postswitch phase (Zelazo et al., 2003), if children are asked to sort objects using novel dimension values during preswitch but familiar dimension values during postswitch (Yerys & Munakata, 2006), if children receive scaffolding between the preswitch and postswitch phases of the task (Brace, Morton, & Munakata, 2006), and if the preswitch task is difficult enough to elicit low levels of preswitch performance (Deák, Ray, & Pick, 2004).

These manipulations, although successful, represent significant changes to the task itself, thereby likely simplifying task demands. The goal of the current research was to reduce demands on executive control while preserving the following task demands: shifting attention between familiar dimension values, in the absence of scaffolding, in a task that elicits successful performance during preswitch and with the conflict between the previously and newly relevant dimensions preserved.

Experiment 1

Perseveration errors in the DCCS task are a type of *switch costs*—decrease in performance after task switch. A number of factors influence switch costs; the most relevant of these for Experiment 1 is saliency of the postswitch cues. Salient cues have been demonstrated to automatically capture attention in children and adults (Koch & Ullman, 1985; Smith, Jones, & Landau, 1996; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Therefore, shifting attention from a less salient dimension to a more salient one should place lower demands on executive control than shifting attention from a more salient dimension to a less salient one (or shifting attention between two equally salient dimensions—as is likely the case in the standard version of the DCCS). A similar prediction was made, albeit not evaluated empirically, by Kirkham et al. (2003).

In Experiment 1, participants were presented with a task in which task demands characteristic of the standard DCCS paradigm were preserved, but dimension saliency was manipulated. Shifting attention from a more salient dimension to a less salient one was expected to result in perseveration errors, whereas shifting attention from a less salient dimension to a more salient one was expected to decrease perseveration.

Method

Participants

The final sample consisted of 27 3-year-olds (mean age = 3.62 years, *SD* = 0.24, 13 girls and 14 boys) recruited from day care centers in a large city. An additional four children were tested but omitted from the final sample (see Results).

Design, materials, and procedure

Children were presented with two target pictures differing on two dimensions (i.e., shape and color) and were asked to match the test pictures with one of the target pictures. Similar to the traditional version of the DCCS task, there were two phases: a preswitch phase and a postswitch phase. During the preswitch phase children were asked to match pictures based on one dimension (e.g., shape), and during the postswitch phase they were asked to match pictures based on the other dimension (e.g., color). There were eight trials during each phase of the task.

The traditional DCCS task was modified in three ways. First, half of the trials in each phase consisted of *no-conflict trials*,[1] where the to-be-sorted object matched one of the target pictures on both dimensions (e.g., the target pictures could be a *red star* and a *pink flower* and the sorting picture was a *pink flower*) (Fig. 1A). The other half of the trials in each phase consisted of *conflict trials*, where the to-be-sorted object matched each of the target objects on only one dimension (e.g., the target pictures could be a *red star* and a *pink flower* and the sorting picture was a *red flower*) (Fig. 1B). This manipulation made it possible to differentiate between children who perseverated during the postswitch phase from children who performed poorly due to fatigue or boredom.

Second, the task was administered on a laptop computer, as opposed to the traditional version of the DCCS in which children place sorting cards in boxes. In the traditional version of the task, the location of each sorting box (i.e., left versus right) is fixed on every trial, making it possible to form motor location–dimension associations akin to those described by Smith and Thelen (2003) in the A-not-B

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[1] Mueller, Dick, Gela, Overton, and Zelazo (2006) also used no-conflict trials in their version of the DCCS task (Experiments 3 and 4). They found that inclusion of no-conflict trials had no effect on the rate of perseveration when no-conflict trials were randomly distributed. Therefore, inclusion of the no-conflict trials in the current experiments was not expected to influence the results given that the order of presentation of all trials was randomized for each participant.

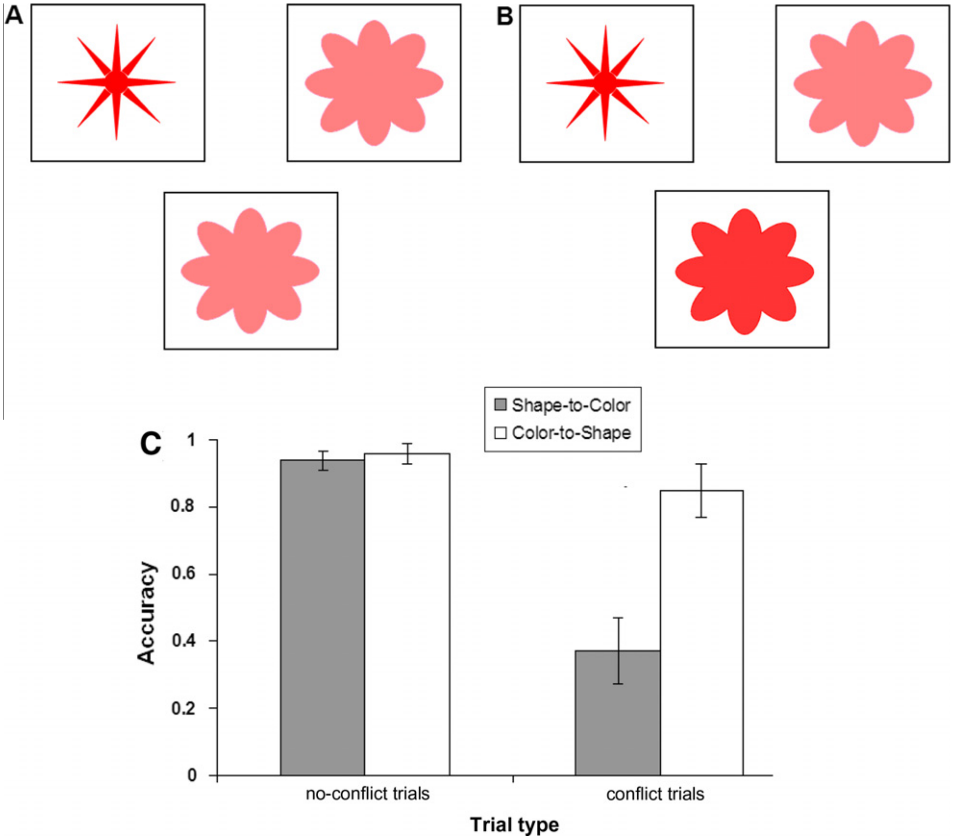

Fig. 1. (A and B) Examples of a no-conflict trial (A) and a conflict trial (B) in Experiment 1. (C) Proportions of correct responses by trial type and experimental condition during the postswitch phase of Experiment 1. Error bars represent standard errors of the mean.

error task. Computerization of the task made it possible to counterbalance location of the target objects across the experiment to control for the possibility that perseveration errors may stem from motor location–dimension associations.

Most important, the dimension of color in this experiment was represented by two similar values: red and pink (RGB values: FF3737 and FF9B9B, respectively). Perceptual saliency in the visual domain is a function of similarity of the elementary features—features into which a stimulus is decomposed during initial processing (i.e., orientation, intensity, and color) (Gao, Mahadevan, & Vasconcelos, 2008). The more similar two values are, the less salient is the contrast between these values.

In prior research, both color and shape were represented by relatively dissimilar values (e.g., bunnies and boats for shape, blue and red for color). If relatively dissimilar values are used to represent the dimension of shape (e.g., stars and flowers) but relatively similar values are used to represent the dimension of color (e.g., red and pink), this arrangement may render the dimension of shape more perceptually salient than the dimension of color.

This prediction was confirmed in a separate calibration experiment with 28 4-year-olds.[2] Children were presented with the conflict trials and were asked to sort objects by either shape or color as fast as

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[2] In the calibration study, 4-year-olds were tested because the dependent measure in this study was response time—a measure that is notoriously difficult to collect from young children. It was assumed that the performance of 4-year-olds in the calibration study could be used as a viable proxy for estimating saliency of the chosen dimension values in 3-year-olds.

possible, entering their responses using a touch-screen overlay. Shorter latencies were expected for responses based on a more salient dimension than for responses based on a less salient dimension. The results indicated that response latency was shorter for sorting by star–flower than for sorting by red–pink (3647 and 4908 ms, respectively, $p < .05$). These results confirmed that dimension values chosen for Experiment 1 rendered shape more salient than color.

The experiment was administered on a laptop computer using SuperLabPro software. The order of trials was randomized for each participant. Children were randomly assigned to either the Color-to-Shape or Shape-to-Color condition. In this and other experiments reported in this article, children were interviewed individually by a hypothesis-blind experimenter in a quiet room at their day care center.

It was expected that shifting attention from a more salient dimension to a less salient one (Shape-to-Color condition) should place high demands on executive control and lead to high perseveration. Shifting attention from a less salient dimension to a more salient one (Color-to-Shape condition) was expected to result in automatic shifts of attention and reduced perseveration.

Results

Two participants in each condition were excluded from the final sample because they incorrectly sorted two or more no-conflict trials during the postswitch phase ($n = 2$) or incorrectly sorted two or more conflict trials during the preswitch phase ($n = 2$). The remaining participants performed with high accuracy on both the conflict and no-conflict trials during the preswitch phase, averaging 98% of correct responses across conditions (all above chance, one-sample $ps < .0001$).

Consistent with prior research, in the Shape-to-Color condition, children exhibited poor accuracy on the postswitch conflict trials (37%), not different from chance (50%), one-sample $t(12) < 1.33$, $p > .20$. Note that poor postswitch performance in the Shape-to-Color condition cannot be attributed to poor discrimination of the specific values of the color dimension chosen for this experiment (i.e., red and pink) because children had no trouble in sorting by this dimension during the preswitch phase of the Color-to-Shape condition (averaging 98% of correct responses).

In contrast to prior research, children in the Color-to-Shape condition exhibited high accuracy on the postswitch conflict trials (86%), above chance, one-sample $t(13) = 4.61$, $p < .0001$. Furthermore, children's performance on the postswitch conflict trials in the Color-to-Shape condition was higher than in the Shape-to-Color condition, independent-samples $t(25) > 5.99$, $p < .0001$, Cohen's $d = 1.5$ (Fig. 1C).

The above analysis was supported by the analysis of the individual response patterns. Children were classified as *switchers* if they sorted all four postswitch conflict trials correctly and as *nonswitchers* if they sorted all four postswitch conflict trials incorrectly; otherwise, children were classified as *mixed responders*. In the Shape-to-Color condition, the majority of children were mixed responders ($n = 7$) and nonswitchers ($n = 5$), with only one child classified as a switcher. By contrast, in the Color-to-Shape condition, the majority of children were classified as switchers ($n = 10$), with only a few mixed responders ($n = 3$) and nonswitchers ($n = 1$). The association between individual response patterns and experimental condition was significant, Fisher's exact $p = .0001$.

Results of Experiment 1 demonstrate that when the saliency of the postswitch dimension is higher than the saliency of the preswitch dimension, there is a dramatic improvement in children's postswitch sorting accuracy. However, it remains to be addressed in future research whether increasing saliency of other dimensions (e.g., shape) would lead to similar effects.

Experiment 2

The idea behind Experiment 2 is based on two important findings of prior research. First, it has been shown that errors in the DCCS task stem from perseveration to preswitch *dimension values* (e.g., red) rather than *dimensions* per se (e.g., color) (Zelazo et al., 2003). Second, it has been shown that the pool of attentional resources is finite; therefore, attentional weights of different attributes are interdependent (Nosofsky, 1984; Sutherland & Mackintosh, 1971). In other words, an overall increase in the number of relevant attributes (i.e., dimension values) should attenuate attention allocated to each individual attribute, thereby decreasing the attentional weight of that attribute. Therefore, an increase in the number of dimension values in the DCCS should decrease the amount of attention allocated to each individual value, thereby reducing its attentional weight.

Experiment 2 tested the possibility that shifting attention away from attributes with high attentional weights should place high demands of executive control (thereby leading to high perseveration), whereas shifting attention away from attributes with lower attentional weights may decrease demands on executive control (thereby leading to decreased perseveration). This hypothesis receives indirect support from the studies of perseverative reaching in infants. Specifically, in their meta-analysis of the studies on the A-not-B error, Wellman, Cross, and Bartsch (1986) concluded, "Intriguingly, infants . . . make fewer perseverative errors on multilocation tasks than on two-location tasks" (p. 19). The notion that an increase in the number of relevant attributes attenuates attention allocated to each attribute provides a way of understanding this intriguing finding.

Method

Participants

The final sample consisted of 38 3-year-olds (mean age = 3.37 years, *SD* = 0.29, 14 girls and 24 boys) recruited from day care centers in a large city. Five more participants were tested and omitted from the final sample (see Results).

Design, materials, and procedure

Experiment 2 had two between-participant conditions: High Attentional Weights (HAW) and Low Attentional Weights (LAW). In the HAW condition, children were presented with the DCCS task in which, similar to prior research, objects differed on two dimensions, with each dimension represented by two relatively dissimilar values (i.e., blue and red for color; star and fish for shape).

In the LAW condition, participants were presented with objects that also differed on two dimensions, but each dimension was represented by four values (i.e., *red*, *blue*, *green*, and *yellow* for color; *star*, *flower*, *fish*, and *butterfly* for shape). Every value of the color dimension and every value of the shape dimension was used twice for the to-be-sorted cards during each phase of the task (once in the conflict trials and once in the no-conflict trials). In the conflict trials, the to-be-sorted cards were a red butterfly, a yellow fish, a blue flower, and a green star (see Fig. 2A for an example of a conflict trial in the LAW condition).

Similar to Experiment 1, each condition consisted of a preswitch phase and a postswitch phase. Each phase included four conflict trials and four no-conflict trials, and children were randomly assigned to experimental conditions and to the starting sorting dimension (i.e., color or shape). The experiment was administered on a laptop computer using SuperLabPro software, and the order of trials was randomized for each participant.

Results

Five participants were excluded from the final sample because they incorrectly sorted two or more no-conflict trials during the postswitch phase ($n = 2$) or incorrectly sorted two or more conflict trials during the preswitch phase ($n = 3$). The remaining participants performed with high accuracy on both the conflict and no-conflict trials during the preswitch phase, averaging 96% of correct responses across conditions (all above chance, one-sample *p*s < .0001). Similar to prior research, the initial sorting dimension did not influence children's postswitch accuracy on conflict trials, $F(1, 41) < .10$, *ns*; therefore, the data were collapsed across the initial sorting dimension.

Consistent with prior research, in the HAW condition postswitch accuracy on the conflict trials was low (41%), not different from chance, one-sample $t(21) = 1$, *ns*. However, children exhibited above-chance accuracy on the postswitch conflict trials in the LAW condition (70%), one-sample $t(20) = 2.79$, $p < .05$. Furthermore, postswitch accuracy on the conflict trials was higher in the LAW condition than in the HAW condition, independent-samples $t(41) = 2.51$, $p < .05$, Cohen's $d = .75$ (Fig. 2B).

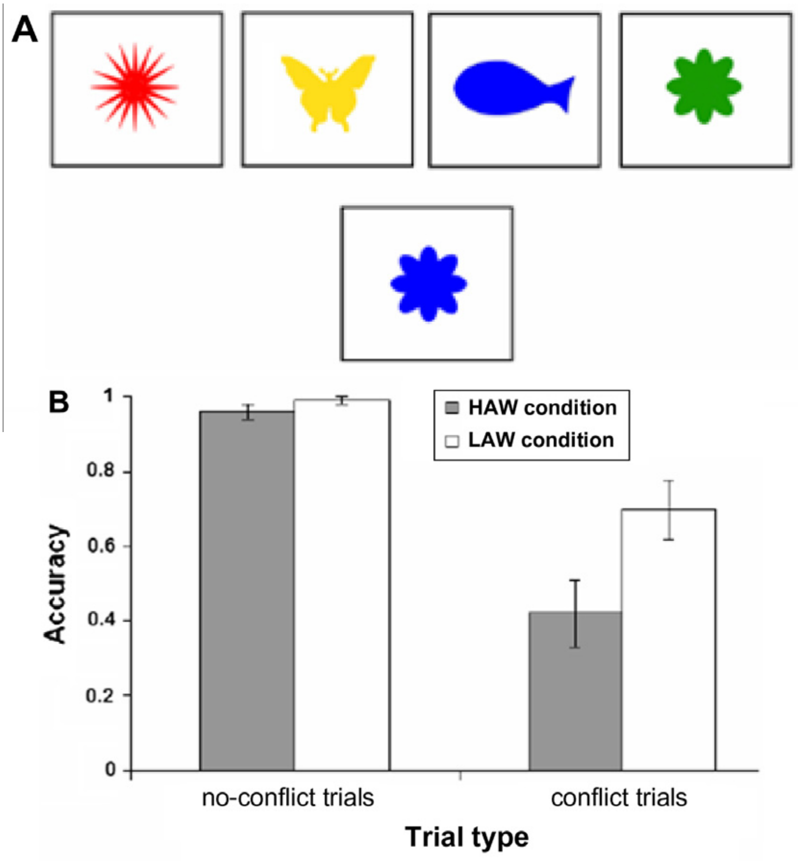

Fig. 2. (A) Example of a conflict trial in the LAW condition of Experiment 2. (B) Proportions of correct responses by trial type and experimental condition during the postswitch phase of Experiment 2. Error bars represent standard errors of the mean. HAW, High Attentional Weights; LAW, Low Attentional Weights.

The analysis of individual response patterns supported the group analyses above. As in Experiment 1, children were classified into switchers, nonswitchers, and mixed responders. In the HAW condition, the majority of children were nonswitchers ($n = 10$), with the rest of participants classified as mixed responders ($n = 6$) and switchers ($n = 5$). By contrast, in the LAW condition, the majority of children were mixed responders ($n = 12$) and switchers ($n = 7$), with only one child classified as a nonswitcher. The association between responder type and experimental condition was significant, Fisher's exact $p = .007$.

General discussion

The experiments presented above point to two novel findings: increasing saliency of the postswitch dimension (Experiment 1) and reducing attentional weights of individual dimension values (Experiment 2) in the DCCS task resulted in marked improvement in postswitch sorting accuracy in 3-year-olds. Both of these manipulations were designed to decrease demands on executive control while preserving demands of the standard DCCS, namely requiring attention shifts between familiar dimension values, in the absence of scaffolding, and with the conflict between the previously and newly relevant dimensions preserved.

It could be argued that other changes to the task in the current research (e.g., adding no-conflict trials) could be responsible for this improvement. However, high rates of perseveration in the

Shape-to-Color condition in Experiment 1 and in the HAW condition in Experiment 2 suggest that this was not the case.

Results presented in this article provide evidence that children as young as 3 years can flexibly shift their attention among multiple object dimensions when demands on executive control are reduced. These results are difficult to reconcile with the account suggesting that successful performance in the DCCS task requires the ability to integrate multiple sets of rules (Zelazo et al., 2003); if anything, the LAW condition of Experiment 2 required children to integrate more rules than the standard versions of the DCCS. These results, however, are compatible with the accounts suggesting that perseveration errors stem from weak working memory representations (Yerys & Munakata, 2006) or immature inhibitory control (Kirkham et al., 2003).

Broader theoretical implications

In addition to the implications for the theories of task switching, the current results have broader theoretical implications. For instance, in the course of language acquisition, children need to learn words that refer to object shape (e.g., *ball*), texture (e.g., *soft*), and color (e.g., *red*). In so doing, children must attend to different dimensions of the same object; focusing exclusively on the dimension of shape would make it impossible to learn words that refer to texture or color. Yet, by 3 years of age, children typically acquire a number of words referring to shape, texture, and color.

Different theoretical approaches emphasize the importance of attentional flexibility in early learning; however, they propose different mechanisms underlying this flexibility. Some researchers argue that attentional flexibility underlying early learning is largely automatic (Fisher, 2007; Sloutsky & Fisher, 2008; Smith et al., 1996). Other researchers, such as Gelman and Medin (1993), suggest that attentional flexibility required for learning early in development may be "conscious and deliberate" (p. 164). The results reported in this article are clearly inconsistent with the latter account but provide strong support to the former account.

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