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Automatic and Voluntary Shifts of Attention in the Dimensional Change Card Sorting Task

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Abstract

Different theoretical approaches to word learning and categorization recognize importance of attentional flexibility, however they assume different mechanisms underlying this flexibility. According to one approach, attentional shifts in the course of word learning and categorization are automatic in nature. According to the alternative approach, these shifts may arise as a result of voluntary processing. The present study evaluated these assumptions in the context of a task routinely used to examine attentional flexibility in young children, a Dimension Change Card Sorting task. Two experiments presented below examined attentional flexibility in 3 year-old children under conditions promoting automatic and voluntary shifts of attention.

Keywords: attentional flexibility, cognitive development, word learning, categorization.

Introduction

Young children's behavior has been demonstrated to be remarkably flexible in some contexts and yet remarkably inflexible in others. For example, 3-year-old children often have trouble switching attention between object dimensions such as shape and color when explicitly instructed to do so. This phenomenon has been widely investigated using a Dimension Change Card Sorting (DCCS) task, which is a simplified version of the Wisconsin Card Sort Test (Berg, 1948). In the DCCS task children are presented with a set of cards depicting familiar objects that differ on two dimensions, such as color and shape (e.g., the cards may depict red and blue flowers, and red and blue boats). Children are first asked to sort cards according to one dimension, for example shape (in this case they need to group blue flowers with red flowers, and blue boats with red boats). Upon completing this task, children are asked to sort cards according to a different dimension, for example color (in this case they need to group red boats with red flowers, and blue boats with blue flowers).

A considerable amount of evidence suggests that despite understanding and remembering the instructions, children younger than four years of age often fail to shift attention away from a previously relevant dimension, perseverating in sorting by the original dimension (Zelazo, Frye, & Rapus, 1996; Jacques, Zelazo, Kirkham, & Semcesen, 1999). It is important to note that children are equally likely to perseverate if they start sorting by shape and switch to sorting by color, and if they start sorting by color and switch to sorting by shape.

At the same time, it has been demonstrated that young children can flexibly shift their attention among different object dimensions in the context of word learning and categorization tasks. In particular, when learning names for animate objects, 2-year-old children are more likely to attend to shape in conjunction with texture than to other object properties, and when learning words for inanimate objects children are more likely to attend to shape alone (Booth & Waxman, 2002; Jones & Smith, 1998). Similarly, 3-year-old children are more likely to group novel rigid objects based on shape, but novel deformable objects based on texture (Samuelson & Smith, 2000).

Both phenomena (children's remarkable tendency to perseverate in card sorting tasks and children's remarkable flexibility in word learning and categorization tasks) have received overwhelming amount of empirical support. However, it remains unclear why children of the same age can be so flexible in some contexts and yet so inflexible in others. The goal of experiments presented in this paper is to explore this issue by identifying conditions under which children can flexibly shift attention among different object dimensions.

Theoretical Approaches to Early Learning
Different theoretical approaches to early learning emphasize importance of attentional flexibility, however they assume different mechanisms underlying this flexibility. According to one approach, attentional shifts in the course of word learning and categorization are automatic in nature (Sloutsky & Fisher, 2005; Smith, Jones, & Landau, 1996). According to the alternative approach, these shifts may arise as a result of "conscious and deliberate processing" (Gelman & Medin, 1993).

Note, that the former (but not the latter) approach can be reconciled with the body of evidence on perseverative errors in the DCCS task in a straightforward manner. In particular, in the DCCS task children are explicitly asked to shift attention from a previously relevant to a newly relevant dimension; therefore, successful performance in this task requires developed ability to shift attention in a voluntary manner. Therefore, young children's difficulty in shifting attention in a voluntary manner is consistent with word learning and categorization approaches arguing that attentional flexibility is automatic early in development, but inconsistent with the approaches arguing that such flexibility may be voluntary.

The argument presented above leads to a prediction that while young children have difficulty shifting attention in a

voluntary manner, they should be able to shift attention automatically. If this is the case, then children should have little difficulty if a DCCS task requires an automatic rather than a voluntary shift of attention to a newly relevant dimension.

There is indirect evidence to support the above possibility. Research indicates that certain modifications to the DCCS task lead to marked improvement in children's performance. For example, 3-year-old children are more likely to succeed on this task if previously relevant dimension values are removed from the post-switch phase (e.g., if children are asked to sort pictures of blue and red objects during the pre-switch phase, and pictures of yellow and green objects during the post-switch phase) (Mueller, Dick, Gela, Overton, & Zelazo, 2006). Similarly, performance improves if children are asked to sort objects using novel dimension values (e.g., a novel shape referred to as a "dax") in the pre-switch phase but familiar dimension values in the post-switch phase (Yerys & Munakata, 2006). Finally, introducing a training phase between the pre- and post-switch phases helps children to switch successfully from a previously relevant to a newly relevant dimension (Brace, Morton, & Munakata, 2006).

These results are consistent with the notion that attentional flexibility in 3-year-old children can be accomplished in an automatic but not in a voluntary manner. However, modifications described above reduce the difficulty of attention shifts by decreasing (or in some cases eliminating) competition between a previously and a newly relevant dimension (e.g., through training, introducing novel dimension values, or removing the previously relevant dimension values from the post-switch phase). At the same time, competition between multiple sources of information represented by familiar dimensions and dimension values is almost always present in natural settings and needs to be resolved in the course of word learning or categorization. Therefore, the goal of the studies presented in this paper was to directly examine whether automatic processes underlie attentional flexibility early in development.

Experiment 1

The overall idea behind Experiment 1 is that dimension saliency may play a crucial role in attentional flexibility, because salient information has been demonstrated to automatically capture attention in children as well as adults (Koch & Ullman, 1985; Smith, Jones, & Landau, 1996; Treisman & Gelade, 1980; Trick & Enns, 1998; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Therefore, shifting attention from a less salient object dimension to a more salient dimension should be performed automatically, whereas, shifting attention from a more salient to a less salient dimension (or shifting attention between two equally salient dimensions, as in previous research using the DCCS task) should require voluntary processing.

In Experiment 1 participants were presented with a DCCS task in which dimension saliency was experimentally manipulated. Consistent with prior research, voluntary shifts of attention (i.e., shifting attention from a more salient to a less salient dimension) were expected to result in perseveration errors in young children during the post-switch phase of the task (Zelazo, et. al., 1996). At the same time, automatic shifts of attention (i.e., shifting attention from a less salient to a more salient dimension) were expected to result in a decrease in perseveration errors.

Method

Participants Participants in Experiment 1 were 26 3-year-old children (M = 3.62 years, SD = .24 years; 13 females and 13 males) recruited from day care centers in the Pittsburgh area. Five more participants were tested and omitted from the sample due to low accuracy on the No Conflict trials (see procedure below). The final sample consisted of 13 participants in each condition.

Design, Materials and Procedure Experiment 1 used a modified version of the DCCS task. Participants were presented with two target pictures differing on two dimensions (i.e., shape and color) and asked to match the test pictures with one of the targets.

Similar to the traditional version of the task (Zelazo et. al., 1996), there were two phases in this task, a pre-switch and a post-switch phase. In the pre-switch phase participants were asked to match pictures based on one dimension (e.g., shape), and in the post-switch phase they were asked to match pictures based on the other dimension (e.g., color). There were eight trials in each phase of the task.

The traditional DCCS task was modified in three ways. First, in contrast to the traditional version of the task, half of the trials in each phase consisted of No-Conflict trials (i.e., the object to be sorted matched one of the target pictures on both dimensions) and the other half consisted of Conflict trials (i.e., the object to be sorted matched each of the target objects on only one dimension). This manipulation ensured that decreased accuracy during the post-switch phase of the task did not stem from extraneous factors (such as fatigue).

Second, the task was presented to participants on a screen of a laptop computer (as opposed to the traditional version of the task in which children are asked to place sorting cards in one of two boxes). This modification made it possible to counterbalance locations (left-right) of the target objects to control for the possibility of perseveration errors stemming from children forming motor location-dimension associations (Smith & Thelen, 2003).

Third, the dimension of color in this experiment was represented by two similar values – red and pink. Increasing similarity of the values representing this dimension (compared to prior research in which the dimension of color was represented by two dissimilar values, such as red and blue) was intended to reduce the saliency of the color dimension relative to the shape dimension (represented by dissimilar shapes – stars and flowers) (see Figure 1). Differential saliency of the chosen dimension values was confirmed in a separate calibration

experiment, in which adults were presented with the Conflict trials and asked to sort objects by shape or by color. Results of the calibration indicated that response latency was shorter when participants sorted by shape than by color (631 and 701 ms, respectively, $p < .05$), confirming that shape was a more salient dimension than color in Experiment 1.
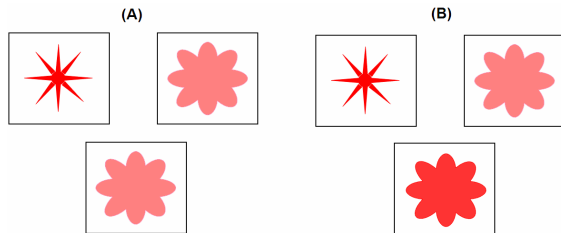

Figure 1: Example of a No Conflict trial (Panel A) and a Conflict trial (Panel B).

Children were randomly assigned to the Color-to-Shape condition (in which they were asked to sort by color in the pre-switch phase and by shape in the post-switch phase) or to the Shape-to-Color condition (in which they were asked to sort by shape in the pre-switch phase and by color in the post-switch phase). Overall, it was expected that switching from sorting by a less salient dimension to sorting by a more salient dimension (Color-to-Shape condition) should result in an automatic shift of attention to the relevant dimension, thus leading to decreased perseveration compared to the condition requiring voluntary attention shifting (Shape-to-Color condition).

Results

Children who failed to correctly sort at least three out of four No Conflict trials during either phase of the experiment were eliminated from the final sample (two participants were eliminated from the Color-to-Shape condition and three participants were eliminated from the Shape-to-Color condition). The remaining participants performed sorting with high accuracy in both Conflict and No Conflict trials during the pre-switch phase, averaging 98% of correct responses across conditions (all above chance, one-sample ps $< .0001$).

Proportions of correct responses in the post-switch phase are presented in Figure 2. Participants' accuracy scores in the post-switch phase were submitted to a 2 (condition: Shape-to-Color and Color-to-Shape) by 2 (trial type: Conflict and No Conflict) mixed ANOVA, with trial type as a repeated measure. The analysis revealed a main effect of condition ($F (1, 24) = 14.64, p < .005$) and a main effect of the trial type ($F (1, 24) = 23.92, p < .0001$). These main effects were qualified by a trial type by condition interaction, $F (1, 24) = 10.63, p < .005$.

Planned comparisons revealed that, consistent with prior research, in the Shape-to-Color condition children perseverated sorting by the previously relevant dimension,

thus exhibiting low accuracy on the Conflict trials ($M = .37$, not different from chance, one-sample $t (12) < 1.33, p > .2$), but high accuracy on the No Conflict trials ($M = .94$, above chance, one-sample $t (12) > 14.5, p < .0001$), and this difference was statistically significant (paired-sample $t (12) = 5.37, p < .0001$).

In contrast to prior research, in the post-switch phase of the Color-to-Shape condition children exhibited high accuracy on both No Conflict trials ($M = .96$, above chance, one-sample $t (12) = 17.72, p < .0001$) and Conflict trials ($M = .85$, above chance, one-sample $t (12) = 4.18, p < .005$), and this difference was not statistically significant (paired-sample $t (12)$ 1.25, $p > .23$). Furthermore, children's performance on the post-switch Conflict trials in the Color-to-Shape condition was above that in the Shape-to-Color condition, independent-samples $t (24) > 3.69, p < .005$).
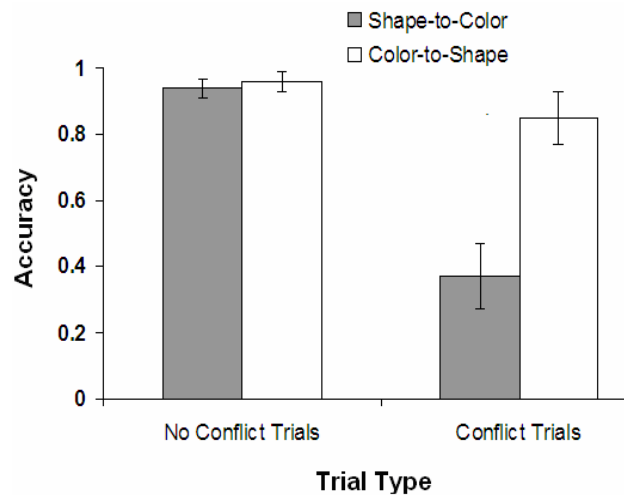

Figure 2: Proportion of correct responses in Experiment 1 by trial type and experimental condition.

Note that poor post-switch performance in the Shape-to-Color condition cannot be attributed to poor discrimination of the specific values of the color dimension values chosen for this experiment (i.e., red and pink), because children had no trouble sorting by this dimension in the pre-switch phase of the Color-to-Shape condition (averaging 98% of correct responses).

The significance of the differences between conditions was confirmed by non-parametric analysis of the individual patterns of responses. In particular, in the Shape-to-Color condition only 31% of participants (4 out of 13 children) successfully switched to sorting by the new dimension (i.e., answered correctly on at least three out of four Conflict trials), whereas 69% of participants (9 out of 13 children) perseverated in sorting by the previously relevant dimension (i.e., answered incorrectly on at least two out of four Conflict trials). In contrast, in the Color-to-Shape condition 85% of participants (11 out of 13 children) switched successfully, whereas only 15% (two out of 13 children)

perseverated. This difference was statistically significant, χ^2 (1) > 7.72, $p < .05$.

Results of Experiment 1 demonstrate that 3-year-old children have trouble switching attention to a less salient dimension, however they can successfully shift attention to a more salient dimension. This finding provides direct evidence that while voluntary shifts of attention are difficult for young children, they can successfully shift attention in an automatic manner.

Experiment 2

Studies of attentional flexibility in 3-year-old children have traditionally used target objects differing on two dimensions (e.g.,, color and shape), with each dimension represented by two values (e.g., red and blue for color; boats and bunnies for shape). However, learning in natural settings is rarely narrowed down to a binary choice between two values of a dimension. What effect would increase in the number of dimension values have on attentional flexibility in young children?

It has been argued that the pool of attentional resources is finite and therefore attentional weights of different attributes are interdependent (Sutherland & Mackintosh, 1971; Nosofsky, 1986). In other words, an overall increase in the number of relevant attributes should attenuate attention allocated to each individual attribute, thus decreasing the attentional weight of this attribute. It is possible that while developed ability to shift attention in a voluntary manner is required to shift attention away from attributes with high attentional weights, shifting attention away from attributes with lower attentional weights may be performed automatically. If this is the case, then increase in the number of relevant attributes in a DCCS task should result in attenuation of attentional weights of each individual attribute, thus leading to an increase in attentional flexibility (i.e., decreased perseveration). This prediction was tested in Experiment 2.

Method

Participants Participants in Experiment 2 were 38 3-year-old children ($M = 3.37$ years, $SD = .29$ years; 14 females and 24 males) recruited from day care centers in the Pittsburgh area. Six more participants were tested and omitted from the sample due to low accuracy on the No Conflict trials. The final sample consisted of 19 participants in each experimental condition.

Materials, Design, and Procedure Experiment 2 included two between-subject conditions, a High Attentional Weights condition and a Low Attentional Weights condition. In the High Attentional Weights condition participants were presented with the DCCS task in which, similar to prior research, objects differed on two dimensions with each dimension represented by two salient values (i.e., blue and red for color; star and fish for shape). In the Low Attentional Weights condition participants were presented with objects that also differed on two dimensions, however

each dimension was represented by four values (i.e., red, blue, green, and yellow for color; star, flower, fish, and butterfly for shape; see Figure 3 for an example).

Similar to Experiment 1, each condition consisted of a pre-switch and a post-switch phase, and each phase included four Conflict and four No Conflict trials. Participants were randomly assigned to the initial sorting dimension (i.e., shape or color).
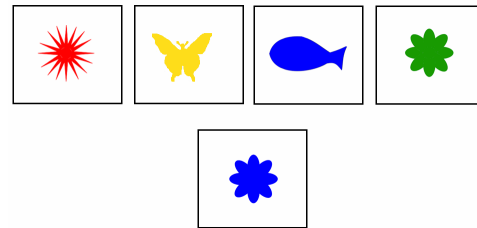

Figure 3: Example of a Conflict trial in the Low Attentional Weights condition of Experiment 2.

Results

Children who failed to correctly sort at least three out of four No Conflict trials during either pre- or post-switch phase were eliminated from the final sample (two participants were eliminated from the High Attentional Weights condition and four participants were eliminated from the Low Attentional Weights condition condition). The remaining participants performed sorting with high accuracy in both Conflict and No Conflict trials during the pre-switch phase, averaging 97% of correct responses across conditions (above chance, all one-sample ps < .0001).

Proportions of correct responses in the post-switch phase are presented in Figure 4. Participants' accuracy scores in the post-switch phase were submitted to a 2 (condition: Low Attentional Weights and High Attentional Weights) by 2 (trial type: Conflict and No Conflict) mixed ANOVA, with trial type as a repeated measure. The analysis revealed a main effect of condition (F (1, 36) = 5.66, $p < .05$) and a main effect of the trial type (F (1, 36) = 44.2, $p < .0001$). These main effects were qualified by a trial type by condition interaction, F (1, 36) = 4.02, $p = .052$.

Planned comparisons indicated that, consistent with prior research, in the High Attentional Weights condition children perseverated sorting by the previously relevant dimension, exhibiting low accuracy on the Conflict trials ($M = .42$, not different from chance, one-sample t (18) < 1), but high accuracy on the No Conflict trials ($M = .96$, above chance, one-sample t (18) > 21.43, $p < .0001$), and this difference was statistically significant ($p < .0001$).

However, children were less likely to perseverate in the post-switch phase of the Low Attentional Weights condition exhibiting above-chance accuracy on both No Conflict trials ($M = .96$, one-sample t (18) = 37, $p < .0001$) and Conflict trials ($M = .70$, one-sample t (18) = 2.53, $p < .005$). Furthermore, children's performance on the post-switch Conflict trials in the Low Attentional Weights condition was

above that in the High Attentional Weights condition, independent-samples $t(36) = 22.34$, $p < .05$).

The significance of differences between conditions was confirmed by non-parametric analysis of the individual patterns of responses. In particular, in the High Attentional Weights condition only 37% of participants (7 out of 19 children) successfully switched to sorting by the new dimension, whereas 63% of participants (12 out of 19 children) perseverated in sorting by the previously relevant dimension. In contrast, in the Color-to-Shape condition 68% of participants (13 out of 19 children) switched successfully, whereas only 32% (6 out of 19 children) perseverated. This difference was statistically significant, $\chi^2(1) > 3.8$, $p < .05$.
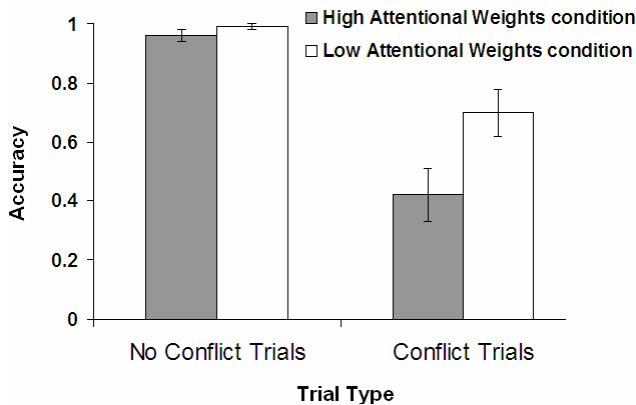

Figure 4: Proportion of correct responses in Experiment 2 by trial type and experimental condition.

Results of Experiment 2 suggest that 3-year-old children exhibit poor attentional flexibility when attentional weights of presented attributes are high, however decreasing attentional weights of presented attributes leads to significant improvement in attentional flexibility. This finding corroborates results of Experiment 1, providing further evidence that attentional flexibility early in development is more likely to arise as a result of automatic rather than voluntary processing.

General Discussion

Two experiments presented above were designed to assess automatic and voluntary shifts of attention in 3-year-old children using the DCCS paradigm. Overall, results point to two novel findings. First, results of Experiment 1 suggest that 3-year-old children could successfully shift attention in a DCCS task when they were required to shift attention to a more salient dimension (Color-to-Shape condition), whereas children had trouble shifting attention to a less salient dimension (Shape-to-Color condition).

The saliency hypothesis has been explored in this paper with regards to the situation in which the dimension of shape is represented by more salient values than the dimension of color. However this hypothesis predicts a reversal of results presented above if the color dimension is

represented by more salient values than the shape dimension. This prediction, however, remains to be addressed in future research.

Second, when attentional weights of each dimension value were decreased (via increasing the overall number of dimension values and thus proportionally decreasing amount of attention allocated to each individual dimension value), 3-year-old children were more likely to successfully shift attention to the newly relevant dimension.

In general, findings presented in this paper indicate that while 3-year-old children have trouble shifting attention in a voluntary manner, they are successful in shifting attention in an automatic manner. It should also be noted that this paper provided the first demonstration of young children's ability to successfully shift attention in the DCCS task without training (Brace et. al., 2006) or introduction of novel dimension values (Mueller et. al., 2006; Yerys & Munakata, 2006).

Implications for the Theories of Word Learning and Categorization

As stated above, different theoretical approaches to word learning and categorization hypothesize different mechanisms underlying these processes. According to one approach, sophisticated learning exhibited early in development is based on representational constraints, determining which dimensions of the environment learners attend to in different contexts (Booth, & Waxman, 2002; Gelman & Williams, 1998). Furthermore, it has been argued that weighting of dimensions in different contexts and shifting attention among dimensions in the course of word learning and categorization may occur in a voluntary manner even very early in development (Gelman & Medin, 1993).

In contrast, proponents of the alternative approach argue that early learning is constrained by the regularities in the input and general information processing rather than representational constraints. According to this view, weighting of dimensions and shifting attention among dimensions occurs automatically, driven by such properties of input as overall perceived similarity, association strength, and saliency (Sloutsky & Fisher, 2004, 2005; Fisher, 2007-a; Smith, et. al., 1996).

Multiple studies on the development of executive function suggest that 2- to 3-year-old children (who are known to be quite proficient in word learning and categorization) are limited in their ability to voluntarily disengage attention from salient information, shift attention among stimulus dimensions, and inhibit prepotent responses (Akshoomoff, 2002; Bunge, et. al., 2002; Durston, et. al., 2002; Napolitano & Sloutsky, 2004; Zelazo, et. al., 1996). Therefore, it has been argued that voluntary control of attention is unlikely to be sufficiently developed in young children to support voluntary dimension weighting and voluntary shifts of attention in the course of world learning and categorization (Fisher, 2007-b). However there has been no direct evidence to suggest that children of this age can succeed on tasks requiring automatic but not voluntary shifts of

attention. Results reported in this paper have important implications for the theories of early leaning because they provide such evidence.

Acknowledgements

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