Learning new categories: Adults tend to use rules while children sometimes rely on family resemblance

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Abstract

We conducted an experiment in which children and adults were asked to learn a set of categories for which a single-feature rule (the criterial attribute) or overall family resemblance would allow for perfect performance. Test stimuli were presented after the category was learned and were designed such that the information provided by the rule conflicted with the information provided by the family resemblance structure. We found that adults made significantly more rule-based responses to the test stimuli than did the children. These data suggest that although adults default to verbal rules under standard learning conditions, children may rely instead on an implicit, non-verbal system to learn the same categories.

Keywords Category Learning; Development; Multiple Systems

Categorization is a fundamental skill that has been studied not only in adults but in children as well (Ashby & Maddox, 2005; Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Minda, Desroches, & Church, 2008; Smith, 1989). Existing research on the cognitive differences between children and adults suggest that children and adults will perform similarly when learning some kinds of categories, but will exhibit specific differences when learning others. First, relative to adults, children have a reduced working memory capacity (Gathercole, 1999; Swanson, 1999). This means that in cases where category learning relies on working memory, children should not perform as well as adults. However, when learning a new category does not tax working memory (or the involvement is minimal), children and adults will perform similarly. Second, relative to adults, children have a generally reduced capacity for executive functioning and rule selection (Bunge & Zelazo, 2006; Casey, Giedd, & Thomas, 2000; Frye, Zelazo, & Palfai, 1995; Zelazo, Frye, & Rapus, 1996). This means that when category learning depends on rule selection, children should be impaired relative to adults. This impairment should not be present when the categories to be learned have little or no rule selection component.

The idea that working memory and executive functioning play a role in the learning of some categories but not in others is one of the central predictions of a multiple-systems theory of category learning called Competition of Verbal and Implicit Systems, or COVIS (Ashby & Maddox, 2005; Ashby et al., 1998; Ashby & Ell, 2001; Minda et al., 2008; Waldron & Ashby, 2001; Zeithamova & Maddox, 2006). This theory suggests that at least two brain systems are fundamentally involved in category learning. The verbal system is assumed to learn rule-described categories. These are categories for which the optimal rule is relatively easy to describe verbally (Ashby et al., 1998). For example, consider a category set in which round objects belong to one group and square objects belong to another group. These categories could be quickly mastered by the verbal system because a rule is easy to verbalize ("category 1 items are round"). According to COVIS, the verbal system is mediated by the prefrontal cortex and it requires sufficient cognitive resources (working memory and executive functioning) to search for, store, and apply a rule (Zeithamova & Maddox, 2006). Furthermore, this system is assumed to be the default approach for normally-functioning adults learning new categories (Ashby et al., 1998).

However, not all categories can be easily described by a verbal rule. COVIS also assumes that an implicit system learns non-rule-described categories. These are categories for which no easily verbalizable rule exists or for which two or more aspects of the stimulus must be integrated at a pre-decisional stage (Ashby & Ell, 2001). That is, the dimensions themselves may be perceptually separable, but they might need to be combined or integrated in order to make a categorization decision. For example, consider a family-resemblance category in which most of the objects are small, most are round, most are reddish, and most are shiny. The objects in this category share an overall family resemblance with each other, but there is no single feature to act as the rule. The rule, "most are small, most are round, etc." is difficult, though not impossible, to verbalize. COVIS assumes that a category like this can be learned more accurately and efficiently by the implicit system, without relying on a verbal rule.

The implicit system is thought to be mediated by subcortical structures in the tail of the caudate nucleus. It relies on a dopamine-mediated reward signal to learn categories and does not rely heavily on working memory and controlled attention. The process of learning in the implicit system is assumed to be a gradual process of associating the perceptual aspects of an object with the correct response. As a result, this system is well-suited to learn categories that have a strong family resemblance structure (Ashby et al., 1998).

Both of these systems are assumed to operate in normally-functioning adults, and both can contribute to performance, even after learning has progressed. In general, COVIS assumes that the two systems can compete during learning and when a classification decision is made, but that the system with the more successful responding strategy will eventually dominate performance (Ashby et al., 1998). For instance, although the verbal system is considered the default system for adults, some categories may not be easily learned by a verbal rule. In this case, the implicit system would produce more accurate responses and would take over. Also, if rule-based categories are learned under conditions in which the learner is distracted and working memory is being used for another task, the implicit system would take over for the struggling verbal system (Minda et al., 2008; Zeithamova & Maddox, 2006).

Because COVIS makes specific assumptions about the brain regions involved in the two types of category learning, there are clear predictions to be made about developmental effects on category learning. Recent work has suggested that the prefrontal cortex develops later than other areas (Bunge & Zelazo, 2006; Casey et al., 2000). Furthermore, verbal working memory and executive functioning develop substantially during childhood and are related to these physical developments in the prefrontal cortex (Gathercole, 1999; Swanson, 1999). Since the prefrontal cortex is assumed to mediate the verbal system, COVIS predicts that children should be impaired relative to adults when learning categories that rely heavily on this verbal system, particularly when learning requires substantial working memory resources (e.g., categories for which the optimal rule is a complex verbal rule). On the other hand, the implicit system of COVIS is mediated by the tail of the caudate nucleus. This structure seems to be fully developed in children (Casey et al., 2004), and as a result, young children should be able to learn non-rule-defined categories as well as adults. Furthermore, because this system does not require working memory resources (Zeithamova & Maddox, 2006), the learning of non-rule defined categories should not be impacted by developmental differences in working memory.

This prediction was recently tested by Minda et al. (2008) who examined the learning of categories by children ages 3, 5, and 8 years old, as well as adults. Relying on a subset of the categories sets of Shepard, Hovland, and Jenkins (1961), Minda et al. found that children performed worse than adults on categories that were optimally learned by a disjunctive rule but that children and adults performed the same on family resemblance categories. However, children as young as 5 were able to learn single-dimensional rules about as well as adults, suggesting that the verbal system and the ability to learn rules was not completely absent in children.

Although these results were generally consistent with the predictions of COVIS, several issues necessitate additional research. First, COVIS makes an explicit assumption about the competition between the two systems. The verbal and the implicit systems compete to learn the categories and provide the response (Ashby et al., 1998). Although Minda et al. found that children learn rule-defined categories less well that adults, they used categories for which only one strategy was viable. A more interesting case concerns categories for which rule-based and non-rule-based strategies might be available. Adults should default to the verbal system and should base classifications on a verbalizable rule, even if the rule conflicts with overall similarity. However, it is not clear how children would perform in this case, although COVIS predicts that they should be less likely to make rule-based classification because they would have difficulty inhibiting a response to the conflicting information. Second, the subjects in Minda et al's study were evaluated on their performance in learning new stimuli, but not in their ability to transfer what they learned to new stimuli. Stimulus generalization is an important aspect of categorization, and COVIS predicts that adults should continue to apply rules to new stimuli, but it is not immediately clear how children would behave (even if they learned a rule).

Experiment

Our experiment examined category learning by a group of five-year old children and a group of university students. We asked them to learn two five-dimensional categories that had a verbal rule that defined category membership, and also had an overall family resemblance structure. This category set could be learned perfectly by the verbal system, using a verbalizable rule based on a single dimension (i.e., the criterial attribute, referred to as the CA) that was perfectly predictive of category membership. This category set could also be learned perfectly by the implicit system using a strategy based on the family resemblance (FR) of members within each category on all five dimensions. Since the areas that mediate the verbal system (the prefrontal cortex) are less well developed in children, we predict that children will be less likely than adults to find the CA. However, since the areas that mediate the implicit system (the basal ganglia) are fully developed by age five, we predict that there will be little impairment on learning the FR structure. Therefore, although we expect that children and adults will learn the categories equally well, we expect that they will do so using different systems and different strategies.

The experiment featured a transfer phase in which subjects provided a classification for a set of novel stimuli for which the evidence provided by the CA conflicted with the evidence provided by the family-resemblance structure. We predicted that since adults would rely on the verbal system to learn the rule, they would classify these items in accordance with the CA. We expected some children to also classify these stimuli in accordance with the CA, but we also predicted that because of the less-well developed verbal system, many children would classify the test stimuli in accordance with the FR evidence or would have difficulty using a consistent classification strategy because of the conflict.

Method

Subjects Subjects included 28 children with a mean age of 5.21 years (*SD* = .62 years) recruited from the University of Western Ontario's YMCA Child Care Centre and Laboratory Preschool. Of the 28 children who participated in the study, three failed to complete the category-learning task. Data from eight additional children was discarded because their performance on the last block of category learning was not significantly higher than chance performance. This left 17 children (11 boys, 6 girls) who showed evidence of category learning. Subjects also included 21 students from the University of Western Ontario who participated in the study for course credit. Data from four adults was discarded because their performance on the last block of category learning was not significantly higher than chance performance. This left 17 adults (4 men, 13 women) who showed evidence of category learning.

Materials Subjects learned to classify drawings of bugs that varied along five binary dimensions: antenna (forward-facing or backward-facing), head (circle or square), wings (rounded or pointy), legs (bent or straight), and tail (bent or straight). A complete set of stimuli is shown in Figure 1. The category set was made up of 10 objects with five objects belonging to each of two categories. The binary structure for Category A and Category B is shown in Table 1. The values 1 and 0 indicate the assigned feature values for each of the five dimensions. For example, round head, forward-facing antenna, rounded wings, straight legs and a straight tail were each be assigned a value of 1, and the complementary set of features were assigned a value of 0. The item 1 1 1 1 1 represents the prototype for Category A and the item 0 0 0 0 0 represents the prototype for Category B while the remaining category members have four features in common with their own category's prototype and one feature of the opposite category's prototype. Note, the fist dimension is the CA. The feature that corresponded to the CA was counterbalanced across participants. Perfect categorization performance can be attained by learning the CA (e.g. "round heads in Category A, otherwise Category B.") or by learning the FR structure.

Transfer stimuli were used to distinguish between CA and FR categorization strategies. That is, the feature corresponding to the CA indicated membership in one category but the overall family resemblance indicated membership in the opposite category. As shown in Table 1, the first dimension of the first transfer stimulus (0 1 1 1 1) was consistent with CA evidence for category B, but the overall FR evidence is consistent with the evidence for Category A.

Procedure Children were tested individually in a room near their daycare classroom. The child and the experimenter were both seated at a table in front of a 13 inch Apple MacBook

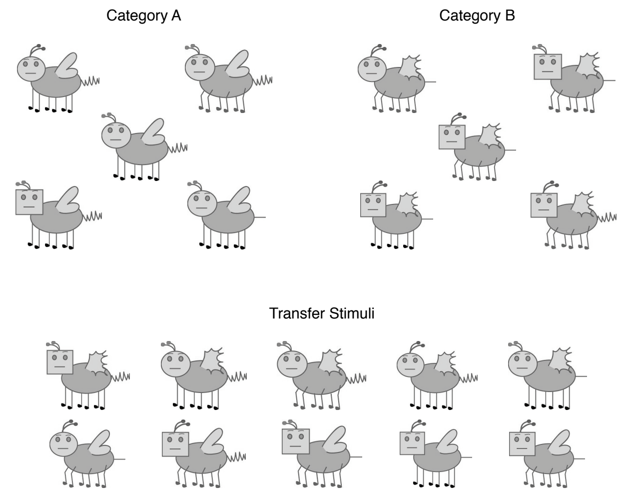

Figure 1: This is an an example of the training items for each category used in the learning stage, along with the test items for the transfer stage. The stimuli shown to subjects were in colour.

Table 1: Stimuli used in the Experiment

Stimulus	CA	d2	d3	d4	d5
Category A					
1	1	1	1	1	1
2	1	0	1	1	1
3	1	1	0	1	1
4	1	1	1	0	1
5	1	1	1	1	0
Category B					
6	0	0	0	0	0
7	0	1	0	0	0
8	0	0	1	0	0
9	0	0	0	1	0
10	0	0	0	0	1
Transfer					
11	0	1	1	1	1
12	0	0	1	1	1
13	0	1	0	1	1
14	0	1	1	0	1
15	0	1	1	1	0
16	1	0	0	0	0
17	1	1	0	0	0
18	1	0	1	0	0
19	1	0	0	1	0
20	1	0	0	0	1

computer. Children were first told that they would be playing a game in which they would see pictures of different creatures on the computer screen. They were told that some of these creatures lived in the mountains and some lived in the forest. Their job was to help these creatures find their homes by pointing to the correct place on the screen.

The learning stage of the experiment consisted of five blocks in which each of ten possible training stimuli was presented in random order, once per block, for a total of 50 trials. On each trial, a picture of a creature appeared in the middle of the screen and pictures of the two category labels (mountains or trees) were shown in the top left and right corners of the screen. As well, ten small white circles were centered along the top of the screen. On each trial, the child indicated the creature's category label and the experimenter clicked with the mouse. If the response was correct, the creature moved to the correct category label and smiled for three seconds. If the response was incorrect, the creature moved to the incorrect category label and frowned for three seconds then moved to the correct category label and smiled for three seconds. Each time a trial was completed, regardless of whether it was correct or incorrect, one circle at the top of the screen turned red. After ten trials, when all of the circles were red, the circles all became white and a new set of ten trials began. The circles were used as a tool for participants to keep track of their progress through the experiment. Pilot work suggested that these progress circles offered a mild incentive for children to complete the experiment. Minda et al. (2008) used stickers for a comparable effect.

Upon completion of the 50 trials, children were told that they would be seeing some additional creatures and that they would be helping them to find their homes. They were told to classify these new creatures using what they had learned during the training phase. The transfer stage consisted of one presentation of each of 10 transfer stimuli presented once in random order. Each trial followed the same sequence of events as in the training stage except that novel creatures were presented (see transfer stimuli in Figure 1) and no feedback was given (although the stimuli smiled when they moved to the selected location).

At the start of the experiment, subjects were asked to indicate to the experimenter if they did not wish to continue, though the experimenter tried to be as encouraging as possible to keep the children interested in the game. Children were allowed to take a short break at any point during the experiment in which they were allowed to colour. All children were given a short break at the end of the learning stage of the experiment. Adults were tested using the same basic procedure as the children except that adults were tested on individual 17 inch iMac computers in a room with up to three other participants. Adults read instructions on their own and completed the task without the aid of an experimenter, using a mouse to select their responses. As well, adults were not specifically told to take a break between the learning stage and the transfer stage, although they did take a break at least long enough to read the transfer instructions.

Results

Learning Analysis We first examined the learning of these categories by both groups of subjects. For children and adults, the average proportion correct for each block of 10 trials was calculated. The resulting learning curves for children and adults are shown in Figure 2A and these data suggest a small early advantage for adults over children but they also show that both groups learned the categories well. A 2 (age) x 5 (block) mixed ANOVA revealed a main effect for block, F (4, 128) = 23.30, $p < .001$, illustrating that learning occurred between the first and fifth blocks. No main effect was found for age, F (1, 32) = 2.38, $p = .13$, and no interaction was found between age and block, F (4, 128) = .27, $p = .90$, indicating that children and adults did not differ in how well they learned these categories. Despite the age difference and the reduced capacity of the verbal system in the children relative to the adults, there was little evidence that the children had any special difficulty learning these categories. However, since these categories could be learned by either a family resemblance strategy (via the implicit system) or a rule-based strategy (via the verbal system), any differences in learning strategy should be revealed in an analysis of the transfer stimuli.

Strategy Analysis In the transfer stage, the stimuli were designed so that a categorization strategy based on the criterial attribute would result in placement of a stimulus in one category and other categorization strategies, such as a family resemblance strategy, would result in placement of a stimulus in the opposite category. In order to analyze performance on the transfer phase, we calculated the proportion of criterial-attribute responses for each subject. These data are shown in Figure 2B and this graph shows that adults tended to make more classifications based on the criterial attribute than did children. A t-test comparing the proportion of criterial-based responding confirmed this difference, t (22) = 2.99, $p < .01$. Despite learning as well as adults, children used strategies such as similarity-based responding more frequently than adults.

The figure also shows individual performances, and shows that while most (though not all) adults made classifications that were rule based (100% CA Performance), a different pattern emerged for the children. Although some of the children did appear to learn the rule, many more did not. And some classified the test stimuli in exactly the opposite way (0% CA), suggesting that they may have relied on the family resemblance to do so. The figure also indicates some variability in the nature of non-CA performances (the individual dots). In the transfer stage, a person using an imperfect single dimensional rule would appear to have a proportion of criterial attribute responding of .2. That is, using dimension 2 as a rule would result in making the same classifications as using the CA for the rule on two of the ten stimuli. Accordingly, each participant's pattern of responses during the transfer stage was correlated with the response pattern

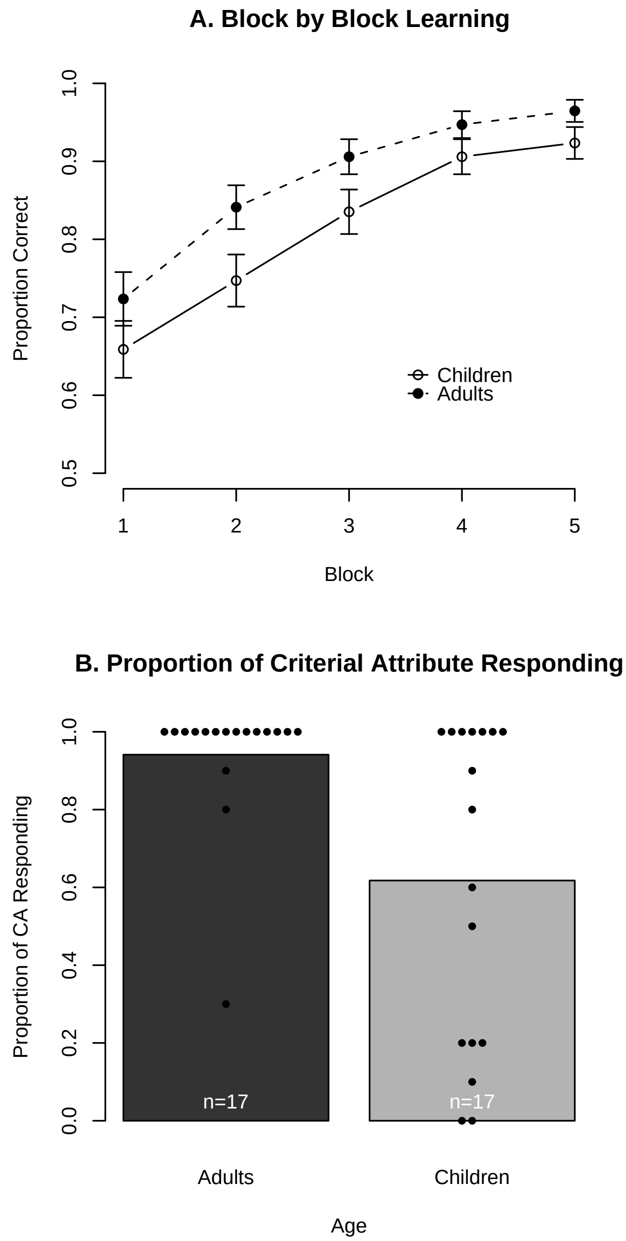

Figure 2: Panel A shows category learning performance for children and adult. Panel B shows the proportion of criterial attribute (CA) responding by children and adults in the transfer stage, with individual subject data shown as points. *Note:* error bars denote *SEM*

Table 2: Tranfer Stimuli Classification Strategies

Age	CA	FR	SD	Other
Children	7	2	3	5
Adults	14	0	0	3

produced by each of seven possible categorization strategies: single dimensional rule based on the CA, single-dimensional rule based on each of four suboptimal dimensions (SD), FR similarity, and other. After calculating correlations, the number of participants whose data was best fit by a criterial attribute strategy, an imperfect single dimensional strategy and a similarity-based strategy was counted. Table 2 shows that adults tended to responded according to a criterial attribute strategy more often than children. A chi square tests confirmed that adults and children use different categorization strategies, $X^2(2) = 7.22$, $p = .03$.

Discussion

In this Experiment we asked children and adults to learn a set of categories that could be acquired by finding a single-feature rule or by learning the overall family-resemblance structure. We then asked them to classify additional test stimuli for which the rule information conflicted with the family-resemblance information. Although the children and adults did not differ from each other in terms of how well they had learned the categories, they did differ in their classifications of the test stimuli. As we predicted, children were significantly less likely to classify the test stimuli according to the criterial attribute rule than were the adults. These results echo earlier developmental work on the holistic / analytic distinction in category learning, which found that children tended to prefer overall similarity and adults tended to prefer rules (Kemler Nelson, 1984). In addition, research using a similar category set found that adults who were asked to learned the categories in the presence of indirect feedback, or via incidental means were also less likely to find the criterial attribute, possibly because there were not relying on their verbal systems (Kemler Nelson, 1984; Minda et al., 2008).

These results are also consistent with a multiple-systems theory (Ashby et al., 1998; Ashby & Ell, 2001). COVIS predicts that the verbal system should learn these categories by testing various rules and eventually applying a verbal description for the correct single-dimensional rule. Adults default to this verbal system under most learning conditions (Ashby et al., 1998; Minda et al., 2008; Zeithamova & Maddox, 2006), and so they apply the rule to classify the test stimuli. However, the implicit system could also learn these categories by relying on the good family resemblance structure. The family resemblance structure is difficult to verbalize because of the number of propositions in the verbal rules, but less difficult to learn procedurally because of the straightforward relationship between features and responses. Children, unlike adults, have more difficulty relying on the verbal system because the prefrontal cortex has not sufficiently developed to allow for its full operation (Bunge & Zelazo, 2006; Casey et al., 2004). Without the efficient use of the verbal system, the child is less able to efficiently engage in hypothesis testing. As a result, children could still learn these categories, but many of the children may have relied instead on the implicit system to learn the categories and subsequent classifications on the transfer stimuli were not likely to be based on a rule.

The verbal system relies on working memory and executive functioning to test and store hypotheses and rules. As such, the category learning differences between children and adults are consistent with other observed differences in working memory ability between children and adults (Gathercole, 1999; Swanson, 1999). Working memory plays a large role in the verbal system and is required to learn categories for which the optimal rule is verbalizable (Waldron & Ashby, 2001; Zeithamova & Maddox, 2006). Adult participants (but children less so) rely on verbal working memory to help learn these categories with the verbal system. Other research has shown that younger children are more sensitive to the relational complexity of hypothesis-testing tasks (Andrews & Halford, 2002; Bunge & Zelazo, 2006; Zelazo et al., 1996), which is also consistent with our claims here.

Although we claim that the verbal system is less effective in children, the results of our experiment suggest that it can (and does) operate. Some of the children in this study were able to learn rules, and many continued to make CA based responses in the transfer phase. It is possible that some children did learn the rule, but were unable to resolve the conflict during the transfer phase. This would be expected to happen in children, since their prefrontal cortex areas are less well developed (compared with adult) and they would have difficulty in inhabiting the response to the family resemblance structure. Furthermore, Table 2 and Figure 2B, also reveal some subjects who relied on other non rule-based strategies. These other strategies could be a mixture of responses from the two systems (some rule-based, some similarity-based) or may also be imperfect exemplar-based strategies. At this point our data do not allow a strong conclusion about this subset of subjects and additional research is needed to understand the interaction of these two learning systems in general and at different stages in development.

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