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Learning categories via rules and similarity: Comparing adults and children

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ABSTRACT

Two experiments explored the different strategies used by children and adults when learning new perceptual categories. Participants were asked to learn a set of categories for which both a single-feature rule and overall similarity would allow for perfect performance. Other rules allowed for suboptimal performance. Transfer stimuli (Experiments 1 and 2) and single features (Experiment 2) were presented after training to help determine how the categories were learned. In both experiments, we found that adults made significantly more optimal rule-based responses to the test stimuli than children. Children showed a variety of categorization styles, with a few relying on the optimal rules, many relying on suboptimal single-feature rules, and only a few relying on overall family resemblance. We interpret these results within a multiple systems framework, and we argue that children show the pattern they do because they lack the necessary cognitive resources to fully engage in hypothesis testing, rule selection, and verbally mediated category learning.

Introduction

Categorization is a fundamental cognitive skill that has been studied in adults as well as in children (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Ashby & Maddox, 2005; Huang-Pollock, Maddox, & Karalunas, 2011; Minda, Desroches, & Church, 2008; Rabi & Minda, 2014; Sloutsky, 2010; Smith,

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1989). Relative to adults, children have a reduced working memory capacity (Gathercole, 1999; Swanson, 1999), and so in cases where category learning relies on working memory, children would not be expected to perform as well as adults. However, when category learning does not tax working memory, children and adults should perform similarly. Relative to adults, children have a reduced capacity for executive functioning and rule selection (Bunge & Zelazo, 2006; Casey, Giedd, & Thomas, 2000; Frye, Zelazo, & Palfai, 1995; Zelazo, Frye, & Rapus, 1996), so 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.

Categories differ in terms of how much working memory, executive function, and verbal ability are required during learning. For example, a *rule-described* category is one in which the optimal rule is relatively easy to describe verbally (Ashby et al., 1998). Consider a category set in which round objects belong to one group and square objects belong to another group. These categories could be mastered quickly because the rule is easy to verbalize ("Category 1 items are round"). However, even a simple classification rule like this requires sufficient cognitive resources such as working memory and executive functioning (Zeithamova & Maddox, 2006). This demand on executive functioning should be particularly important if the rule is difficult to find or if there are several potential rules to test and exclude.

However, not all categories can be easily described by a verbal rule. *Non-rule-described* categories (sometimes referred to as family resemblance categories) are categories for which no easily verbalizable rule exists (Ashby & Ell, 2001). For example, consider a category in which most of the objects are small, most are round, and most are shiny. These objects share a family resemblance with each other, but there is no single feature to act as the rule. The rule, "most are small, most are round, and so forth" is difficult to verbalize and might not be a reliable classifier. Instead, these categories may be learned procedurally/implicitly by encoding the overall similarity of category members (Ashby & Maddox, 2005; Brooks, 1978; Kemler Nelson, 1984; Smith, Minda, & Washburn, 2004; Smith & Shapiro, 1989).

Several recent studies have explored the role of working memory and executive functioning in category learning. In some cases, researchers have proposed that multiple brain systems are involved during acquisition, and that observed learning differences come about because of the differential involvement of these systems (Ashby & Ell, 2001; Ashby & Maddox, 2005; Ashby et al., 1998; Huang-Pollock et al., 2011; Minda & Miles, 2010; Minda et al., 2008; Zeithamova & Maddox, 2006). In other cases, the emphasis has been on the single and central role of working memory (Lewandowsky, 2011). The current work was motivated by the multiple systems approach, although we consider alternatives in the General Discussion.

According to multiple systems theories, of which COVIS (competition between verbal and implicit systems) is a well-known example, a *verbal system* is assumed to learn rule-described categories (Ashby et al., 1998; Minda & Miles, 2010). This system is thought to be mediated by the prefrontal cortex, the medial temporal cortex, the anterior cingulate cortex, and the head of the caudate. This system requires sufficient cognitive resources to search for, store, and apply a rule (Zeithamova & Maddox, 2006), and it is assumed to be the default approach for normally functioning adults when learning new categories (Ashby et al., 1998; Minda & Miles, 2010). The multiple systems approach also assumes that an *implicit system* learns non-rule-described categories. The implicit system is assumed to rely on the visual processing of the stimuli and the correct association of cues to responses. The system is mediated by subcortical structures in the tail of the caudate nucleus, it relies on a dopamine-mediated reward signal to learn, and it does not rely as heavily on verbal working memory and controlled attention. Once a to-be-categorized stimulus is viewed, the visual information is sent from the visual cortex to the caudate nucleus (Ashby & Ennis, 2006). This system is well suited to learn categories that have a strong family resemblance structure (Ashby et al., 1998). It is not well suited for rapid rule learning or for categories that require a disjunctive rule and, thus, have no clear family resemblance structure (Minda et al., 2008).

COVIS and other multiple systems theories make several predictions about developmental effects on category learning because the regions of interest are known to develop at different rates. Research suggests that the prefrontal cortex develops later than other areas (Bunge & Zelazo, 2006; Casey et al., 2000), and 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). On the other hand, the implicit system is mediated by the tail of the caudate nucleus, which seems to be fully developed in children (Casey et al., 2004). Moreover, because this system does not require verbal working memory (Zeithamova & Maddox, 2006), the learning of non-rule-described categories should not be affected by developmental differences in working memory. As a result, young children should be able to learn non-rule-described categories as well as adults, but children should be impaired relative to adults when learning categories that rely heavily on this verbal system.

This prediction was tested by Minda and colleagues (2008), who found that children (3-, 5-, and 8-year-olds) performed worse than adults on categories that were optimally learned by a complex disjunctive rule but that children and adults performed the same on family resemblance categories. Children were also able to learn single-dimensional rules about as well as adults, suggesting that children are capable of learning rules if the rules are easy to identify. This seems to suggest that younger children might not always share the initial bias for rule-based learning that adults are assumed to have. However, there are several limitations to this work that preclude this strong conclusion. First, the results from this study suggested that children are able to learn the simple rule-described categories as well as adults (with 3-year-olds being the obvious exception). Second, the equivalent performance between children and adults on non-rule-described categories was shown for a category set that had weak family resemblance and very few features and for which both children and adults performed relatively poorly.

More recent work has examined the possible strategy differences between children and adults, and the results are mixed. Huang-Pollock and colleagues (2011) found that adults performed better than school-aged children on rule-described and non-rule-described categories, and the primary reason was children's overreliance on single-dimensional rules. Rabi and Minda (2014) conducted an extensive study of rule-based category learning in children ranging from 4 to 11 years of age as well as adults, and they found considerable evidence that rule-based category learning is possible and that in many cases children can perform as well as adults. Furthermore, Rabi and Minda showed that working memory and inhibitory control were related to rule-based category learning and that as these abilities improved with age, so did category learning performance. Both of these studies suggest that children have access to the rule learning system but that this system operates less efficiently in children because of their less well-developed hypothesis-testing abilities.

Although the COVIS theory is consistent with these results, several issues necessitate additional research. First, although the previous research suggested that children are able to learn some single-feature rules, these studies used category sets with only two or three dimensions. This reduces the hypothesis testing space with respect to rule learning and decreases the strength of the family resemblance within the category, which could affect the reliance on an alternative similarity-based strategy. A better test of children's rule learning or similarity learning abilities would require a category set with more dimensions.

Second, COVIS and other multiple systems theories assume that the verbal and implicit systems compete to learn the categories and to provide the response (Ashby et al., 1998). Minda and colleagues' (2008) findings related to a category set for which only one strategy was viable. Similarly, in Rabi and Minda (2014) and in Huang-Pollock and colleagues (2011), children learned categories that had only one optimal strategy. To further examine the types of categorization strategies that are preferred by children and adults, it is useful to examine categorization sets for which both rule-described and non-rule-described strategies are available and workable. Multiple systems theories assume that the verbal system initially dominates, meaning that adults typically start by using the verbal system and base classifications on a verbalizable rule even if the rule conflicts with overall similarity (Johansen & Palmeri, 2002). Children may also engage in rule learning but may have difficulty in finding and applying the optimal rule.

In line with this prediction, Visser and Raijmakers (2012) examined category learning in school-aged children (4–13 years) and adults when categorizing stimuli that could be learned by adopting a similarity-based or a rule-based strategy. The found no evidence of similarity-based representations occurring in children. In addition, many younger children did not complete the pre-training phase of the study, where participants learned to categorize single-dimensional stimuli and were required to obtain a certain number of correct classifications before they could progress to the test phase. The fact that younger children struggled to achieve criterion in pre-training demonstrates that developmental differences in categorization may be related to the differences in the efficiency of the verbal system rather than an increasing dominance of the verbal system over the implicit system.

Contrary to the claims of Minda and colleagues (2008) and of earlier works by Kemler Nelson and colleagues (Kemler Nelson, 1984; Smith & Shapiro, 1989), Visser and Raijmakers (2012) suggested that rule learning may be the default approach in children as well as adults. A potential shortcoming of their work is that, like Minda and colleagues (2008) and the other research discussed here, they employed categories of low dimensionality. This may favor rule use because there were relatively few rules to test before finding the optimal rule. It may work against similarity-based learning or family resemblance learning because stimuli that share only two of these features do not have very high perceptual similarity. A stronger test of the occurrence of rule-based and/or similarity-based category learning should consider categories with higher dimensionality and stronger family resemblance.

We designed two experiments that extend the research of Minda and colleagues (2008) and Visser and Raijmakers (2012) and examined the relative differences between children's and adults' category learning abilities and styles. To address the aforementioned issues, we used category sets with a higher dimensionality (five dimensions) so that the categories would afford a more demanding hypothesis testing process as well as a stronger family resemblance structure. We asked our participants to learn a set of categories that could be learned either by finding a perfectly predictive feature, by relying on a suboptimal rule, or by attending to the overall family resemblance of the category set. In both experiments, we also presented participants with a variety of transfer stimuli and other tests following learning to ascertain how they had learned the categories.

Based on the theoretical and neurobiological descriptions of COVIS and other multiple systems theories, we assumed that adults have a fully developed verbal system as well as a fully developed implicit system. Children, on the other hand, should have fewer resources available for the verbal system to operate and, as a result, should be less effective at finding the optimal rule. We predicted that adults would generally learn these categories by finding the rule and would tend to make rule-based classifications of the test stimuli. We predicted that fewer children would learn the rule and that fewer children would make rule-based classifications of the test stimuli. Instead, we predicted that children, lacking a fully developed verbal category learning system, would be more likely to rely on suboptimal rules based on dimensions that readily capture attention or would rely on the family resemblance structure of the category.

Experiment 1

We first examined category learning by a group of young children (5-year-olds) and a group of university students. We chose to study 5-year olds because prior research has demonstrated that changes in categorization are quite salient at this age and children younger than 5 years often struggle to identify the task-appropriate strategy in categorization tasks (Minda et al., 2008; Rabi & Minda, 2014). Children were asked to learn two five-dimensional categories that had a single-dimensional rule that defined category membership and also had a good family resemblance structure. This category set could be learned perfectly by a rule based on a single dimension (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 using all five dimensions.

During the transfer phase, participants classified test stimuli for which the evidence provided by the CA conflicted with the evidence provided by the other features and the overall FR structure. We predicted that adults would rely on the verbal system and would classify these test items in accordance with the CA. We expected some children to also classify these stimuli in accordance with the CA (even if by chance), but we also predicted that some children would classify the test stimuli in accordance with the FR evidence, would classify the test stimuli in accordance with a suboptimal rule, or would have difficulty in using a consistent classification strategy because of the conflict. The conflict could pose a challenge to children because their executive functioning abilities are not as well developed as they are in adults (Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006; Zelazo, 2004). Among those children who classify using a suboptimal rule, we expected them to base their classifications on salient dimensions because their verbal category learning system is not developed enough to disengage from a salient rule on feedback.

Method

Participants

Participants included 25 children with a mean age of 5.21 years ($SD = 0.62$) recruited from the University of Western Ontario's YMCA Child Care Centre and Laboratory Preschool. Data from 8 children were discarded because their performance on the last block of category learning was not significantly higher than chance performance. This left 17 children (11 boys and 6 girls) who showed evidence of category learning. Participants also included 21 students from the University of Western Ontario who participated in the study for course credit. Data from 4 adults were discarded because their performance on the last block of category learning was not significantly higher than chance performance.[1] This left 17 adults (4 men and 13 women) who showed evidence of category learning.

Materials

Participants learned to classify drawings of bugs that varied along five binary dimensions. An example of the training and test stimuli is shown in Fig. 1. The underlying logical structure for the stimuli is shown in Table 1. The values 1 and 0 indicate the assigned feature values for each of the five dimensions (instantiated as features on the bugs). Note that the first dimension was perfectly correlated with category membership and was the CA. The feature that corresponded to the CA was counterbalanced across participants. Learning the CA or learning the FR structure could eventually result in perfect performance. Attending to one of the non-criterial dimensions would result in imperfect performance. A pilot study (details are in the Appendix) was conducted to collect feature salience ratings by adults and by children for each of the features of the stimuli.

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 was consistent with the evidence for Category A. The 10 most diagnostic transfer items were specifically chosen to test how participants generalized their acquired category knowledge to classifying a limited set of novel transfer items.

Procedure

Children were tested individually in a room near their classroom. Both children and the experimenter were seated at a table in front of a 13-inch Apple MacBook. Children were first told that they would be playing a game in which they would see pictures of different bugs on the computer screen. They were told that some of these bugs lived in the mountains and some lived in the forest. Children's job was to help these bugs find their homes by pointing to the correct place on the screen.

The training phase of the experiment consisted of five blocks in which each of 10 possible training stimuli was presented in random order, once per block, for a total of 50 trials. On each trial, a picture of a bug appeared in the middle of the screen and pictures of the two category labels (mountains and trees) were shown in the top left and top right corners of the screen. In addition, a row of 10 small white circles was centered along the top of the screen. On each trial, children pointed to the bug's category label and the experimenter clicked with the mouse. If the response was correct, the bug moved to the correct category label and smiled for 3 s. If the response was incorrect, the bug moved to the incorrect category label and frowned for 3 s and then moved to the correct category label and smiled for 3 s. 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 10 trials, when all of the circles were red, the circles reset to white and a new set of 10 trials began. The circles were used as a tool for participants to keep track

[1] We discarded data from participants who failed to learn above chance (.76 using binomial proportion). We conducted analyses on strategy use during the transfer phase, and it was necessary that participants demonstrated some degree of learning during the initial phase.

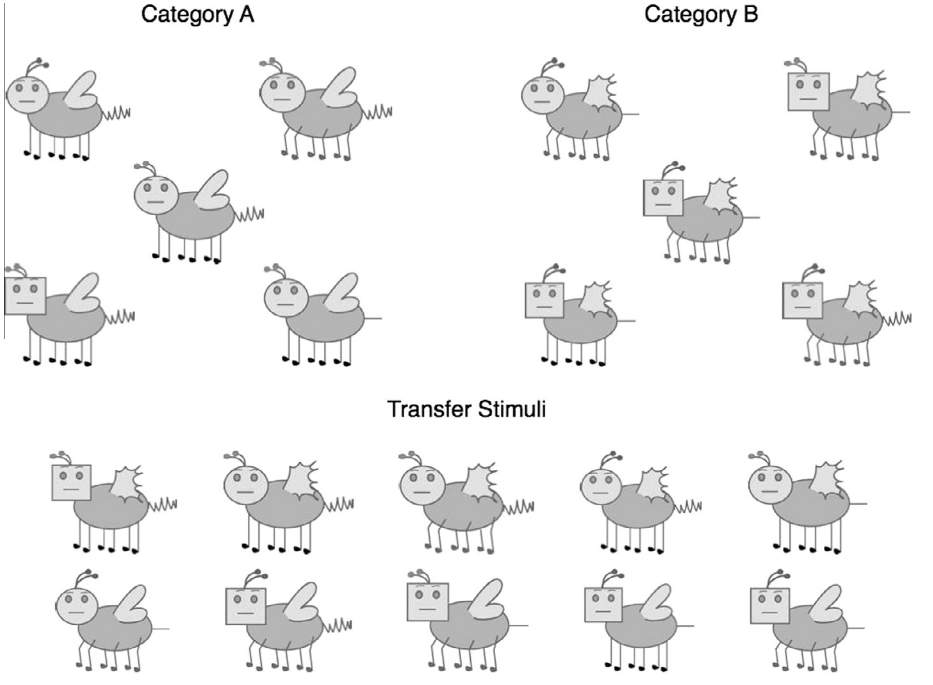

Fig. 1. Example of the training items for each category used during the training phase along with the transfer items for the transfer phase. These bugs varied along five binary dimensions: antenna (forward-facing/red or backward-facing/purple), head (circle or square), wings (rounded or pointy), legs (bent with blue feet or straight with black feet), and tail (bent or straight). The stimuli shown here are in greyscale, but the the stimuli shown to participants in the experiment were in colour: the body was light blue, unless otherwise indicated above.

Table 1
Structure for the stimuli used in Experiments 1 and 2.

Stimulus	CA	d_2	d_3	d_4	d_5
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

of their progress throughout the experiment. Pilot work suggested that these progress circles offered a mild incentive for children to complete the experiment, and Minda and colleagues (2008) used stickers for a comparable effect.

On completion of the 50 training trials, children were told that they would be helping some new bugs to find their homes. They were told to classify these new bugs using what they had learned during the training phase. The transfer phase consisted of one presentation of each of 10 transfer stimuli shown once in random order. Each trial followed the same sequence of events as in the training phase except that no feedback was given (although on each trial the stimuli smiled when they moved to the location selected by the participant regardless of whether the participant's classification decision was correct or incorrect).

At the start of the experiment, participants were asked to indicate to the experimenter if they did not wish to continue, although the experimenter tried to be as encouraging as possible to keep children interested in the game. Children were allowed to take a short break as needed during the experiment, and all children were given a short break at the end of the training phase of the experiment.

Adults were tested using the same basic procedure as children except that adults were tested on individual 17-inch iMac computers in a room with up to 3 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. Adults took a break between the learning and transfer phases to read the transfer instructions.

Results

Learning analysis

Average performance was calculated for adults and children at each block. The resulting learning curves for children and adults are shown in Fig. 2A and suggest an early advantage for adults, but they also show that both groups learned the categories well. A 2 (Age) $\times$ 5 (Block) mixed analysis of variance (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 Age $\times$ Block interaction was found, $F(4,128) = 0.27$, $p = .90$, indicating that children and adults did not differ significantly in how well they learned these categories.[2]

Transfer analysis

Fig. 2B shows that adults made significantly more classifications based on the CA than children. A Mann–Whitney *U* test found this difference to be significant, $U = 76.0$, $p = .007$.[3] We also conducted a *t* test to examine this difference; however, because both analyses led to the same conclusions, we reported only the Mann–Whitney *U* test results (due to the non-normal distribution of our data). Fig. 2B also shows each participant's individual performance and indicates that whereas most adults made classifications that were based on the perfectly predictive rule (i.e., 100% CA performance), a different pattern emerged for children. Although some children did learn the rule, many did not. Some classified the transfer stimuli in exactly the opposite way (i.e., 0% CA), suggesting that they may have relied on the family resemblance to do so. Other participants showed performance that was a mixture, with some rule-based responses and some non-rule-based responses.

Strategy analysis

For each participant, we calculated the correlation between the participant's responses to each stimulus for the final training block and the full transfer block (i.e., 20 trials) and the responses produced by each of six possible ideal observer categorization strategies: single-dimensional rule based on the CA, single-dimensional rule based on one of the four suboptimal dimensions (SDs), or FR similarity. We assumed that a strong correlation ($r > .50$) between a participant's pattern of responding and strategy indicated a possible reliance on that strategy. If $r > .80$, the model with the highest

[2] When we ran the same analysis with data from non-learners included, we found a significant main effect for age because most of the non-learners were children.

[3] This result was still significant even when we included all of the non-learners.

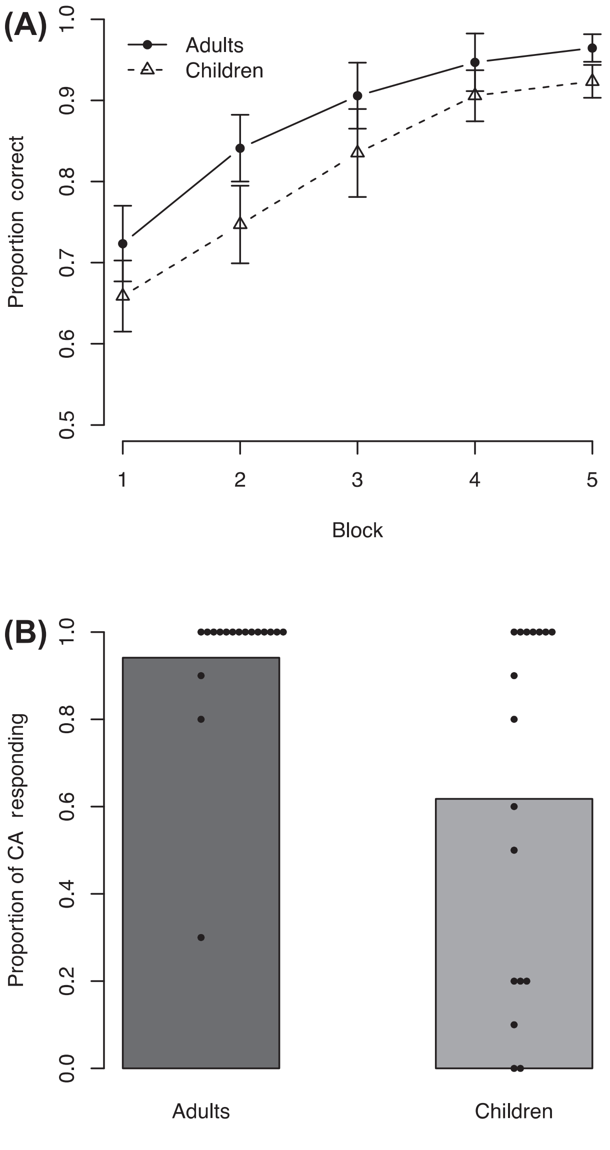

Fig. 2. (A) Average categorization performance for children and adults across each learning block. (B) Proportion of criterial attribute (CA) responding by children and adults during the transfer phase. Points on the bar graph represent data from individual participants. Error bars denote standard errors.

correlation was deemed to be the best fitting model. If the highest correlation value had an $r < .80$, additional criteria were considered to determine strategy use.[4] We then counted the number of participants whose data were best fit by a CA strategy, one of the four suboptimal SD strategies, or an FR

[4] The highest positive correlation value below .80 was flagged. If the flagged value was below .50, was tied with another value, and/or was not the highest absolute value, participants were labeled as "other" strategy users.

Table 2
Number of participants using each strategy in Experiment 1.

Age group	CA	FR	SD	Other
Children	9 (.53)	3 (.18)	4 (.24)	1 (.06)
Adults	16 (.94)	0 (.00)	0 (.00)	1 (.06)

Note. Proportions are in parentheses.

strategy. Participants whose data were not fit by any of the strategies (i.e., no correlation >.50) or whose data were fit equally well by two strategies were counted as "other." Table 2 summarizes these counts and shows that the CA model best captured the performance of most adults and that a variety of models described children's data. A chi-square test provided marginal evidence that adults and children used different categorization strategies, $\chi^2(3) = 6.74$, $p = .08$.

Feature salience analysis

We examined the relationship between the tendency to find the CA and the feature that corresponded to the CA. Our pilot study (details are in the Appendix) showed that some features (head, wing, and tail) were more perceptually salient than other features (legs and antenna). Fig. 3 shows that only children who were assigned the wing or the head as the CA tended to categorize according to the CA. No such relationship existed with adults (there was no apparent feature preference). An ANOVA on proportion of CA responding with age and CA feature (e.g., head, wing) as between-participants factors found an interaction between age and feature, $F(4,24) = 7.20$, $p < .001$, suggesting that children and adults differed in how the identity, and perhaps salience, of the CA affected their ability to find the CA. We also observed main effects of age and feature, $F(1,24) = 18.32$, $p < .001$, and $F(4,24) = 3.20$, $p = .03$, respectively.

We followed this omnibus test with contrasts comparing the proportion of CA responding for features whose pilot ratings were highest (head, wing, and tail) with that for those whose ratings were lowest (legs and antenna). For adults, there was no difference in proportion of CA responding for the high-salience and low-salience features, $F(1,15) = 0.81$, $p = .38$. For children, proportion of CA responding was significantly higher for high-salience features than for low-salience features, $F(1,15) = 12.62$, $p = .003$. Adults were equally likely to find the CA for all dimensions, but children were more likely to use the CA when it was a salient dimension.

Discussion

In Experiment 1, we asked children and adults to learn a set of categories that could be acquired by finding a perfect single-feature rule, by finding a suboptimal rule, or by learning the overall family resemblance structure. As we predicted, adults tended to use the optimal rule; children were significantly less likely to classify the transfer stimuli according to the CA. However, children did not show any special preference for learning the FR structure. Indeed, only 3 children seemed to show this preference. These results are only partially in line with earlier developmental work on the holistic/analytic distinction in category learning, which found that adults tended to prefer rules and children did not (Kemler Nelson, 1984). If children really were holistic categorizers and defaulted to the implicit category learning system, they would shy away from trying to find a rule (optimal or suboptimal) and would instead rely on the implicit system to learn which bugs go together in the categories and would show a preference for FR learning.

We found very little evidence for FR learning, and so our results run counter to Kemler Nelson's *holistic-to-analytic-shift* account and provide support for an alternative account of perceptual development called the *differential sensitivity* account (Cook & Odom, 1992). The differential sensitivity account proposes that both children and adults can perceive different stimulus dimensions and will preferentially use dimensional rules; however, children will apply these rules inconsistently and are less sensitive to dimensional differences. In addition, children fixate on single dimensions, and that

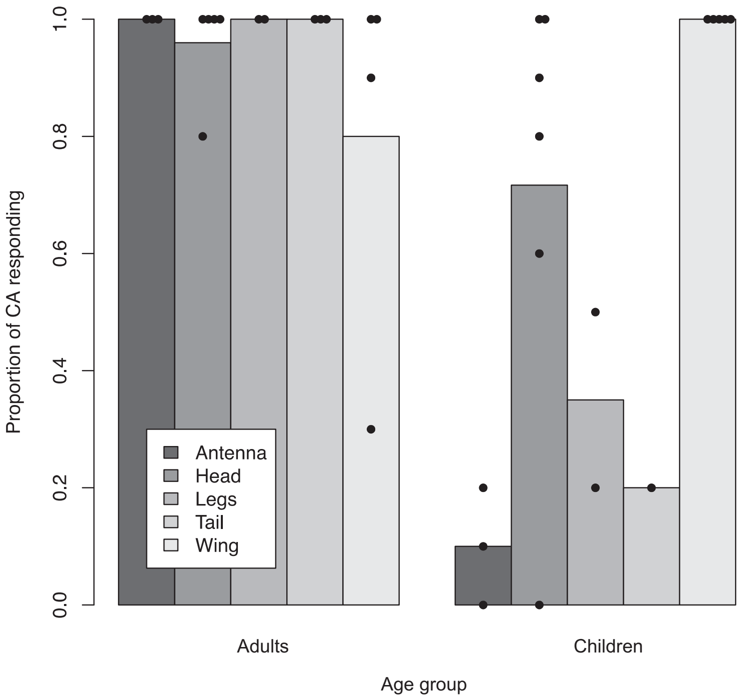

Fig. 3. Proportion of criterial attribute (CA) responding for children and adults according to the feature assigned as the criterial attribute.

consistency in following classification rules improves with age (Thompson, 1994). The differential sensitivity account has received support from a number of studies (Raijmakers, Jansen, & van der Maas, 2004; Schwarzer, Kuefer, & Wilkening, 1999; Thompson & Markson, 1998; Visser & Raijmakers, 2012; Ward & Scott, 1987). Similar to our study, Ward, Vela, and Hass (1990) presented children (5- to 9-year-olds) and adults with stimuli that could be classified by any of four dimensions or by overall family resemblance. Findings were consistent with the differential sensitivity account, showing that all participants primarily used analytic rule-based classifications. Although the number of accurate analytic classifiers was greater in adults compared with children, there was no evidence of holistic classifiers among participants.

Our current findings lead us to believe that children at this age are simply not FR learners and are not holistic classifiers but instead try to learn the rules. They differ from adults because they are not as good at finding the rules and applying them consistently. However, another possibility is that our stimuli did not highlight the family resemblance structure within each category. This is a concern because our initial worry with existing research on this topic (Huang-Pollock et al., 2011; Minda et al., 2008; Visser & Raijmakers, 2012) was that the stimuli used might not have given the FR structure a fair chance. Although Experiment 1 in the current work was an improvement, with each bug having exactly the same body shape and size, it could be that the category was not perceived as being well differentiated enough to result in strong FR performance. Perhaps a different set of stimuli would produce a better test of the FR hypotheses.

Another interesting result was the ability of children to find and use the CA when it corresponded to one of the perceptually salient features. In other words, children appeared to be more stimulus bound when learning categories relative to adults. This attentional capture allows for CA performance without much of a demand on hypothesis testing and without the need to switch away from a salient feature. In line with this finding, Hammer and Diesendruck (2005) showed that children's categorization performance is affected by the relative distinctiveness of the stimulus dimensions. Work with adults has also shown that feature salience and feedback information may influence how well adults learn categories (Hammer, Sloutsky, & Grill-Spector, 2012). In addition, prior research has demonstrated that inefficiency in discrimination learning among young children has been linked to dimensional preferences related to different saliency of stimulus dimensions or attentional bias (Block, Erickson, & McHoes, 1973; Schmittmann, van der Maas, & Raijmakers, 2012; Schmittmann, Visser, & Raijmakers, 2006).

We decided to further explore the role of feature salience during category learning in a second experiment by testing participants on a different set of stimuli with features that were more homogeneous in terms of perceptual salience and by including additional tests of featural knowledge. We predicted that children should show less CA performance than in the first experiment and instead show more performance based on single features or family resemblances. However, children were not expected to have a preference for any particular feature, in contrast to the results of Experiment 1.

Experiment 2

Experiment 2 was designed to reproduce and extend the key results of Experiment 1 but with a few differences. First, we designed new stimuli that we hoped would have a greater family resemblance within the category. Second, this set of stimuli was created with features that children rated as being approximately equal in salience. Third, we included both training and transfer items during the transfer phase. Fourth, in the second part of the transfer phase, participants performed a single-feature test in which they indicated plausible category membership for features presented in isolation. We expected that children and adults would differ in their tendency to learn criterial and non-criterial attributes, with adults again showing a greater preference for CA rules compared with children. Finally, each participant's working memory was measured with forward digit span and backward digit span tasks. Our main prediction was that lower working memory scores should be associated with greater difficulty in finding the CA.

Method

Participants

Participants included 38 children with a mean age of 5.60 years ($SD = 0.43$) recruited from the University of Western Ontario's YMCA Child Care Centre and a Montessori School in London, Ontario, Canada. Data from 11 children were discarded because their performance on the training items combined over the final training block and transfer block was not significantly higher than chance performance.[5] This left 27 children (11 boys and 16 girls) who showed evidence of category learning.[6] Participants also included 37 students from the University of Western Ontario who participated for course credit or money. Data from 2 adults were discarded because their performance was not significantly higher than chance performance. This left 35 adults (16 men and 19 women) who showed evidence of category learning. Forward digit span and backward digit span were not measured in 1 child who was not available for a second session, and 3 other children were missing backward digit span scores because they did not understand the backward digit span instructions.

Materials

Participants learned to classify drawings of fish that varied along five binary dimensions. An example set of stimuli is shown in Fig. 4. The training and transfer stimuli used in Experiment 2 had the same logical structure as those used in Experiment 1 and as shown in Table 1.

[5] Chance performance was .68, determined using a test of binomial proportion.

[6] In Experiments 1 and 2, children who learned the category set did not differ from non-learners on age. In Experiment 2, children who learned the category set did not differ from non-learners on working memory, and neither did adults.

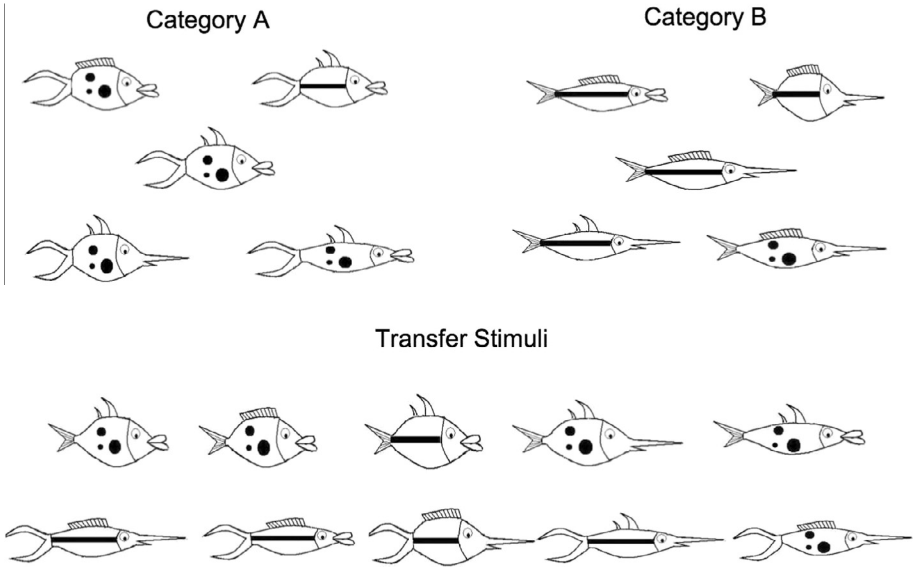

Fig. 4. Example of the training items for each category of the training phase along with the transfer items of the transfer phase. These fish varied along five dimensions: body shape (round or oval), tail (straight or curved), body pattern (striped or dots), top fin (flat or pointy), and mouth (pointed or lips). The stimuli shown to participants were in black and white.

Procedure

Children were first told that they would be playing a game in which they would see pictures of different fish on the computer screen. They were told that some of these fish lived in the aquarium and some lived in the fishbowl. Children's job was to help these fish find their homes by clicking on the correct place on the screen. As in Experiment 1, the learning phase consisted of five blocks in which each of 10 possible training stimuli was presented in random order, once per block, for a total of 50 trials. On each trial, a picture of a fish appeared in the middle of the screen and pictures of the two category labels (aquarium and fishbowl) were shown in the top left and top right corners of the screen. In addition, a row of 10 small white circles was shown along the top of the screen (as in Experiment 1). On each trial, participants clicked on the fish's category label. Correct responses were indicated with a green check mark displayed in the center of the screen for 3 s, and incorrect responses were indicated with a red X. In addition, the correct category label was circled during this period regardless of whether the response was correct or incorrect.

On completion of the 50 training trials, participants were told that they would be seeing some additional fish and that they should help the fish to find their homes using what they had learned during the training phase. The transfer phase consisted of two blocks of 10 stimuli in which the 10 training stimuli and the 10 novel transfer stimuli were shown once each in random order (see transfer stimuli in Fig. 4). Each trial followed the same sequence of events as in the training phase except that no feedback was given.

Participants then completed the single-feature phase and were shown each individual feature of the fish (e.g., a straight tail, a pointed mouth) on the computer screen one at a time, and they indicated in which category the feature was most often found by clicking on either the fishbowl or aquarium. The single-feature phase consisted of one block of 10 trials, and feedback was not given (as in the transfer phase).

The current experiment also involved two tests of working memory (forward digit span and backward digit span) completed 2 to 3 weeks after the categorization task. For the forward digit span task, children heard recordings of number sequences varying in length and repeated the sequences back to the experimenter. Sequences were recorded by a female experimenter at a rate of approximately 1

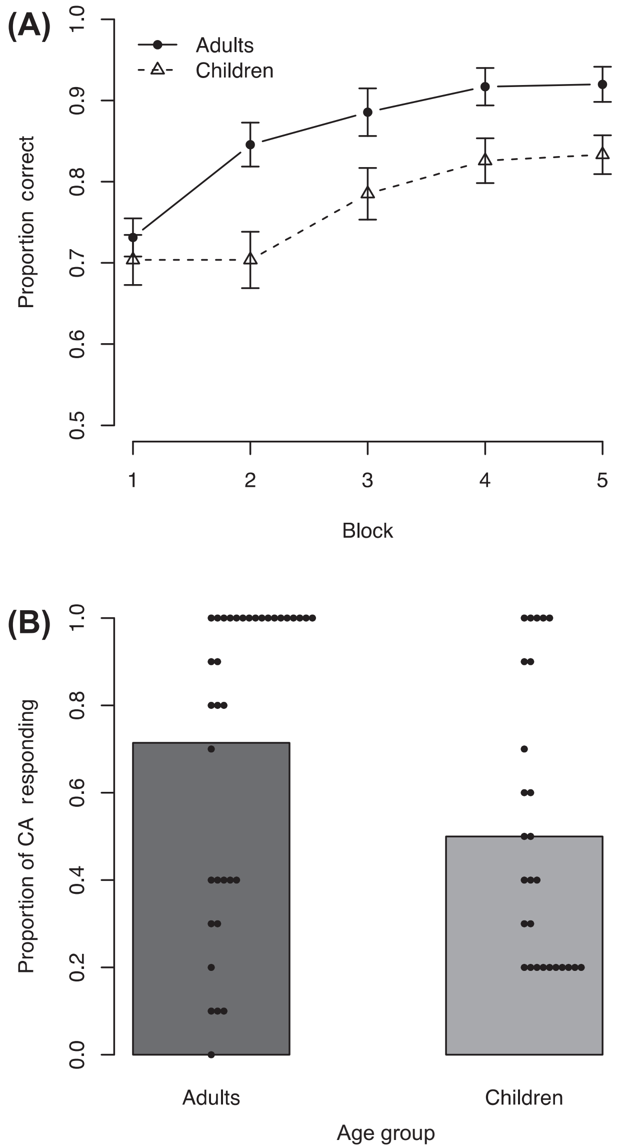

Fig. 5. (A) Average categorization performance for children and adults across each learning block. (B) Proportion of criterial attribute (CA) responding by children and adults during the transfer phase. Points on the bar graph represent data from individual participants. Error bars denote standard errors.

digit per second. The task began with three practice trials of increasing length (1, 2, and 3 digits) in which children repeated back the sequence and received feedback. In the test trials, children heard two sequences at each sequence length (beginning with 1), and as long as they repeated at least one of them correctly, they continued on to the next sequence length. The task was over once children were unable to repeat either of the sequences at a given length. The digit span score was the total number of correct responses given.

Table 3
Number of participants using each strategy in Experiment 2.

Age group	CA	FR	SD	Other
Children	8 (.30)	2 (.07)	10 (.37)	7 (.26)
Adults	23 (.66)	4 (.11)	6 (.17)	2 (.06)

Note. Proportions are in parentheses.

The procedure was exactly the same for the backward digit span except that there were four practice trials (two of 2 digits and two of 3 digits) and children were instructed to repeat the sequence in reverse order so that the last number was said first and the first number was said last. Adults were tested in the same way but on the same day as their category learning sessions rather than 2 to 3 weeks later. These time frame differences were simply a matter of convenience.

Results

Learning analysis

Learning curves were calculated by averaging performance for each age group at each block. The resulting learning curves, shown in Fig. 5A, suggest that adults performed better than children, especially later in learning. A 2 (Age) × 5 (Block) mixed ANOVA revealed a main effect for block, $F(4,240) = 22.34$, $p < .001$, and a main effect for age, $F(1,60) = 9.88$, $p = .003$. There was no interaction between age and block, $F(4,240) = 1.93$, $p = .11$.[7]

Transfer analysis

As a measure of general competence, we calculated the proportion correct on the training items that were presented during the transfer phase (old items) and compared that with performance on the last block of the training phase. A non-significant result would suggest that performance was in the same general range during both phases. Adults performed slightly better on the old items that were presented during the transfer phase ($M = .97$, $SD = .06$) than on the final training block ($M = .92$, $SD = .13$), $t(34) = 2.31$, $p = .03$. Children performed equally well on the old items that were presented during the transfer phase ($M = .82$, $SD = .12$) and on the final training block ($M = .83$, $SD = .12$), $t(26) = 0.44$, $p = .66$.

The proportion of CA responding by each group of participants is shown in Fig. 5B. As in Experiment 1, we conducted a Mann–Whitney U test because our data was non-normally distributed.[8] Adults tended to make more classifications based on the CA than children, $U = 312.5$, $p = .02$.[9] In addition, Fig. 5B shows each individual data point and suggests that most adults made classifications that were rule based (i.e., 100% CA performance). Although a few children learned the rule, most did not. Many participants seemed to show performance that was a mixture of strategies, with some rule-based responses and some non-rule-based responses or rule-based performance using the wrong feature, which results in a proportion of CA responding of .20. However, only 2 children showed any evidence of pure family resemblance learning.

Strategy analysis

We carried out the same strategy analysis used in Experiment 1 in which we correlated each participant's pattern of responding on the final training block and transfer block (including old and new items) with the patterns predicted by six ideal observer models that relied on either the CA, one of the four suboptimal rules, or FR. Table 3 shows that adults tended to respond according to a CA strategy more often than children; children were equally distributed across all strategies, excluding FR. We

[7] This result held when we analyzed the data from all of the participants, including all of the non-learners.

[8] In Experiment 2, we also ran t tests in addition to all of the Mann–Whitney U tests reported. However, both analyses led to the same conclusions, so we reported only the Mann–Whitney U test results (because this test was more fitting given the non-normal distribution of our data).

[9] This result held when we analyzed the data from all of the participants, including the non-learners.

Table 4
Single-feature performance by age and strategy use in Experiment 2.

Age group	CA	FR	SD	Other
Children	.68 (.12)	.60 (.14)	.66 (.21)	.54 (.11)
Adults	.83 (.20)	1.00 (.00)	.68 (.23)	.90 (.14)

Note. Standard deviations are in parentheses.

analyzed children's and adults' strategy use with a chi-square test and confirmed that adults and children used different categorization strategies, $\chi^2(3) = 10.85$, $p = .01$.

Single-feature analysis

We calculated the proportion correct (defined as selecting the category that was most associated with each individual feature) for each single-feature item and averaged across participants. Overall, adults ($M = .83$, $SD = .20$) made more correct single-feature classifications than children ($M = .63$, $SD = .16$).[10] A Mann–Whitney *U* test confirmed a group difference on single-feature performance, $U = 216.0$, $p = .00$. We also examined the performances on the single-feature test for participants in each strategy bin shown in Table 3. The results are summarized in Table 4, and these results show that children essentially performed at chance on the single-feature test regardless of which strategy they adopted (.60 would result for a participant who performed perfectly on one single feature and was guessing on the other four). Adults showed much better performance on the single-feature test. Even the CA learners (the largest group of adults) performed well on the other non-CA features. The 6 adults who relied on a single non-criterial dimension were closest to children's performance levels.

Working memory analysis

Forward digit span and backward digit span scores were calculated for children and adults.[11] Not surprisingly, adults ($M = 12.54$, $SD = 2.21$) had higher forward digit span scores than children ($M = 8.85$, $SD = 1.12$), $t(53) = 8.52$, $p < .001$, and adults ($M = 8.03$, $SD = 2.51$) had higher backward digit span scores than children ($M = 2.96$, $SD = 0.71$), $t(42) = 11.28$, $p < .001$. Among children, final block categorization performance was significantly correlated with performance on the forward digit span task ($r = .50$, $p = .005$) and marginally significantly correlated with performance on the backward digit span task ($r = .30$, $p = .08$). In addition, performance on the single-feature test was significantly correlated with backward digit span task performance ($r = .37$, $p = .043$) but not with forward digit span task performance ($r = .27$, $p = .096$). Children's digit span performance was not correlated with transfer performance or proportion of criterial attribute use ($p > .40$ in all cases). Among adults, we found a marginally significant correlation between transfer performance and backward digit span ($r = .25$, $p = .076$). No other correlations were significant in adults ($p > .09$).

Discussion

Overall, the results of Experiment 2 replicated many of the core findings in Experiment 1. Adults were more likely to classify transfer stimuli in accordance with the CA, and the majority of adults' performance was best described by a CA model. But despite showing the strong preference for the CA in classification, adults also displayed better category-level knowledge of the non-CA features in the task. In short, most of our children were able to learn the categories—better than chance—but very few showed any indication that they were able to find a perfect rule among five possible rules. This key result is consistent with several predictions of COVIS but is inconsistent with one aspect of the developmental results reported by Minda and colleagues (2008). A core prediction was that adults would

[10] For ease of comprehension, we reported the mean scores of the two age groups (although the Mann–Whitney *U* test did not compare mean scores).

[11] Digit span data were not collected for some children (1 child did not complete the digit span task, and 3 children did not understand the backward digit span task instructions).

show a bias for the rule learning of the verbal system. That prediction was confirmed here. All of the features were verbalizable, and (with a few exceptions) our adults were able to learn the categories by finding the CA. A second prediction of COVIS that was confirmed here is that children, relative to adults, should be less able to find and use verbal rules. Indeed, many 5-year-old participants were unable to find the correct rule.

Given the modest support for a relationship among working memory, categorization performance, and strategy, the data suggest that working memory affects one's ability to learn new categories in a general way but may also have some subtle effect on the ability to learn the CA. This claim is in line with what was found by Rabi and Minda (2014). This claim is also largely consistent with research by Lewandowsky and colleagues (Craig & Lewandowsky, 2012; Lewandowsky, 2011), although they argued that working memory is the primary determinant of overall categorization performance in tasks like these.

Another prediction of COVIS that was possibly confirmed was the prediction that both systems operate simultaneously. We made this claim because of the fairly high (.84) performance on the single-feature test by adults who ultimately learned the CA. If adult participants had only encoded the CA, we would have expected a lower proportion correct overall (they would be at chance on non-CA features). Good performance on the single-feature test indicates the presence of category-level knowledge of the other non-CA features and may suggest that even after the rule was learned, the individual exemplar traces were encoded and incorporated into the category representation. The system that is best designed for such an encoding is the implicit system. Early research in exemplar learning also argued for flexible restructuring of conceptual knowledge (Brooks, 1978). Other very recent work has explored this idea of knowledge restructuring, from a different perspective and using very different stimuli (Sewell & Lewandowsky, 2011). Alternatively, the high performance on the single-feature test by adults may be explained by the differential sensitivity theory (Cook & Odom, 1992). That is, the theory posits that with age, individuals are able to discover a greater number of dimensional relations and there is a developmental increase in sensitivity to those dimensional relations. Furthermore, in the current study, adults may have had greater awareness of and sensitivity to the stimulus features even though they were not using them when making categorization judgments, allowing them to perform quite well on the single-feature test.

Another difference between Experiments 1 and 2 was that the children in Experiment 2 did not perform as well during the learning phase as the children in Experiment 1. At least three possibilities exist to explain this difference. First, the fish stimuli from Experiment 2 might have presented some children with a greater challenge because the fish features were less separable than the bug features, and that may have resulted in slightly lower performance. Second, we relied on a different participant sample. The University Laboratory School was used in Experiment 1 but not in Experiment 2. These children are familiar with acting as research participants (that is part of the school's mission), and they may have simply grasped the nature of the task more readily.

Finally, despite our attempts to make these stimuli more amenable to family resemblance learning, we found no evidence that children showed a preference for FR learning. Only 2 of our child participants learned the FR structure. In fact, we found evidence that these stimuli produced a small increase in FR learning by adult participants. Not only did 4 adults produce FR performance during the transfer phase, but these same 4 participants performed the best on the single-feature test, suggesting that they had encoded strong category-level information about all of the features. In short, true family resemblance learning certainly is possible but was observed in adults rather than in children.

General discussion

The results of both experiments indicated that children are not as effective as adults at searching for and applying a categorization rule. However, children did not adopt a family resemblance strategy either. Rather, they displayed a variety of learning strategies, in some cases learning the correct rule and in other cases learning a suboptimal rule. In this way, our results are similar to those of Visser and Raijmakers (2012) in that both studies found that children tend to use the verbal system inefficiently rather than use the implicit system. In addition, Visser and Raijmakers' results suggest that some features are more likely than others to be used for the categorization rule. In our study, we specifically investigated the possibility that feature salience is an important factor in determining the likelihood that a feature will be used for the categorization rule. In Experiment 1, children, but not adults, were much more likely to find the CA when it was a salient feature. In Experiment 2, where salience was equated across features, this was no longer the case. Our research extends the results of Visser and Raijmakers in part by illustrating that feature salience is an important determiner of rule use by children but not by adults. These results have implications for our understanding of the role of attention in category learning (Blair & Homa, 2005; Blair, Watson, & Meier, 2009).

Relationship to multiple systems theory

Our results are generally consistent with a multiple systems theory of category learning such as COVIS (Ashby & Ell, 2001; Ashby et al., 1998; Sloutsky, 2010). COVIS predicts that the verbal system should learn the categories in Experiments 1 and 2 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 family resemblance structure. The family resemblance structure is difficult to verbalize because of the number of propositions in the verbal rule, but it is less difficult to learn if one bases classifications on the overall similarity of an item to its category.

Children, unlike adults, are expected to have more difficulty in relying on the rule-based 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, children are less able to engage in hypothesis testing and less able to inhibit responses to incorrect rules. The predicted difficulty that children have with the verbal system could result in children relying on the implicit associative system, in which case FR performance would result. The data from our experiments suggest that 5-year-old children tend to prefer looking for rules, but their rule search is ineffective and often suboptimal. There was very little evidence of FR learning in children. This does not mean that FR learning by children is impossible. However, this does mean that when children are faced with a stimulus set that can be learned by either a single-feature rule or a family resemblance strategy, they will default to a rule learning strategy. It is certainly possible that other stimulus sets or longer learning sessions might have found different results.

Although children can learn a single-feature rule, they often have difficulty in switching to another rule if the one they initially used was not the CA. As a result, children often perform less well than adults, and their subsequent classifications of the transfer stimuli were not likely to be based on a CA rule. Other children were unable to negotiate the conflict between evidence provided by the rule and evidence provided by overall similarity. This would be expected to happen in children more so than adults because children's prefrontal cortex areas are less well developed (compared with adults) and they would have difficulty in inhibiting the categorization response to other features.

The effects of a weaker inhibitory process in children relative to adults can be accounted for by COVIS with the computational version's perseveration parameter, γ (Ashby et al., 1998). The γ parameter only has an effect on the verbal system, and it controls the probability of switching to a new rule by allowing the current rule to have greater sticking power. That is, when γ takes on a high value, it is unlikely that the system will switch to another rule. Ashby and colleagues' (1998) simulations of data contrasting the category learning performance by depressed and non-depressed participants relied on the γ parameter to model the tendency of depressed participants to fail to find optimal rules, much like the children in our current study (Ashby et al., 1998; Smith, Tracy, & Murray, 1993). A computational treatment of our data would likely rely on the same parameter settings, although that modeling is beyond the intended scope of the current article.

Our data also revealed a subset of participants who were classified as using an "other" strategy. Similar results were obtained by Raijmakers and colleagues (2004), who examined rule use in perceptual classification among adults and 4- to 12-year-old children and found that a large subset of adults and children relied on one-dimensional rules when making classification decisions, whereas no evidence of holistic strategy use was found. A group of participants who showed no consistency were identified and were termed the "muddling through" group. Raijmakers and colleagues speculated that these participants may have been unsystematically switching between rules during the course of the task. With respect to the current study, it may be the case that children classified as "other" strategy users were switching between rules more frequently or unsystematically, thereby preventing them from being clearly classified as using a rule-based or similarity-based strategy. At this point, our data do not allow a strong conclusion about this subset of participants.

The holistic/analytic distinction

These results relate to earlier developmental work on the holistic/analytic distinction in category learning (Brooks, 1978; Kemler Nelson, 1984, 1988; Smith, 1989; Smith & Kemler Nelson, 1984, 1988; Smith & Shapiro, 1989; Ward & Scott, 1987). Some of this research found that children tended to prefer overall similarity and adults tended to prefer rules (Kemler Nelson, 1984). This research linked children's performance on category learning tasks with a holistic process that encourages stimuli to be learned as whole exemplars and discourages rule-based performance. In the current research, however, the evidence points decidedly away from a strictly holistic interpretation; many children in the current study were finding and using rules. Our data instead supports the differential sensitivity account of perceptual classification by suggesting that children are capable of applying rule-based category learning strategies and rely on rules over family resemblance. However, in contrast to adults, children's executive functioning abilities are still developing, and so children may apply these rules inconsistently or rely on suboptimal rules. Furthermore, with development, categorization performance improves as children are able to detect more dimensional relations and become perceptually sensitive to them.

Working memory

One possible explanation for the pattern of results that we observed is the working memory difference between children and adults (Gathercole, 1999; Swanson, 1999). We found that adults had greater working memory capacity than children, and adults also were more likely to find the CA and have greater featural knowledge. Additional recent work has investigated the relationship between working memory and category learning and found similar results. For example, Lewandowsky (2011) found a strong relationship between working memory capacity (measured in a variety of ways) and categorization performance on a range of category types. This study found that working memory capacity not only mediated performance on rule-described tasks but also mediated performance on non-rule-described tasks.

More recent work by Rabi and Minda (2014) has extended prior category learning findings by examining children's category learning ability in concert with measures of working memory and inhibitory control. Findings revealed that rule-based categorization performance improved with age, as did the use of the task-appropriate strategy. That is, earlier in childhood, children often relied on guessing while categorizing, suggesting that they struggled with identifying the correct rule or did not apply a rule consistently (similar to our "other" group of participants). However, by 10 years of age, children were able to perform similarly to adults on the categorization task. Executive functioning abilities were also measured, revealing that both working memory (i.e., digit span score) and inhibitory control (i.e., Flanker task score and Simon task score) were related to rule-based categorization performance and improved with age.

Conclusions

When faced with learning a category, adults often try to accomplish the task by searching for a verbalizable rule. When the rule is viable, this becomes the classification strategy. Children also try to learn a rule, but they are less likely to find an optimal one among several candidates. Our current data and our earlier research (Minda et al., 2008) also suggest that despite the age difference, children and adults can learn perceptual categories in a comparable task. More research is needed concerning the examination of developmental differences in category learning, which can illuminate the various cognitive systems that are involved in this fundamental cognitive process.

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Appendix

Pilot feature rating study

We conducted a pilot study with 44 University of Western Ontario undergraduate students and 24 children with a mean age of 5.32 years ($SD = 0.44$). Participants rated feature salience in both sets of stimuli.

Experiment 1 stimuli

Adults were shown two of the bugs simultaneously with opposing values on each of the five dimensions. Participants were asked to examine the contrasting bugs and to rate the salience of each dimension on a scale of 1 (*not at all salient*) to 7 (*extremely salient*). Children completed the same task except that they rated how noticeable each dimension was by drawing a mark on a line divided into seven sections (rather than giving a number). The dimensional salience ratings for children and adults are presented in Table A1. For adults, the resulting salience rating of the five dimensions was not equal, $F(4,168) = 26.59$, $p < .001$. A Tukey's HSD (honestly significant difference) test revealed that the head, wings, and tail were significantly more salient to adults than the antenna and legs. Children rated the noticeability of the five dimensions to be marginally unequal, $F(4,92) = 2.27$, $p = .067$. We further explored these data with a Tukey's HSD test because of the marginal significance of the result and because children showed the same quantitative pattern as adults. Just like adults, children found that the head, wings, and tail were significantly more noticeable than the antenna and legs. The wing–antenna difference was not significant, but all other relevant comparisons had $ps < .05$.

Experiment 2 stimuli

We used the same rating task as above. The dimensional salience ratings for children and adults are presented in Table A2. Adults indicated that the salience of the five dimensions was not equal, $F(4,168) = 23.78$, $p < .001$. The mouth was more salient than the body pattern and tail, which were

Table A1
Dimensional salience ratings by children and adults in Experiment 1.

Age group	Head	Wings	Tail	Antenna	Legs
Children	5.46 (0.42)	5.17 (0.48)	5.38 (0.46)	4.42 (0.43)	4.00 (0.48)
Adults	5.63 (0.17)	5.40 (0.22)	4.84 (0.25)	3.72 (0.28)	3.40 (0.23)

Note. Standard errors are in parentheses.

Table A2
Dimensional salience ratings by children and adults in Experiment 2.

Age group	Mouth	Body pattern	Tail	Body shape	Fin
Children	4.58 (0.50)	5.54 (0.43)	4.83 (0.47)	3.88 (0.49)	5.04 (0.43)
Adults	6.23 (0.20)	5.07 (0.28)	4.95 (0.23)	3.86 (0.30)	4.23 (0.24)

Note. Standard errors are in parentheses.

more salient than the body shape but not the fin. However, children did not rate the mouth, body pattern, tail, body shape, and fin as being noticeably different, $F(4,92) = 1.87$, $p = .12$.

References

Ashby, F. G., Alfonso-Reese, L. A., Turken, A. U., & Waldron, E. M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review, 105*, 442–481.
Ashby, F. G., & Ell, S. W. (2001). The neurobiology of human category learning. *Trends in Cognitive Sciences, 5*, 204–210.
Ashby, F. G., & Ennis, J. M. (2006). The role of the basal ganglia in category learning. *Psychology of Learning and Motivation, 47*, 1–36.
Ashby, F. G., & Maddox, W. T. (2005). Human category learning. *Annual Review of Psychology, 56*, 149–178.
Blair, M. R., & Homa, D. (2005). Integrating novel dimensions to eliminate category exceptions: When more is less. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 258–271.
Blair, M. R., Watson, M. R., & Meier, K. M. (2009). Errors, efficiency, and the interplay between attention and category learning. *Cognition, 112*, 330–336.
Block, K. K., Erickson, J. R., & McHoes, L. N. (1973). Quantitative models for children's concept learning from a developmental perspective. *Developmental Psychology, 8*, 187–201.
Brooks, L. R. (1978). Nonanalytic concept formation and memory for instances. In E. Rosch & B. Lloyd (Eds.), *Cognition and categorization* (pp. 169–211). Hillsdale, NJ: Lawrence Erlbaum.
Bunge, S. A., & Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science, 15*, 118–121.
Casey, B. J., Davidson, M. C., Hara, Y., Thomas, K. M., Martinez, A., Galvan, A., et al (2004). Early development of subcortical regions involved in non-cued attention switching. *Developmental Science, 7*, 534–542.
Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. *Biological Psychology, 54*, 241–257.
Cook, G. L., & Odom, R. D. (1992). Perception of multidimensional stimuli: A differential-sensitivity account of cognitive processing and development. *Journal of Experimental Child Psychology, 54*, 213–249.
Craig, S., & Lewandowsky, S. (2012). Whichever way you choose to categorize, working memory helps you learn. *Quarterly Journal of Experimental Psychology, 65*, 439–464.
Crone, E. A., Donohue, S. E., Honomichl, R., Wendelken, C., & Bunge, S. A. (2006). Brain regions mediating flexible rule use during development. *Journal of Neuroscience, 26*, 11239–11247.
Frye, D., Zelazo, P., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development, 10*, 483–527.
Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences, 3*, 410–419.
Hammer, R., & Diesendruck, G. (2005). The role of dimensional distinctiveness in children and adults' artifact categorization. *Psychological Science, 16*, 137–144.
Hammer, R., Sloutsky, V., & Grill-Spector, K. (2012). The interplay between feature-saliency and feedback information in visual category learning tasks. In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), *Proceedings of the 34th annual conference of the Cognitive Science Society*. Austin, TX: Cognitive Science Society.
Huang-Pollock, C. L., Maddox, W. T., & Karalunas, S. L. (2011). Development of implicit and explicit category learning. *Journal of Experimental Child Psychology, 109*, 321–355.
Johansen, M. K., & Palmeri, T. J. (2002). Are there representational shifts during category learning? *Cognitive Psychology, 45*, 482–553.
Kemler Nelson, D. G. (1984). The effect of intention on what concepts are acquired. *Journal of Verbal Learning & Verbal Behavior, 100*, 734–759.
Kemler Nelson, D. G. (1988). When category learning is holistic: A reply to Ward and Scott. *Memory & Cognition, 16*, 79–84.
Lewandowsky, S. (2011). Working memory capacity and categorization: Individual differences and modeling. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 720–738.
Minda, J. P., Desroches, A. S., & Church, B. A. (2008). Learning rule-described and non-rule-described categories: A comparison of children and adults. *Journal of Experimental Psychology: Learning Memory, and Cognition, 34*, 1518–1533.
Minda, J. P., & Miles, S. J. (2010). The influence of verbal and nonverbal processing on category learning. In B. H. Ross (Ed.). *The psychology of learning and motivation* (Vol. 52, pp. 117–162). New York: Academic Press.
Rabi, R., & Minda, J. P. (2014). Rule-based category learning in children: The role of age and executive functioning. *PLoS ONE, 9*, e85316.
Raijmakers, M. E. J., Jansen, B. R. J., & van der Maas, H. L. J. (2004). Rules and development in triad classification task performance. *Developmental Review, 24*, 289–321.
Schmittmann, V. D., van der Maas, H. L. J., & Raijmakers, M. E. J. (2012). Distinct discrimination learning strategies and their relation with spatial memory and attentional control in 4- to 14-year-olds. *Journal of Experimental Child Psychology, 111*, 644–662.
Schmittmann, V. D., Visser, I., & Raijmakers, M. E. J. (2006). Multiple learning modes in the development of performance on a rule-based category learning task. *Neuropsychologia, 44*, 2079–2091.
Schwarzer, G., Kuefer, I., & Wilkening, F. (1999). Learning categories by touch: On the development of holistic and analytic processing. *Memory & Cognition, 27*, 868–877.
Sewell, D. K., & Lewandowsky, S. (2011). Restructuring partitioned knowledge: The role of recoordination in category learning. *Cognitive Psychology, 62*, 81–122.
Sloutsky, V. M. (2010). From perceptual categories to concepts: What develops? *Cognitive Science, 34*, 1244–1286.
Smith, L. B. (1989). A model of perceptual classification in children and adults. *Psychological Review, 96*, 125–144.
Smith, J. D., & Kemler Nelson, D. G. (1984). Overall similarity in adults' classification: The child in all of us. *Journal of Experimental Psychology: General, 113*, 137–159.

Smith, J. D., & Kemler Nelson, D. G. (1988). Is the more impulsive child a more holistic processor? A reconsideration. *Child Development, 59*, 719–727.

Smith, J. D., Minda, J. P., & Washburn, D. A. (2004). Category learning in rhesus monkeys: A study of the Shepard, Hovland, and Jenkins (1961) tasks. *Journal of Experimental Psychology: General, 133*, 398–414.

Smith, J. D., & Shapiro, J. H. (1989). The occurrence of holistic categorization. *Journal of Memory & Language, 28*, 386–399.

Smith, J. D., Tracy, J. I., & Murray, M. J. (1993). Depression and category learning. *Journal of Experimental Psychology: General, 122*, 331–346.

Swanson, H. L. (1999). What develops in working memory? A life span perspective. *Developmental Psychology, 35*, 986–1000.

Thompson, L. A. (1994). Dimensional strategies dominate perceptual classifications. *Child Development, 65*, 1627–1645.

Thompson, L. A., & Markson, L. (1998). Developmental changes in the effect of dimensional salience on the discriminability of object relations. *Journal of Experimental Child Psychology, 70*, 1–25.

Visser, I., & Raijmakers, M. E. (2012). Developing representations of compound stimuli. *Frontiers in Psychology, 3*, 73. http://dx.doi.org/10.3389/fpsyg.2012.00073.

Ward, T. B., & Scott, J. (1987). Analytic and holistic modes of learning family resemblance concepts. *Memory & Cognition, 15*, 42–54.

Ward, T., Vela, E., & Hass, S. (1990). Children and adults learn family-resemblance categories analytically. *Child Development, 61*, 593–605.

Zeithamova, D., & Maddox, W. T. (2006). Dual-task interference in perceptual category learning. *Memory & Cognition, 34*, 387–398.

Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences, 8*, 12–17.

Zelazo, P. D., Frye, D., & Rapus, T. (1996). An age-related dissociation between knowing rules and using them. *Cognitive Development, 11*, 37–63.