### Title

Perceptual Category Learning: Similarity and Differences Between Children and Adults




### Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 36(36)

### ISSN

1069-7977



### Authors

Rabi, Rahel
Minda, John Paul



### Publication Date

2014

Peer reviewed

# Perceptual Category Learning: Similarity and Differences Between Children and Adults

**Rahel Rabi (rrabi@uwo.ca)**
Department of Psychology, The University of Western Ontario
London, ON N6A 5C2 CANADA

**John Paul Minda (jpminda@uwo.ca)**
Department of Psychology, The University of Western Ontario
London, ON N6A 5C2 CANADA

**Abstract**

Studies of category learning have supported the idea that people rely on at least two cognitive systems when learning new categories. A verbally-mediated system is best suited for learning rule-based categories, and a nonverbal, procedural system is best suited for learning categories that are not defined by a rule. To further examine the cognitive systems involved in categorization, two experiments explored developmental differences in perceptual category learning. In the first experiment, children and adults were asked to learn a set of categories consisting of stimuli equated on feature salience. A single-feature rule (the criterial attribute) or overall similarity would allow for perfect performance on this task. We found that adults made significantly more rule-based responses to the test stimuli than did children. A second experiment examined non-rule-based category learning by having children and adults complete a prototype abstraction task. Children showed evidence of prototype abstraction, with many children showing a similar pattern of responding to adults. Results are discussed within the COVIS framework.

**Keywords:** Category learning; Development; COVIS

## Introduction

Categorization is a fundamental process that allows us to meaningfully parse the world, and to group like objects together so that they can be treated equivalently. This process has been examined in both adults and children (Ashby & Maddox, 2005; Minda, Desroches, & Church, 2008; Huang-Pollock, Maddox, & Karalunas, 2011; Rabi & Minda, 2014), with research suggesting that children have a reduced capacity for executive functioning and rule selection (Bunge & Zelazo, 2006; Casey et al., 2004). Due to these limited capacities, adults should outperform children on categorization tasks involving rule selection, but performance differences should be minimized in cases where to be learned categories have little or no rule selection component.

One way to understand any possible differences between children and adults is to consider the possibility that multiple cognition systems underlie category learning. According to multiple-systems theories (the Competition between Verbal and Implicit Systems, or COVIS, is a well known example) a *verbal system* is assumed to learn rule-based categories (Ashby et al., 1998). This system is mediated primarily 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). This system is assumed to be the default approach for normally-functioning adults when learning new categories (Ashby et al., 1998). The multiple-systems approach also assumes that a *nonverbal system* learns non-rule-based categories. The nonverbal system is mediated by sub-cortical structures in the tail of the caudate nucleus, relies on a dopamine-mediated reward signal to learn, and does not rely as heavily on verbal working memory and controlled attention. This system is well suited to learn categories that have a strong family resemblance (FR) 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). Both systems compete during learning and when a classification decision is made. Ultimately, the system with the more successful responding strategy will tend to dominate performance (Ashby et al., 1998).

COVIS and other multiple-systems theories make several predictions about developmental effects on category learning, because the regions of interest are known to develop with age. For example, research has shown that developmental changes in rule use reflect the rate of development of the prefrontal cortex (Bunge & Zelazo, 2006). As such, we might expect age-related improvements in explicit rule-based categorization if the prefrontal cortex is assumed to mediate many of the cognitive aspects of the verbal system (hypothesis testing, selective attention, etc.). In contrast, the nonverbal system is mediated by the tail of the caudate nucleus, which seems to be fully developed in children (Casey et al., 2004). Thus, young children should be able to learn non-rule-based categories in a similar manner to adults.

Prior research has consistently demonstrated age-related improvements in rule-based category learning. For example, Minda, Desroches, and Church (2008) compared categorization performance in 3-, 5-, and 8-year-olds, as well as adults. Results revealed that adults outperformed children on categories that were optimally learned by a disjunctive rule (e.g., 2 of the 3 stimulus features were relevant for the disjunctive rule). However, children could learn single-dimensional rules about as well as adults, suggesting that the ability to learn rules was not completely absent in children. Huang-Pollock and colleagues (2011) examined the ability of school-aged children and adults to learn rule-based or non-rule-based categories. They found that the adults performed better than the children in both cases, and the primary reason was children's over reliance on single dimensional rules. Both of the studies suggest that children do have access to the explicit, rule learning system, but this system operates less efficiently in children because of their less well-developed hypothesis-testing abilities (i.e., searching for, storing, updating, and applying rules) and relatively less successful inhibitory control. Recently, work in our lab has examined rule-based category learning in children ages 4-11 and its connection to executive functioning (Rabi & Minda, 2014). Younger children showed the strongest rule-based deficit relative to older children. Interestingly, a larger working memory capacity (e.g., on a digit span task) and stronger inhibitory control abilities (e.g., on a Flanker task) were associated with better categorization performance.

While these findings are in line with multiple-systems theories, additional research is required to better understand developmental differences in categorization. COVIS and other multiple-systems theories assume that the verbal and nonverbal systems compete to learn the categories and to provide the response (Ashby et al., 1998). Minda et al.'s (2008) findings related to a category set for which only one strategy was viable. Similarly in Huang-Pollock et al., the children learned categories that had only one optimal strategy (Huang-Pollock et al., 2011). 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-based and non-rule-based strategies are available. For example, Minda and Miles (2009) asked children and adults to learn a set of categories for which both a single-feature rule or overall similarity would allow for perfect performance. Findings revealed that adults made more rule-based responses to test stimuli than did the children. Additionally, some stimulus features were more salient than others, and as a result, the proportion of criterial attribute responding in children was higher for high salience features than for low salience features. This type of attentional capture may have reduced hypothesis-testing demands, allowing children to identify the correct rule with more ease. However, the question remains: how would children perform when given a different set of test stimuli with features of equal salience?

## Experiment 1

In Experiment 1 we extended the research of Minda & Miles (2009) to examine the relative differences between children's and adults' category learning abilities and styles. Similar to Minda & Miles, we asked participants to learn two five-dimensional categories that could be learned perfectly by the verbal system, using a verbalizable rule based on a single dimension (the criterial attribute, CA) or by the implicit system by using a strategy based on the family resemblance of category members. Our study differed from Minda & Miles, in that we designed a set of stimuli with features that children rated as being approximately equal in salience. Additionally, we created a single-feature test in which participants indicated plausible category membership for features presented in isolation. We predicted that children in our study would show less CA performance than children in Minda & Miles study, because using stimuli with equally salient feature would encourage children to take part in hypothesis testing to test various rules. Instead, it was expected that children would base responses on single features or family resemblance.

## Method

**Subjects** Subjects included 39 children with a mean age of 5.61 years (*SD* = 0.43 years) recruited from the University of Western Ontario's YMCA Child Care Centre and a Montessori School in London, Ontario. Of the 39 children who participated in the study, data from 11 children were discarded because they did not complete the experiment, indicated that there were guessing, or their performance on the last block of category learning was not significantly higher than chance performance. This left 28 children (11 boys, 17 girls) who showed evidence of category learning. Participants also included 37 students from the University of Western Ontario who participated for course credit or money. Data from 4 adults were discarded because their performance on the last block of category learning was not significantly higher than chance performance and they indicated that they were guessing or responding randomly. This left 33 adults (16 men, 17 women) who showed evidence of category learning.

**Materials** Participants learned to classify drawings of fish that varied along five binary dimensions. An example 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 was identical to the Minda & Miles (2009) study. Stimuli consisted of a prototype for Category A and Category B, and the remaining category members had four features in common with their own category's prototype and one feature of the opposite category's prototype. Perfect

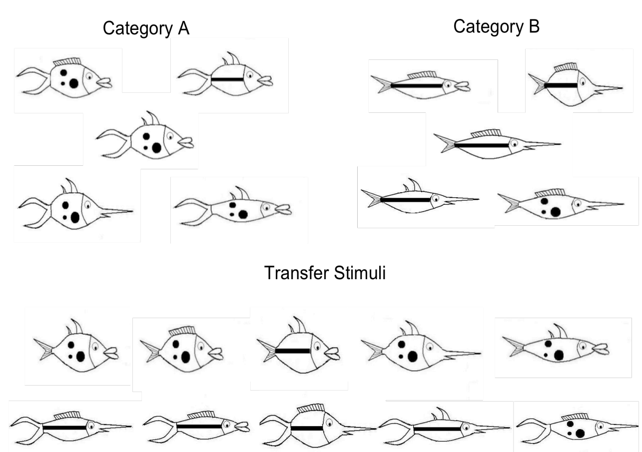


**Figure 1:** This is an example of the training items for each category used in the learning stage, along with the test items for the transfer stage.

categorization performance could be attained by learning the CA (e.g., “striped tail fish in Category B, otherwise Category A”) or by learning the family resemblance structure. In a separate feature rating study, we tested the perceived perceptual salience of the fish stimuli in a group of 24 children (mean age of 5.32 years). Results revealed that children rated all the features as being equally noticeable, $F(4,92) = 1.87$, $p = .12$.

**Procedure** Participants 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. Their job was to help these fish find their homes by clicking on the correct place on the screen. The learning stage 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 fish appeared in the middle of the screen and pictures of the two category labels (aquarium or fishbowl) were shown in the top left and right corners of the screen. 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 seconds 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.

Upon completion of the 50 training trials, participants were told that they would be seeing some additional fish and that they should help the fish find their homes using what they had learned during the training phase. The transfer stage 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 Figure 1). Each trial followed the same sequence of events as in the training stage 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, etc.) 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 fish bowl or aquarium. The single feature phase consisted of one block of 10 trials and as in the transfer phase, feedback was not given.

## Results

**Learning Analysis** Learning curves were calculated by averaging performance for each age group at each block. The resulting learning curves, shown in Figure 2A, suggest that at the start both groups were performing at the same level, but with practice adults outperformed children. A 2 (age) x 5 (block) mixed ANOVA revealed a main effect for block, $F(4, 236) = 27.62$, $p < .001$, and a main effect for age, $F(1, 59) = 12.58$, $p < .001$. An interaction was found between age and block, $F(4, 236) = 3.10$, $p = .02$, indicating that across the 5 blocks a difference emerged between children’s and adults’ performance.

**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 at .94 (SD = .09) correct on the final training block and .97 (SD = .06) correct on the old items that were presented during the transfer phase, $t(32) = 1.79$, $p = .08$. Children performed at .83 (SD = .11) correct on the final training block and .80 (SD = .15) correct on the old items that were presented during the transfer phase, $t(27) = -1.33$, $p = .19$. The proportion of CA responding by each group of participants is shown in Figure 2B. Adults tended to make more classifications based on the CA than

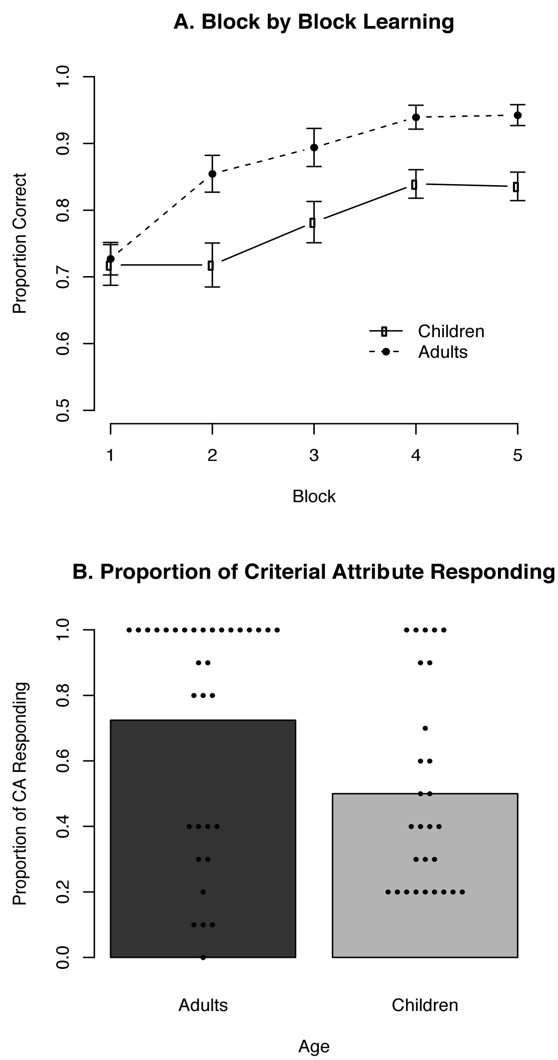


**Figure 2:** Panel A shows category learning performance for children and adults. Panel B shows the proportion of CA responding for children and adults in the transfer stage, with individual subject data shown as points.

did children, $t(59) = 2.62$, $p = .01$. In addition, the figure shows each individual data point and suggests that most adults made classifications that were rule based (i.e., 100% CA performance), but a different pattern emerged for the children. Although a few of the 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. No children, however, showed any evidence of pure family-resemblance learning.

**Strategy Analysis** We designed a strategy analysis that compared each subject's performance on all the exemplars shown in the transfer phase with the predicted performance of several different idealized strategies. For each subject, we calculated the correlation between their pattern of responses on each stimulus with the responses produced by each of 6 possible categorization strategies: rule based on CA, rule based on each of 4 suboptimal dimensions (SD), or FR similarity. Subjects whose data was not fit by any of the strategies were counted as "other". We assumed that a strong correlation between performance and strategy indicated a possible reliance on that strategy and the model with the strongest correlation was deemed to be the best fit. Next, we counted the number of subjects whose data was best fit by each type of strategy. Table 1 shows that adults tended to respond according to a CA strategy more often than children; children tended to be "other". We analyzed these differences with a chi-square test and confirmed that adults and children used different categorization strategies, $X^2(2) = 13.12$, $p = .001$.

**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 made more correct single-feature classifications than did children ($M = .84$, $SD = .37$ for adults and $M = .64$, $SD = .48$ for children), $t(59) = 4.24$, $p < .001$. We also examined the performances on the single feature test for participants in each strategy bin shown in Table 1. The results are summarized in Table 2 and these results show that children essentially performed at chance on the single feature test regardless of which strategy they adopted (0.6 would result for a subject who performed perfectly on one single feature and was guessing on the other 4). Adults showed much better performance on the single feature tests. The adults who were classified as FR subjects performed the best, consistent with the claim that they were taking into account all of the features. Even the CA learners (the largest group of adults) performed well on the other features. The 2 adults who relied on a single, non-criterial dimension were closest to the children's performance levels.

## Discussion

Despite learning the category set relatively well, children and adults differed in their classifications of the test stimuli. Adults were more likely to classify transfer stimuli in accordance with the CA compared to children, with many children relying on "other" strategies. These other strategies seemed to be a mixture of responses from the two systems (some rule-based, some similarity-based). Additional research is needed to understand this subset of subjects. Only a small subset of children showed any indication that they were able to find a perfect rule among 5 possible rules. This key result is consistent with the predictions of COVIS, in that adults showed a bias for rule learning of the verbal system. Another prediction of COVIS that was possibly confirmed was the prediction that both systems operate simultaneously, because the single feature performance of adults who ultimately learned the CA was fairly high (.84). Good performance on the single feature test indicates the presence of category level knowledge of the other, non-CA features. Overall, we found no evidence that children showed a preference for family resemblance learning, indicating that children did not rely on an overall similarity approach (nonverbal system) when categorizing stimuli.

**Table 1:** Number of Participants Using Each Strategy in Transfer Stage

| Age | CA | FR | SD | Other |
|---|---|---|---|---|
| Children | 7 | 0 | 5 | 16 |
| Adults | 19 | 4 | 2 | 8 |

**Table 2:** Single Feature Performance by Strategy Use

| Age | CA | FR | SD | Other |
|---|---|---|---|---|
| Children | .66(.11) | na(na) | .66(.15) | .61(.19) |
| Adults | .84(.20) | .90(.20) | .70(.42) | .80(.17) |

Note: Standard deviations are in parentheses.

## Experiment 2

Experiment 1 revealed that in contrast to adults, children struggled to find the optimal rule in the categorization task. Furthermore, young children may not yet be able to engage in systematic and effective rule learning. Given that children are equipped with the ability to learn new categories: are there category learning tasks on which children can perform relatively well, and in a way that is strategically similar to adults? In Experiment 2, we asked children and adults to learn a set of nine-dot prototype distortions of the kind that have been used in the past to assess prototype abstraction (e.g., Smith & Minda, 2002). Given that this kind of category learning has been linked to primary and secondary visual areas (Reber, Stark, & Squire, 1998b) and is not rule based, we predicted that children would perform relatively well on this task, relative to adults.

## Method

**Subjects** 20 adults were recruited from the University of Western Ontario and 17 children (8 male, 9 female) were recruited from the University Laboratory School at the University of Western Ontario. Children were all between 4 and 5 years old and the mean age was 4.53 ($SD$ = .26). The data from one child was excluded because that child had difficulty understanding the task.

**Materials** The dot-distortion task was created with a well-established method that generates a family of dot patterns from a single prototype. The distortions were similar to, but not exactly like, the originating prototype. Small adjustments to the location of some dots resulted in items that were "low distortions" of the prototype, and large adjustments resulted in "high distortions". We connected the dots to form irregular, 9-point polygons. The training set consisted of the prototype, 20 low-level distortions, 20 high-level distortions, and 20 random patterns. See (J.D. Smith & Minda, 2002) for complete details.

**Procedure** The training phase consisted of 2 random-order blocks of all 40 high-distortion training stimuli (80 trials). On each trial, subjects viewed the shape and then clicked the "OK" button to advance to the next stimulus. The testing phase consisted of a random order of 4 presentations of the prototype, 20 low-level distortions, 20 new high-level distortions, and 20 random patterns (64 trials). On each trial, subjects were told that they were going to see more shapes, and that they were to indicate if each shape was part of the same category they had just seen.

## Results

The proportion of category endorsements (saying "yes" to a stimulus in the test phase) for the prototypes, low distortion, high distortion, and random items were calculated (see Figure 3). Both children and adults showed typicality gradients with prototypes being endorsed strongly and random items being endorsed weakly. To verify this effect, we conducted an age (children, adults) x stimulus type (prototype, low, high, random) ANOVA. We found a main effect of stimulus type, $F(3, 102) = 87.52$, $p < .001$, indicating that subjects were able to reliably distinguish category members from non category members. There was no significant main effect of age, $F(1, 34) = 1.92$, *ns*, indicating overall performance did not differ between children and adults. Additionally, a significant interaction was found, $F(3, 102) = 5.45$, $p < .01$. Post-hoc analyses revealed that the children and adults significantly differed on the proportion of prototype endorsement, $F(1, 34) = 6.50$, $p < .05$, but did not significantly differ on other stimulus types. A closer look at the data revealed that the majority of children were endorsing the prototype at a similar level to adults, with the exception of 2 children (1 child displayed 0% prototype endorsement, and the second child endorsed each stimulus type an equal amount). After removing these 2 children from analyses, a t-test confirmed that children did not differ from adults on the proportion of prototype endorsement, $t(32) = 1.85$, $p = .074$.

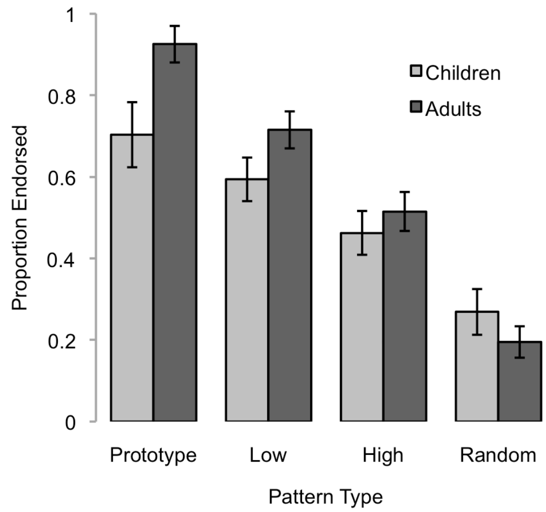


**Figure 3:** Performance of children and adults on the four kinds of test stimuli.

## Discussion

In contrast to Experiment 1 in which children and adults seemed to adopt different strategies when learning the categories, the results of Experiment 2 suggest that when there is no rule to learn, children and adults appear to learn via a similar strategy. That is, children were able to distinguish category members from non category members and that the level of endorsement depended on how close or far items were from the originating prototype. The data from adult participants followed nearly the same pattern as that shown by children, with the exception of the finding that adults endorsed the prototype to a greater extent than children. This finding is not all that surprising given the fact that we were testing young children. Age-group differences may be more attributable to differences in metaskills and experience, rather than to differences in capacities/non-rule-based category learning. While the difference in prototype endorsement between children and adults may have been driven by the outlier performance of two specific children, given our limited sample size, future research is required to better understand the role of prototypes in children's categorization behaviour. Overall, the typicality gradient observed among adults and most children, suggests that children can generally perform well in this task because there are no rules to learn, the stimuli cannot be described verbally, and the nearly incidental learning paradigm reduced the demands on working memory. Freed from the strict demands of the hypothesis testing tasks, children appear capable of abstracting a visual prototype and generalizing to new items, even after a relatively short training interval.

## Conclusions

Experiment 1 revealed that children are less likely to classify stimuli according to the criterial attribute rule compared to adults. Experiment 2 showed that when children are learning category sets that are not amenable to rule learning, they can perform relatively well, and adopt strategies similar to adults. However, differences in the stimuli used across studies may also partly explain performance differences.

The results of Experiment 1 are generally consistent with a multiple-systems theory of category learning, in that COVIS predicts that the verbal system should learn categories by testing various rules and eventually applying a verbal description for the correct single-dimensional rule (Ashby et al., 1998). Children, unlike adults, are expected to have more difficulty relying on the verbal, rule-based system. As a result, children should be less able to efficiently engage in hypothesis testing and inhibit incorrect rules. While children did struggle with finding the criterial attribute rule, surprisingly, no children adopted a purely, family-resemblance based strategy. This could be due to children using a mixture of strategies (e.g., "other" group), or possibly because the stimulus-response associative process of implicit learning takes more time than what was given in our task.

Compared to the Minda & Miles (2009) study involving stimuli with features of varying salience, controlling for feature salience in Experiment 1 resulted in a decrease in children's categorization performance. Such findings suggest that children may have learned the CA more so in the Minda & Miles study because the feature that corresponded to the CA was perceptually salient. In other words, if the CA required some degree of testing and inhibition, children may not have been able to find it. They may have relied instead on an imperfect rule and/or overall similarity, as evidenced by the large subset of children classified as using "other" strategies. While the majority of children in Experiment 1 struggled to identify the correct categorization rule, a handful of children were able to identify the criterial attribute. So, what factors differentiate children who can learn correct categorization rules from those who cannot? Rabi and Minda (2014) examined the cognitive processes involved in rule-based category learning, and suggest that working memory and inhibitory control, may be able to explain some of the observed developmental differences in category learning.

The results of Experiment 2 demonstrate that children are capable of learning categories that do not require rules to solve. Children demonstrated a similar pattern of performance on the dot pattern task compared to adults. That is, similar to adults, most children showed a typicality gradient with prototypes being endorsed strongly and random items being endorsed weakly. Additionally, the fact that participants are first exposed to a set of category exemplars under incidental learning conditions suggests that the nature of this task may be more relatable to naturalistic category learning. Future research should further examine the incidental learning capabilities of children using different tasks.

Our data do allow the basic conclusion that when children need to search for a rule to optimize learning, they have difficulty relative to adults, and often succumb to their cognitive limits by selecting a suboptimal rule. When the task does not have a rule, and features an implicit learning task, they seem to be able to learn the categories in a similar manner to adults. 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.

## Acknowledgments

This research was supported by a grant from the Natural Sciences and Engineering Research Council of Canada to the second author. Correspondence should be addressed to Rahel Rabi by email at rrabi@uwo.ca.

## 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., & Maddox, W. T. (2005). Human category learning. *Annual Review of Psychology, 56,* 149-178.

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.

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.

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, & Cognition*, *34*, 1518-1533.

Minda, J. P., & Miles, S. J.(2009). Learning new categories: Adults tend to use rules while children sometimes rely on family resemblance. *Proceedings of the 31st Annual Conference of the Cognitive Science Society.* Hillsdale,NJ: Lawrence Erlbaum Associates, Inc.

Rabi, R., & Minda, J. P. (2014). Rule-based category learning in children: The role of age and executive functioning. *PLoS ONE, 9*(1), e85316.

Reber, P., Stark, C., & Squire, L. (1998b). Cortical areas supporting category learning identified using functional MRI. *Proceedings of National Academy of Sciences, 95,* 747-750.

Smith, J. D., & Minda, J. P. (2002). Distinguishing prototype-based and exemplar-based processes in dot-pattern category learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28,* 800-811.

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