Selective attention and development of categorization: An eye tracking study

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Abstract

Some researchers argue that categorization in early development is knowledge-based rather than perceptually based. This approach requires young children to be able to attend to unobservable properties instead of perceptual features, which are usually more salient. However, potential immaturity of selective attention makes this possibility questionable. Current study tested both young children and adults with a match-to-sample task in which perceptual features were in conflict with the matching rule. Both behavioral and eye tracking data were collected. Eye-tracking results suggested that young children (3- and 4-year-olds) could not inhibit attention to the perceptual features, although behaviorally, 4-year-olds could. These findings are discussed with respect to theoretical accounts of category learning in early development.

Keywords: Cognitive Development, Categorization, Attention, Psychology, Human Experimentation.

Introduction

The ability to learn categories is a critical component of human cognition and this ability is present early in development (e.g., see Eimas & Quinn, 1994; Madole & Oakes, 1999, for reviews). However the mechanisms underlying category learning remain highly contested. Some researchers argue that early categories are perceptually-based, whereas other argue that even early in development, unobservable conceptual properties (such as animacy) play an important role in infants and young children's category learning and category use (see Rakison & Poulin-Dubois, 2001; Sloutsky, in press, for reviews). According to the latter view, early categorization (some have argued that as early as at 7 months of age) is based on features that are not given directly in the input. However, to be able to do so, infants and young children have to be able to selectively attend to these unobservable properties. This problem is particularly evident when salient perceptual features are in conflict with less salient, often unobservable, "conceptual" features. For example Gelman & Markman (1986) presented 4-year-olds with an inductive inference task. The task was structured as a match to sample triad, such that one of the items belonged to the same kind as the target (but was dissimilar) and another looked similarly (but belonged to a different kind. The authors argued that the unobservable conceptual feature (i.e., taxonomic kind) would override the salient observable features (e.g., appearance similarity). In this case, in addition to the ability to attend selectively to less salient input, young children should also have the ability to inhibit more salient (yet irrelevant) choice option. Given the critical immaturities in the executive function early in development (see Rueda, Fan, McCandliss, Halparin, Gruber, Lercari, & Posner, 2004, Davidson et al., 2006, for reviews), such selectivity seems questionable.

Current research addresses this issue by presenting participants with a simple match-to-sample task and examining their eye movement in the course of the task. This task is substantially simpler than the match-to-sample task used by Gelman and Markman (1986). First, in the current task, participants were explicitly told which aspect of the stimuli they should focus on. And second, instead of pitting appearance versus unobservable properties, we pitted more salient features against less salient ones. Our reasoning was as follows. If participants focus on unobservable information in a more difficult induction task, they should have no difficulty focusing on less salient information in this highly simplified task.

The task includes a target and two test items. There are three within-subjects conditions. In the Supportive condition, the test item that shares the matching rule with the target is also similar to the target. In the Neutral condition, both items are equally similar to the target, with one test item sharing the matching rule. And finally, in the Conflict condition, one test item shares the matching rule, whereas the other one looks similar to the target. Therefore, the latter condition required participants to reject a salient appearance-based item in favor of less salient rule-based item. In sum, the task requires the ability to attend selectively that is critical for many category learning and inductive inference tasks. Given that the task is exceedingly simple, participants' failure in the conflict condition might be particularly informative. If they cannot resolve the conflict in this simple task, it is reasonable to ask: how could they resolve a conflict in more difficult and demanding categorization and induction tasks?

Experiment 1

Method

Participants Sixteen adults (6 women and 10 men, *M* = 20.1 years, *SD* = 2.7 years) participated in this experiment. Adults were undergraduate students from The Ohio State University participating in the experiment for course credit. The experiment used a within subject design and each subjects took all the three conditions in the experiment: Supportive, Neutral, and Conflict conditions. All the participants were tested in a quiet room on campus.

Stimuli consisted of triads of artificial creatures, which were irrelevant components of the task. Each triad also included three rows of circles (referred to as cookies that creatures eat). Examples of stimulus triads are presented in Figures 1-3. These cookies were the critical features that participants were instructed to focus on in the current matching task. To make the irrelevant features perceptually more salient, creatures were bigger and colorful, while the critical features were smaller and shared the same color. The only difference for the critical features was different patterns on the cookies. Two had wave lines on them while the remaining one had diagonal lines. The irrelevant features were drawn from two categories. One category consisted of objects with hands and feet, and the other consisted of bug-like objects with wings and tails. In each triad, the bottom object was the target item, and the two top ones were test items. Half of target and test items were selected from one category and half were selected from the other category. The top two sets of cookies were always different with only one matching the target set. At the same time, irrelevant items varied across the conditions. In the Supportive condition, the "matching distracter" (i.e., the one that had the same kind of cookies as the target) came from the same category as the target. So the one that looked more similar to the target item also shared the matching rule with the target item. Therefore, the perceptually irrelevant information was consistent with and supportive of the critical features. In the Conflict condition, the "matching distracter" came from the opposite category than the target distracter. So the perceptual information was in conflict with the matching rule. Finally, in the Neutral condition, both test distracters and the target distracter came from the same category. As a result, the matching rule was neither supported, nor in conflict. The right and left sides of the stimuli were counterbalanced.

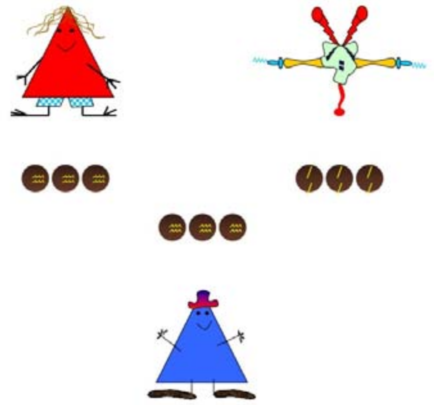

Figure 1: An example of the stimuli in the supportive condition

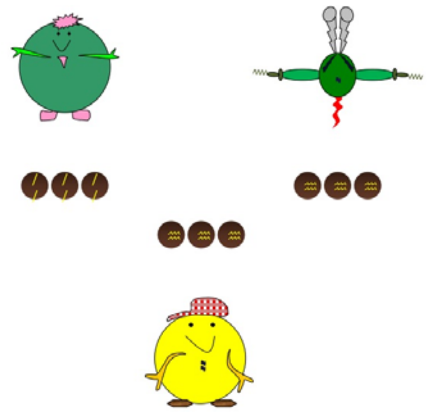

Figure 2: An example in the conflict condition

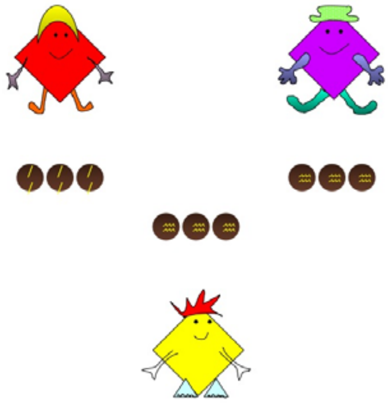

Figure 3: An example in the neutral condition

The locations of the cookies and the creatures were fixed for each trial. The distracters were subtended at visual angles equaling to 6.2° horizontally and 5.2° vertically. The cookies were subtended at visual angles equaling to 4.2° horizontally and 1.6° vertically. The distance between the creatures and the cookies were 2.6° vertically.

Procedure Eprime 2.0 was used for controlling the experiment and Tobii T60 with the sampling rate of 60 Hz was used for collecting eye tracking data.

Before the task, the eye tracker was calibrated to each participant. Participants were told that in this matching task they should choose one of the objects on the top to match the object at the bottom by matching the cookies. They were also instructed to make the choice as quickly as possible. If it was the left creature that matched, they should press "1", and press "4" if it was the right one. They were given the following instructions: *This is a matching game. The game is to decide which one on the top goes with the one at the bottom. To win the game, you need to choose the one likes the same as cookies as the one as the bottom.*

Prior to testing, participants had three warm-up trials at first, one for each condition. Feedback was provided for the three warm-up trials. During the test phase, participants were given 30 trials, with 10 Supportive, 10 Neutral, and 10 Conflict trials. The trials were mixed and pseudo-randomly assigned into 3 blocks, with 10 trials in each block. The order of the three blocks and the order of the trials within each blocks were randomized. Each trial was preceded by a fixation point at the center of the screen. The duration of the fixation varied between 300 ms to 800 ms. No feedback was provided during the test phase.

Eye tracking Dependent Variables A stream of eye fixations corresponding to their x-y locations on the screen were collected by the eye tracking software for each subject. Six areas of interest (AOIs) for fixations were defined: three circular areas encompassing the creatures and three rectangular areas encompassing the cookies displayed on the screen. All fixations outside the AOIs were discarded.

Results and Discussion

Behavioral Data The average of accuracy across the three conditions was 97% (SE = 2.1%) and exceeded chance level, one-sample t compared to 50%, $t(15) = 22.94$ $p = .01$. No difference was found between different conditions, $F(2, 30) = .92$, $p = .41$.

Eye Tracking Data The primary analyses focused on the proportion of the eye fixation on the critical features, which were the kinds of cookies in this study. The proportion was calculated by total fixations on the triads of cookies divided by the sum of fixations on the triads of cookies and the fixations on the triads of creatures. The absence of a preference would result in comparable looking across the areas of interest. Before 200 ms, all the eye fixations were at the center of the screen which indicated that participants did focus on the fixation stimulus and did not exhibit eye movements during that period. The time window for eye tracking analysis was two standard deviations above the mean reaction time (M = 1013.8 ms, SD = 480.7). Therefore, the time window for eye tracking analyses was between 200 ms and 2000ms. The proportions of looking at the critical feature in the Conflict condition across time are presented in Figure 5. The overall proportion of looking at the critical features, i.e., the cookies, was 84.4% (SE= 5%). No difference was found across the three conditions, $F(2, 30) = 765$, $p = 474$. Perhaps not surprisingly, these findings indicate that adults had little difficulty focusing on the critical features and ignoring more salient distracters. As a result, participants exhibited near ceiling accuracy in all three conditions. The importance of these data is that they represent a necessary point of comparison for children's data. Experiment 2 focused on performance of 3- and 4-year-old children.

Experiment 2

Method

Participants Young children were recruited from the suburbs of Columbus, Ohio. There are 15 4 year olds (9 girls and 6 boys, M = 50.5 months, SD = 2.5 months) and 15 3 year olds (8 girls and 7 boys M = 41.8 months, SD = 3.4 months). All participants were tested in a lab on campus.

Procedure The procedure for young children was almost identical to that for adults, except for the following differences. First, a female experimenter presented the task to the participants, controlled the pace of the experiment, and pressed the key based on children's verbal response during the experiment. And second, the instructions "Choose the one that likes the same kind of cookies as the one at the bottom" were repeated before each trial.

Results and Discussion

Behavioral Data Accuracy data are presented in figure 4. For 3-year-olds, difference was found in accuracy across the three conditions, F (2, 28) = 6.81, p < .01. Specifically, accuracy in the conflict condition did not exceed chance, one-sample t compared to 50%, t (14) = 1.56, p = .14, two-tailed. However, the accuracy was above chance in the neutral and supportive condition, *ts* (14) > 5.78, *p*s < .01. For 4-year-olds, accuracy for all the three conditions exceeded chance, one-sample t compared to 50%, *ts* (14) >3.67, *p*s < .01, one-tailed. Difference was also found across the three conditions, F (2, 28) = 3.7, p = .037. In particular, participants were less accurate in the conflict condition than the other two conditions.

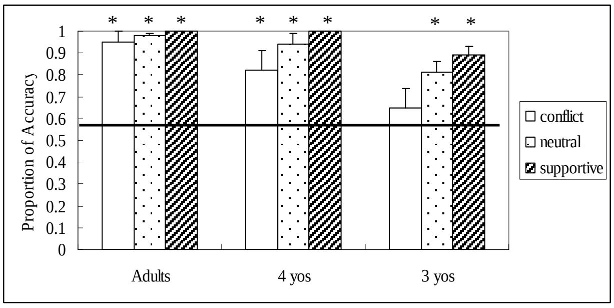

Figure 4 Behavioral data of different age groups
Note: * -- Above chance, p < .05.

Eye Tracking Data The time stream between 1000ms and 3000ms was used for analysis. Before 1000ms, eye fixations did not reliably move from the center of the screen to the areas of interest. Data were analyzing by averaging across trials and individuals. The proportions of looking at the critical feature in the Conflict condition by sampling rate (16 ms) and age are presented in Figure 6. Main effect of age was found in proportion of looking at the critical feature, F (1, 238) = 408.219, p < .01. 4 year olds showed more fixations on the critical features than 3 year olds. Difference between conditions was found, F (2, 476) = 109.4, p < .01. There was an age by condition interaction, F (2, 476) = 14.94, p < .01, with larger age difference in looking at the critical feature found in Conflict condition. Therefore, 4-year-olds were not only more accurate in the conflict condition, but also were more likely to look at the critical feature in the Conflict condition. At the same time, the proportion of looking at critical features by 3- and 4-year-olds was consistently below 50%.

Individual patterns of responses were also analyzed. We were particularly interested whether individuals who were more likely to look at the critical features in the Conflict condition also exhibited greater accuracy. For 3-year-olds, a significant correlation was observed between the accuracy and the overall proportion of looking at the critical features in the Conflict condition (r = .574, p = .03). This indicated that accurate participants were more likely to pay attention to the critical features. However, there was no significant correlation in 4-year-olds, r = .29, p = .29. This is probably because there was very little variability in the accuracy of 4-year-olds.

To further examine the connection between looking and response accuracy, we split the children into two groups according to their accuracy in the Conflict condition. Those with accuracy above .5 were assigned to the high accuracy group, and those with accuracy below or equal to .5 were assigned to the low accuracy group. Difference in overall proportion of looking was found in conflict condition between these two groups. Those high accuracy children were more likely to focus on the critical features (M = 36.1%, SE = 5%) than those low accuracy children (M = 16.5%, SE = 6%), t (28) = 2.26, p = .016, one-tailed.

Further analysis was carried out for examing the online learning during the task. If there was any learning or strategy optimization happening during the task, we should expect the difference in looking across trials. The participants should show more looking to the critical featuers during the later part of the task than during the earlier part. To test this, data was divided into the earlier 5 and later 5 trials of each condition. Comparison between these two half of the task were made for each condition and each age group. However, no difference was found, t (14) < .05, p > .16, one-tailed. Therefore, in the absence of feedback given to participants, there was little evidence of on-line learning to allocate attention to critical features.

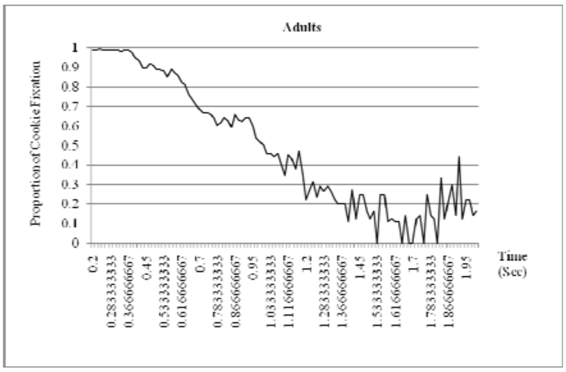

Figure 5: Adults' eye tracking data in Conflict condition

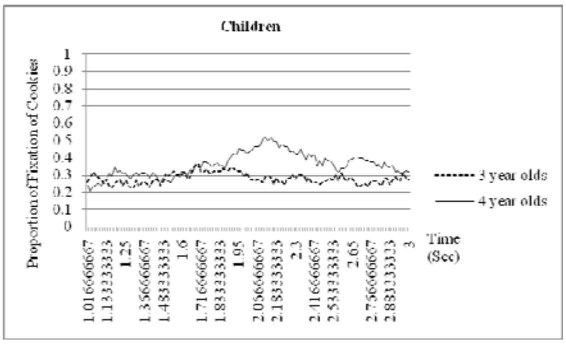

Figure 6: Childrens' eye tracking data in Conflict condition

General Discussion

The results point to several important findings. First, under comparable experimental conditions, adult participants and 4-year-olds were less likely to be distracted by the appearance of the stimuli, which were the irrelevant features in this study. When the critical features conflicted with the irrelevant features, their behavioral performance was still above chance, although performance of 4-year-olds (but not of adults) decreased in the Conflict condition. However 3-year-olds could not ignore the irrelevant features and their performance was at chance in the Conflict condition.

Second, performance in the Conflict condition was associated with the proportion of looking to the critical feature. This proportion in adults was greater than in 4-year-olds, and in 4-year-olds greater than in 3-year-olds. In addition in 3-year-olds, correlation was found between the proportion of looking to the critical features and the accuracy on the task in the Conflict condition. Moreover, when children were divided into the groups by their performance in conflict condition, difference was observed in their looking pattern. Thus, the proportion of looking to the target in the Conflict condition was a predictor of performance on the task in this condition.

Third, for 4 year olds, the pattern of their behavior data looked more like adults data, while their pattern of eye tracking data was closer than that of 3 year olds. During the task, most adults' fixations were focusing on the critical features, while children spent more looking on the irrelevant features. Proportions of looking at the critical features in 4-year-olds were above of those in 3-year-olds, but were remarkably lower than that of adults and never excelled that of looking at the irrelevant features. This indicated that even though 4-year-olds exhibited high accuracy in the Conflict condition, they could not inhibit looking at the irrelevant features. Unlike adults, 4-year-olds' performance was not optimized and their choice between critical features and irrelevant features was not as efficient as adults. This suggested that children at this age were more likely to be attracted to the salient perceptual features instead of the critical but less salient one. Therefore, it is likely that if task demands were increased, 4-year-olds' performance in the Conflict condition would decrease as well.

Fourth, there was no evidence for the learning during the task. Participants did not look more to the critical features later in the task. This indicated that participants used the same strategy throughout the task and the trend that young children could not inhibit looking at more salient perceptual features was robust.

These findings indicate that young children have difficulty attending to less salient but critical task features, while ignoring more salient, but irrelevant features. Even in the very simple task used in the current research with warm up trials and instructions repeated on every trial, 3-year-olds failed in the Conflict condition, whereas 4-year-olds exhibited significant performance decrease. These findings present interesting challenges to the knowledge-based assumption that young children (and even infants) are capable of learning and using categories by spontaneously focusing on unobservable features, while ignoring salient observable features.

At the same, the study also raises a number of important questions for future research. One of them is how the low proportion of looking to critical features explained the high accuracy for 4-year-olds and whether the pattern will change for more difficult tasks. We have preliminary evidence addressing this issue. In an ongoing study, young children were presented with a more challenging induction task. While the stimuli and the procedure are the same as in the current talk, participants are asked a more difficult questions. They are informed about an unobservable property of the creature at the bottom and asked which at the top had the same property. For instance, on one trial, experimenter pointed to the creature at bottom, told children that "this one has thick blood", and asked them "Which one on the top do you think also has thick blood". The instructions that those like the same kind of cookies go together in the matching task were changed into that those like the same kind of cookies have the same thing inside. Similar to the current task, this rule of induction was also repeated every time before each trial. Compared to the matching task, the induction task was more challenging to young children as there was more information they needed to keep track during the task. As a result, the working memory demand was higher and so was the executive function demand. Considering the results of the matching task presented here (i.e., 4-year-olds spent most of the time looking at the irrelevant features), we expected that accuracy of 4-year-olds will drop in the Conflict condition. The results support this prediction: 4-year-olds exhibited low accuracy in the Conflict condition, and it did not exceed accuracy of 3-year-olds in the current study.

Another issue that has to be addressed in future research is related to the online strategy learning and whether children could move from a less efficient learning strategy to a more efficient one during the task. For instance, whether the time pressure and the feedback will help children pay less attention to the irrelevant features.

Finally, an investigation of whether training on selective attention would accelerate children's category learning in general would provide some insight into the development of this ability and also the interaction between the development of executive function and generalization ability.

In summary, many studies have examined how young children learn new categories. The current study provided evidence indicating that young children have difficulty inhibiting attention to irrelevant information. This evidence provides challenges to the knowledge-base approach assuming the ability of infants and young children to focus on less salient aspects of the input, while ignoring more salient.

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