Attention and the Development of Inductive Generalization: Evidence from Recognition Memory

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Abstract

Induction, the ability to generalize knowledge from known to novel instances, is essential for human learning. This study investigates how attention allocation during category learning and induction affects what information is represented and encoded to memory. In Experiment 1 5-year-olds and adults learned rule-based categories. They were then presented with an Induction-then-Recognition task. Similar to previous results with familiar categories, children exhibited better memory for items than adults. In Experiment 2, adults learned similarity-based categories and then were presented with an Induction-then-Recognition task. In this condition, adults' memory was as good as children's memory in Experiment 1. These results indicate that the way categories are represented affects the way induction is performed.

Keywords: Induction; Learning; Memory.

Introduction

By means of induction humans have the ability to generate new knowledge, reason about new objects, and learn in new situations. Induction enables the generalization of properties from the familiar to the novel. For example, if one learns that honey bee exoskeletons are composed of chitin, this knowledge could be extended to other types of bees and wasps, to all hymenoptera, or even to all arthropods. There is considerable evidence that inductive generalization appears early in development (Gelman & Markman, 1986; Sloutsky & Fisher, 2004a), with infants as young as 9-months exhibiting this ability (Baldwin, Markman & Melartin, 1993; Graham, Kilbreath, & Welder, 2004; McDonough & Mandler, 1998; Mandler & McDonough, 1998), and further evidence that the development of induction is protracted to at least 11 years of age (Fisher& Sloutsky, 2005). Despite considerable literature describing the mechanisms of induction, it is still not understood *what*, if anything, develops. Thus, the goal of the current study is twofold: (1) to understand *what* changes, and (2) to determine how those changes are reflected in the use of different mechanisms of induction.

In order to describe the mechanisms of induction, two theories have been proposed: the knowledge-based and the similarity-based views. Each theory presents arguments for how induction is performed and describes what developmental changes may occur. According to the knowledge-based view, induction is always based on category information, even in young children. In knowledge-based induction, the category of a novel item is identified and properties are inferred based on whether the novel item belongs to the same category as the familiar target. Proponents contend that children are able to make knowledge-based inferences because they hold many a priori assumptions about categories (Gelman & Markman, 1986). For example, assumptions that natural kind categories share many properties, including internal structure (Gelman, 1988; see Murphy, 2001 for a review). Considering children are most familiar with basic-level categories, this view posits that children are more likely to infer properties at the basic-level.

According to the similarity-based view, knowledge-based induction is a product of development and not reliant on a priori assumptions, while early induction is similarity-based. In similarity-based induction, multiple features of the novel input are assessed for similarity to a familiar entity. Properties are then inferred based on how similar the novel item is to the known target. There is evidence that, in addition to visual features (Sloutsky & Fisher, 2004a), linguistic labels (Deng & Sloutsky, 2013) and salient motion (Deng & Sloutsky, 2012) may factor in the similarity computation. According to this view, in knowledge-based induction, a novel item is labeled (either externally or by self-generating the label), then the label of the novel item is compared to the label of the familiar target and properties are inferred based on whether the entities belong to the same category. As such, this mechanism depends on the knowledge that items from the same category share many properties, including shared labels (Deng & Sloutsky, 2013), but also causal (Badger & Shapiro, 2012Bulloch & Opfer, 2009), and ontological (Gelman & Davidson, 2013) properties.

A critical difference between the above accounts is whether children use a different mechanism than adults when performing induction. In order to test this, Sloutsky and Fisher (2004a) developed the Induction-then-Recognition paradigm (ITR) in which participants perform an induction task followed by a surprise memory test of items that were presented during induction and items that were not. The ITR paradigm is based on the "level-of-processing effect" in which deeper semantic processing increases recognition accuracy (i.e., "hits"; Craik & Lockhart, 1972; Craik & Tulving, 1975), while at the same time also increasing the proportion of false recognitions of non-presented, but categorically related, items (i.e., "false alarms"; Koutstaal & Schacter, 1997; Rhodes & Anastasi, 200; Tharpar & McDermott, 2001). Thus, the overall result (i.e., hits – false alarms) is negative. In contrast, shallower perceptual processing may yield similar proportions of hits, but false alarms will be much lower (Marks, 1991). The result in this case is more accurate memory.

Following the above logic, Sloutsky and Fisher (2004a) proposed that memory for items presented in an induction task may reveal the level of processing used when performing induction. That is, use of a similarity-based mechanism, which is shallower than the semantic level of processing, will result in more accurate memory following induction. This pattern of memory was predicted for young children with either familiar or novel categories and for adults with novel categories. And while the above account has received much empirical support (Sloutsky & Fisher, 2004a; 2004b; Fisher & Sloutsky, 2005), many questions remain. For example, if the knowledge-based theory is correct and children use the same mechanism as adults, what explains age related differences in memory for items following induction (Sloutsky & Fisher, 2004a; Fisher & Sloutsky, 2005)? However, if the similarity-based view is accurate and children use a different mechanism than adults, what accounts for high induction performance in tasks where perceptual information is in contrast with category label (Gelman & Markman, 1986)? To address these questions, each view posits specific predictions about *what* develops.

The knowledge-based view posits that what develops is category knowledge (Gelman, 1988). This view holds that the mechanism driving induction does not change, and any changes in how induction is performed can be explained by changes in children's knowledge. Such age related gains include a shift from domain general to domain specific knowledge, knowledge regarding the hierarchical structure of categories, and scientific knowledge (Gelman & E. Markman, 1986; Gelman & Heyman, 1999; Gelman, 2004). For example, Gelman and O'Reilly (1988) found that school age children were able to successfully perform induction when superordinate category labels were provided, while preschool children did not. According to the authors, this finding demonstrates developmental gains in understanding of, and the ability to use, hierarchical category structure.

On the other hand, the similarity-based view holds that what develops is a different mechanism of induction (Sloutsky & Fisher 2004a). That is, changes in induction performance are due to a shift from an early similarity-based mechanism to a mature knowledge-based mechanism. If this is the case, then Gelman and O'Reilly's (1988) findings could result from children failing to make inferences within the superordinate category because the exemplars provided for the broad category of "animal" were too perceptually different to promote similarity-based induction. Importantly, according to this theory, a similarity-based mechanism would still be available for use by adults with novel categories, not that one mechanism replaces the other.

Adding to the above arguments regarding *what* develops, there is growing evidence in the category learning literature indicating that developmental changes in attention contribute in key ways to changes in category learning and representation. In an eye-tracking study by Best, Yim, and Sloutsky (2013), it was found that adults, but not 6- to 8-month-old infants, demonstrated a cost of attention when switching from categorizing learned categories to novel categories. Adults continued to focus on the previously learned category rule feature even when new categories were introduced. Infants, however, did not show a similar cost. It was argued that the difference between infants' and adults' switching was due to adults' more developed selective attention and resulting focus to a single predictive feature. Similar results with adults were found by Hoffman and Rehder (2010). In that study, participants demonstrated the same cost of attention such that they continued to attend to a category rule feature even when new categories were introduced.

The changing role of attention in categorization was also demonstrated by Deng and Sloutsky (2015). In that study, children and adults were trained to perform either item classification or feature inference, it was found that older children and adults demonstrated an asymmetry between their responses during item classification and feature inference such that participants relied on a single deterministic feature when classifying, but on multiple probabilistic features when inferring a missing feature. The same asymmetry was not found in younger children. The authors argued that younger children's representations remained similarity-based regardless of training, while older children's and adults' representations were flexible (i.e., capable of being knowledge- or similarity-based) depending on the demands of the task.

Considering that categorization, like induction, is a generalization process, it is possible that developmental changes in attention also contribute to changes in how inductive generalization is performed. Distributed attention may promote forming a similarity-based category representation as well as a similarity-based mechanism of induction. If this is the case, then memory for specific items would be high. That is, attention to multiple features would result in encoding the overall appearance of an item (Marks, 1991). Alternately, attention focused to a single feature, such as a rule feature or label (Deng & Sloutsky, 2013), would promote forming a knowledge-based representation and use of a knowledge-based mechanism of induction. It then follows, use of this mechanism would result in poor memory discrimination for individual entities because encoding would be limited to a single feature.

Overview of the Current Study

The current experiments were designed to further examine the mechanism of induction across development. In Experiment 1, children and adults were taught rule-based categories. After testing their categorization, participants were given an Induction-then-Recognition task with one of the studied categories after which their memory for items was tested. If children perform induction on the basis of similarity, and adults on the basis of the rule, then children should exhibit better memory for items than adults. However, even if children's memory is better than adults', it could be argued this effect stems from adults being more efficient in their induction. This issue was addressed in Experiment 2 where adults learned similarity-based categories and were then presented with the ITR task. If adults are merely more strategic at induction than young children, then memory for items in this condition should remain as low as in Experiment 1. In contrast, if Experiment 1 reflects differences in how induction is performed, then adults in this experiment should exhibit better memory for items after induction than in Experiment 1.

Experiment 1: Deterministic Instructions

Method

Participants Thirty-one adults (M_{age} = 20.3 years) and thirty-four children (M_{age} = 5.4 years) participated in the experiment. One additional child and two additional adults were dropped from analysis due to failure to follow directions during part of the experiment. Two children were dropped from analysis for not responding above chance to High and Medium Similarity items at Category Testing.

Materials Both experiments presented here used visual stimuli consisting of two categories of artificial insects. The category structure was similar to that previously used by Deng and Sloutsky (2012, 2013). Each category was provided a novel label: dax (Category D), and fep (Category F). Items in both categories were composed of seven features (head, body, legs, wings, antennae, claws, and tail), which differed between categories on the shape and color of each feature. All the default features of Category D were given the value of 1 (e.g., head1, body1, etc.), and all default features of Category F were given the value of 0 (e.g., head0, body0, etc.; see Table 1 for example stimuli structures). Each category had one prototype that was assembled from all of the default feature values for that category (Prototypes are pictured in Figure 1). The remaining stimuli were constructed by exchanging probabilistic features between categories or introducing new probabilistic features.

Of the seven features present on each stimulus, one was deterministic and was never exchanged between categories. That feature (the tails) remained constant within a category and perfectly predicted category membership (i.e., the category rule feature). The remaining six features were probabilistic and varied from one exemplar to the next so that the overall appearance of the items was also predictive of category membership. Subsets of the primary stimuli described above were created for use during different phases of the experiment.

Procedure The experiment consisted of four phases: (1) Instructions and Category Training, (2) Category Testing, (3) Induction, and (4) Recognition Memory. Instructions and feedback for all phases and both age groups were presented in text on the computer monitor. Adults read the instructions at their own pace, while children were read the instructions aloud by an experimenter. Adults made keyboard responses, and children made verbal responses which were then logged by the experimenter via the keyboard.

Instructions and Category Training: In Instructions prior to Training, participants were shown the default deterministic feature for Category D, then the default deterministic feature for Category F. Features were presented one at a time along with the feature label and a statement directing attention to that feature (e.g., "Daxes always have this kind of tail."). During Training, corrective feedback was provided after every trial with statements directing attention to the deterministic feature (e.g., "Correct! That one is a dax. It has a dax tail."). This phase contained three blocks of twelve trials each. Only High Similarity items were presented in this phase (see Table 1 for stimuli structure).

Category Testing: Participants were told to continue categorizing, as in Training phase. This phase contained two blocks. Block one presented the same twelve High Similarity items from Training, plus twelve new Medium Similarity items. Block two presented twelve Switch items (see Table 1 for stimuli structures). No feedback was provided in this phase.

Induction: Participants were shown an example of a High Similarity Category F exemplar and were informed that "This fep has beta-cells in its body." Participants were then asked to view other animals and decide whether they also have this property. Corrective feedback followed each trial indicating that only the target category (Category F) exemplars had beta-cells (e.g., Incorrect. That one does not have beta-cells). Items included six Probabilistic New items from each category, six Probabilistic Switch items from each category (see Table 1 for stimuli structures), and twelve Distracter items. This phase contained one block of 36 trials. The upcoming recognition memory test was not mentioned.

Recognition Memory: Participants were instructed they would be presented "old" items from the Induction phase as well as "new" items that had not been presented at any time during the experiment. Subjects were asked to determine

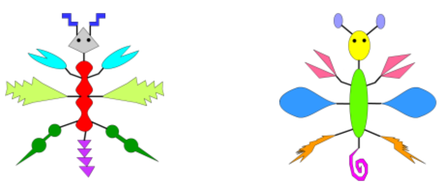
Table 1: Example of stimulus structures used in Experiments 1-2

Category F								Category D							
	Head	Body	Legs	Wings	Antenna	Claws	Tail		Head	Body	Legs	Wings	Antenna	Claws	Tail
Prototype	0	0	0	0	0	0	0	Prototype	1	1	1	1	1	1	1
High Sim.	0	0	1	0	0	0	0	High Sim.	1	0	1	1	1	1	1
Med Sim.	1	1	0	0	0	0	0	Med Sim.	0	0	1	1	1	1	1
Switch	1	1	0	1	1	1	0	Switch	0	0	0	0	1	0	1
Prob. New	0	0	0	0	N0	0	0	Prob. New	1	N1	1	1	1	1	1
Prob. Switch	0	0	0	N1	0	0	0	Prob. Switch	1	1	N0	1	1	1	1
Low Sim.	N1	1	1	N2	N0	0	0	Low Sim.	1	1	N1	N2	N0	1	1

Note: 0 = dimension corresponding with Category F features; 1 = dimension corresponding with Category D features. Nn = new feature and the corresponding feature identifier.

Figure 1: Prototypes of Category F and Category D

Category D	Category F



Note: Prototypes were not presented during the experiment.

which items were old and which were new. Items included the same twelve target category items from the Induction Phase (old Category F exemplars), twelve novel Low Similarity target category items (new Category F exemplars, see Table 1 for stimuli structures), six non-target category items from the Induction Phase (old Category D exemplars,), and six novel Distracters.

Results and Discussion

Accuracy in Category Training was high for both children (M = 95%) and adults (M = 97%) with both groups performing significantly better than chance (both ps < .001). Proportions of rule-based responses to High Similarity and Switch items in Category Testing are reported in Table 2 along with results of Experiment 2. Both children and adults made significantly more rule-based responses than would be expected by chance (both ps < .001). Induction accuracies were also above chance for children (M = 85%, $t(30)$ = 13.14, p < .001) and adults (M = 91%, $t(30)$ = 18.88, p < .001). The remaining analysis focused on results of the Recognition Memory Phase.

Memory discrimination was analyzed using signal detection d' scores calculated from the Z-score normalized proportions of hits (H) and false alarms (FA). If participants do not discriminate old from new items, d' is at or below 0. Experiment 1 d' scores are presented in Table 3 alongside d' scores for Experiment 2. Children's memory (H(.77) – FA(.31) = .46, d' =1.48) was significantly better than that of adults (H(.80) – FA(.45) = .36, d' = 1.06), $t(60)$ = 1.92, one tailed p=.03.

Results of Experiment 1 indicate that both children and adults ably learned the categories, generalized learning to new exemplars, and correctly inferred properties to the target category. Furthermore, children's proportion of rule-based responses on Switch items was very high, suggesting that they (like adults) did learn a rule-based category. However, children exhibited better memory than adults, indicating they did not use their knowledge of the rule to perform induction. This finding suggests that children were likely attending to more than just the category defining feature during induction. These findings are consistent with the theory that children rely on overall similarity when performing induction. It could be argued however, that these memory differences simply reflect developmental differences in the efficiency of allocating attention during induction. Experiment 2 addresses this question.

Experiment 2: Probabilistic Instructions

This experiment was similar to Experiment 1, with one exception: adults were trained on similarity-based (rather than rule-based) categories. If Experiment 1 simply reflects differences in attentional efficiency during induction, adults' memory after induction should remain low in Experiment 2. In contrast, if memory for items is reflective of the mechanisms of induction, adults' memory in Experiment 2 should be higher than that in Experiment 1.

Method

Participants Thirty-seven adults (M_{age} = 20.3 years) participated. Four additional adults were dropped for failing to follow directions (N = 2) or not meeting category learning criteria described in Experiment 1, N = 2).

Materials, Design and Procedure Visual Stimuli were identical to those used in Experiment 1. Procedures for this experiment were similar to those described in Experiment 1, with two exceptions: (1) Instructions preceding Category Training, and (2) feedback during Category Training. In this experiment, instructions preceding Category Training introduced each probabilistic feature, one feature at a time, and one category at a time, for both categories. Each feature was presented with text indicating the feature label and a statement directing attention to that feature (e.g., "Most feps have this kind of head."). Feedback during this phase re-directed attention to overall appearance of the items (e.g., "Correct! This is a fep. It looks like a fep.").

Results and Discussion

Accuracy in Category Training was high (M = 86%) and significantly better than chance ($p < .001$). Proportions of rule-based responses to High Similarity and Switch items presented in Category Testing are reported in Table 2. The proportion of rule-based responses on High Similarity items was significantly better than chance ($p < .001$), however, Switch item responses in this experiment were lower than adults in Experiment 1 ($F(1, 62) = 497.65$, $p < .001$) and lower than chance ($t(32) = -10.36$, $p < .001$). Induction accuracy was high (M = 81%), perhaps somewhat lower than that in Experiment 1 but still significantly higher than chance ($t(32) = 10.21$, $p < .001$). The remaining analysis focused on memory discrimination in the Recognition Memory Phase.

Table 2:Mean Proportions of Rule-based Responses during Category Testing Phase

	High Similarity	Switch
Adults- Experiment 1	.98 (.03)	.97 (.07)
Children- Experiment 1	.92 (.09)	.91 (.17)
Adults-Experiment 2	.82 (.10)	.16 (.19)

Note: Experiment 1 (Deterministic Instructions), Experiment 2 (Probabilistic Instructions). Standard deviations are in parentheses.

Memory discrimination d' scores for Experiment 2 are presented in Table 3, alongside d' scores for Experiment 1. To further examine adults' memory discrimination, d' scores from both experiments were submitted to a One Way ANOVA. The analysis revealed a significant difference between the experiments, $F(1, 60) = 10.28$, $p = .002$, with adults in Experiment 2 having higher memory sensitivity scores (H(.79) – FA(.23) = .56, $d' = 1.80$).

Results of Experiment 2 clearly indicate that post-induction memory is reflective of how induction was performed. Adults' high memory in this experiment indicates that results of Experiment 1 do not stem from adults' having more efficient attention allocation than young children.

Table 3:Mean d' scores for Experiments 1 and 2

Age Group	d'
Adults – Experiment 1	1.06 (.88)
Children – Experiment 1	1.48 (.84)
Adults – Experiment 2	1.80 (.80)

Note: Experiment 1 (Deterministic Instructions), Experiment 2 (Probabilistic Instructions). Standard deviations are in parentheses.

General Discussion

The two experiments reported here aimed to further understand the development of induction, and specifically, the role of attention in the development of inductive mechanisms. To do so, novel categories were introduced as a means to test how adults and children attend to entities during category learning, how they represent those categories for purposes of generalization, and how well they discriminate between entities encoded to memory.

In Experiment 1, adults focused on a single rule feature, resulting in a constricted, knowledge-based representation as evidenced by high proportions of rule-based responses to Switch items and low memory discrimination. However, in Experiment 2 adults' attention was broadened to the overall appearance, thus their representation included more detail as evidenced by low proportions of rule-based responses to Switch items and greater memory discrimination.

Importantly, adults' responses to Switch items and their memory scores in Experiments 1 and 2 correspond with the instructions and feedback provided during Category Training. Low memory in Experiment 1 was not due to more efficient induction, but rather a result of training. And, while children had high proportions of rule-based responses to Switch items in Experiment 1, their memory discrimination was higher than that of adults who were provided the same training on the category inclusion rule. It is clear that children followed the category rule when categorizing but seems very likely that their attention remained distributed across multiple features of the stimuli. As such, children formed similarity-based representations during category learning, used a similarity-based mechanism during induction, and had higher memory discrimination in the recognition test.

Together, these findings demonstrate that adults can use either a knowledge- or similarity-based mechanism of induction, while children use only a similarity-based mechanism. The question being addressed here was *what* underlies the development of the mature knowledge-based mechanism? Results presented here implicate attention as the catalyst of representational and mechanistic change.

That is, as children develop the ability to attend selectively to relevant visual input and filter out the irrelevant (Enns & Cameron, 1987), the kinds of representations formed during category learning and the inductive mechanisms used develop in kind. In sum, the inductive mechanism is directly related to the pattern of attention during category learning and the subsequent representation formed.

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