Attention, Memory, and Development of Inductive Generalization

THESIS

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Abstract

Induction, or the ability to extend knowledge from familiar to novel instances, appears early in development and is an essential aspect of human learning and reasoning. While its importance is universally agreed upon, there is a long standing debate regarding its development. On one hand, it is argued that the underlying mechanism of induction is the same across development. This view holds that changes in induction performance are due to gains in domain specific knowledge and improved understanding of the hierarchical structure of categories. Conversely, the other view argues for developmental change, positing that induction has two routes: an early perceptual mechanism and a slow developing semantic mechanism. The studies presented here provide evidence for the latter, showing that the default (or early emerging) mechanism is based on perceptual similarity, and the development of a knowledge-based mechanism can be attributed to improvements in selective attention. In Chapter 2, a series of three experiments are presented that attempt to determine whether 5-year-old children spontaneously use either semantic or perceptual information when performing induction. In Experiment 1, we attempt to “impair” perceptual processing by introducing a secondary Visual Search task. Experiment 2 examines semantic processing under the demands imposed by the secondary task. Experiment 3 investigates whether children perform category-based induction under the task demands of Experiment 1 when trained to do so. Results of these experiments indicate that induction performance is impaired by the Visual Search task, and that, despite processing semantic information under the demands of that task, children fail to perform induction. In Chapter 3, two experiments are presented investigating how attention allocation
during category learning and induction affects what information is represented and encoded to memory. In Experiment 4, 5-year-olds and adults were directed to attend to a category rule. They were then presented with an induction task followed by a recognition memory test. Similar to previous results with familiar categories, children exhibited better memory for items than adults. In Experiment 5, 5-year-olds and adults were directed to attend to overall category similarity, followed by the same induction and memory tasks. In this experiment, adults’ memory was as good as children’s, and better than adults’ memory in Experiment 4. Results indicate that the way attention is allocated affects how categories are represented, the way induction is performed, and what information is encoded to memory. Together, findings of these 5 experiments indicate that (1) a similarity-based mechanism of induction is the developmental default, (2) memory following induction reflects category representation and the mechanism of induction, (3) category-based induction is a product of development, and (4) the development of category-based induction can be attributed to improvements in selective attention.
To my husband, Will.
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CHAPTER 1: INTRODUCTION

By means of induction, humans generate new knowledge, reason about new objects, and learn in new situations. Induction enables the generalization of nonobvious 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. With such a wide range of possible entities about which an inference could be made, how does one restrict inductions to meaningful sets? Specifically, what allows for ready inferences to some entities while also making inferences to others highly unlikely? To address this question, two theoretical approaches have been proposed: the knowledge-based and the similarity-based. In addition to describing how induction is performed, each theory also describes what developmental changes may occur.

The Knowledge-based Theory of Induction

According to the knowledge-based view, induction, even in young children, is based on category information. This view grants young children a number of a priori category assumptions (see Murphy, 2001 for a review). Some of the assumptions important to performing induction are that 1) entities with common labels belong to the same category, 2) entities contain essential properties that make them what they are, and 3) natural kind categories share many internal properties. And evidence supporting these assumptions is not lacking.
For example, in a study by Gelman and Markman (1986) young children were asked to infer a property from one entity (i.e., the target item) to one of two other entities (i.e., test items). One item looked perceptually similar to the target but had a different label, and the other was perceptually dissimilar to the target but shared the same label. Results showed that children made inferences to same labeled items rather than to perceptually similar items. It was concluded that children made inferences based on their understanding of the importance of category labels as markers of category membership, and that this understanding was a pre-condition of category learning.

In another study (Keil, Smith, Simons, & Levin, 1998), researchers investigated the extent to which children assign importance of a particular property to category membership, and whether the amount of importance, or property essentialism, differed depending on category kind (i.e., animal versus machine). A property by category kind interaction was found such that some properties were considered more essential for the animal category, while other properties more essential for the machine category. Researchers argued that children’s responses demonstrated their a priori understanding of the differential nature of property essentialism.

In a related study by Gelman (1988), children were instructed on unfamiliar and familiar internal properties of familiar categories. Following this instruction, they were asked to infer the property to new exemplars. Results demonstrated that young children inferred even unknown internal properties within basic-level categories, and inferences were also more likely within highly homogeneous categories. The author argued these findings demonstrate that external homogeneity promotes children’s inference of internal
homogeneity, especially for natural kind categories, and that this was not a product of learning.

Together, the above evidence suggests that even young children’s inductions are supported by many category assumptions, and proponents of this view hold that these assumptions are a priori. Thus, when performing induction, children, and adults use these assumptions to identify and label the category of an item, and then infer properties based on whether the novel item belongs to the same labeled category as the familiar target. And because children are most familiar with basic-level categories, they are more likely to infer properties at the basic-level.

Despite the evidence indicating the importance of category assumptions, there are issues this theory does not explain. For example, if the assumptions are pre-conditions of learning, as proponents claim, what is their source? While there is evidence for other early emerging cognitive abilities, including infants’ abilities to estimate time (Colombo & Richman, 2002), discriminate quantity (Xu & Spelke, 2000), and represent spatial location (Rieser, 1979), even innate abilities must have developed from something in our evolutionary past. If this is the case, then the argument that they are not products of development at all is severely weakened.

Another deficit of the knowledge-based approach is that it cannot explain memory differences between children and adults following an induction task. That is, if both age groups are using category information, why would children have better memory for items presented during an induction task as compared to adults (Sloutsky & Fisher, 2004a, 2004b, 2005)? These findings seem counter to the theory that children and adults are using the same information, such as category label, to guide inferences.
The Similarity-based Theory of Induction

In contrast to the approach described above, the similarity-based view does not propose that category assumptions are necessary for performing induction. This view argues that mature induction may be based on one of two mechanisms: similarity-based and knowledge-based. According to this approach, when categories are novel, both children and adults use perceptual similarity to perform induction. However, in adults, induction with familiar categories will be based on knowledge of the category. Thus, differences in how induction is performed are due in part to developmental differences (i.e., development of a mature mechanism), but also to familiarity with the category (i.e., category knowledge).

In similarity-based induction, multiple features of the novel input (i.e., test items) are assessed for similarity to a familiar entity (i.e., target item). Properties are then inferred based on how similar the features of novel item are to the features of 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. Importantly, according to this account, both children and adults would have the ability to perform similarity-based induction.

As stated, this view holds that when categories are familiar, adults will rely on a knowledge-based mechanism. In knowledge-based induction the 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. Properties are then inferred based on whether the entities belong to the same-labeled category. As such, this mechanism does depend on category knowledge, such as knowledge that items from the same category share many
properties, including shared labels (Deng & Sloutsky, 2013), but also causal (Badger & Shapiro, 2012; Bulloch & Opfer, 2009) and ontological (Gelman & Davidson, 2013) properties.

A critical aspect of the similarity-based view of induction is the hypothesis that young children rely on a different mechanism than adults when performing induction with familiar categories. In order to test this hypothesis, Sloutsky and Fisher (2004a) developed the Induction-then-Recognition paradigm (ITR). 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; Tharp & 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 logic described above, 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. These predictions have received much empirical support (Sloutsky & Fisher, 2004a; 2004b; Fisher & Sloutsky, 2005), however the evidence does not explain what drives the development of a different mechanism of induction.
What develops?

Considering the lack of consensus regarding which account of induction, the knowledge- or similarity-based, best explains the underlying mechanisms of induction, many questions remain to be addressed. 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)? Conversely, 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). That is, the mechanism driving induction does not change, and any changes in how induction is performed can be explained by changes in children’s knowledge. Changes include age related gains in 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 and use of hierarchical category structures.

On the other hand, the similarity-based view holds that what develops are the underlying mechanisms 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. There are a number of suggestions as to why this developmental transition may take place, including (a) better understanding of the taxonomical structure of categories (Fisher, et al., 2015), (b) accumulation of evidence that label is a better cue to category membership than appearance (Deng & Sloutsky, 2012; 2013), (c) the increasing ability to attend selectively (Deng & Sloutsky, 2015; Rabi & Minda, 2014); (d) the increasing working memory capacity (Fisher, Godwin, & Matlen, 2015; Rabi & Minda, 2014); or (e) a combination of these factors.

Clearly there is much to be done in order to understand what develops regarding inductive generalization. The goal of this paper is to address some of the questions concerning what develops and why. Specifically, is the similarity-based mechanism of induction the developmental default? Second, is category-based induction a product of development? Third, what accounts for the development of category-based induction? And last, does memory in the ITR paradigm reflect category representation and mechanism of induction?

Chapter 2 will address the first two questions in a series of three experiments. These experiments introduce a novel dual task paradigm in which visual processing is “impaired” in order to determine whether children use category-based processing during induction when perceptual processing is attenuated. The last two questions are addressed in Chapter 3. In this chapter, two novel experiments are presented in which category representation is manipulated and then induction and memory accuracies are measured to determine if the mechanism used during induction is consistent between children and adults and across representation types.
CHAPTER 2: DISCRIMINATING BETWEEN SIMILARITY- AND CATEGORY-BASED INDUCTION

Recall, that according to the similarity-based account, induction is initially similarity-based, but becomes category-based as a result of development. Therefore, young children rely primarily on perceptual similarity (i.e., similarity-based induction is a default), whereas their ability to rely on semantic information emerges in the course of development.

In contrast, according to the knowledge-based account, the mechanism of induction does not change in the course of development. In this case, some of the recognition memory results reported within the ITR paradigm (Sloutsky & Fisher, 2004a; 2004b) could be explained by differences in attention to perceptual information between children and adults. For example, it has been suggested that higher memory accuracy in children reflects their inability to filter out irrelevant perceptual information (Hayes, McKinnon, & Sweller, 2008; Wilburn & Feeney, 2008). That is, adults can focus primarily (or even exclusively) on semantic (or category-level) information, whereas children cannot attend efficiently. As a result, children process both semantic and perceptual information.

To support the above claim, Wilburn and Feeney (2008) reported a sharp decrease in children’s memory accuracy when stimulus display time during induction was limited (i.e., 250 ms). While children and adults could still perform induction under the limited
time condition, they could not discriminate between previously presented items and new items from the same category (i.e., they exhibited low verbatim memory). However, memory for presented categories (i.e., gist memory) was high for both children and adults. The authors argue that their results indicate children perform category-based induction. However, it may be that the time limit was not long enough for children to fully process and encode perceptual information to memory. The current research will investigate this possibility by selectively “impairing” perceptual processing, and then examining the consequences of that “impairment” on induction performance. If children rely primarily on perceptual information, then impairing perceptual processing should impair induction. In contrast, if children can rely on either perceptual or semantic information, then “impairing” perceptual processing should not impair induction because semantic information would still be available for performing induction.

To introduce the perceptual “impairment” we presented children with a secondary visual search task while they were performing induction. In contrast to previous research (Sloutsky & Fisher, 2004a; Wilburn & Feeney, 2008), only five-year-old children were included in the study because it is with this age group in which the mechanisms of inductive processing are most highly debated.

In what follows, we addressed the following questions: (1) is the similarity-based mechanism of induction the developmental default, and (2) is category-based induction a product of development? Experiment 1 introduced a novel manipulation and compared children’s induction performance in this condition to a no-manipulation baseline. Experiment 2 examined semantic processing under the visual search manipulation introduced in Experiment 1. And Experiment 3 investigated whether children can
perform category-based induction when trained to do so, under the visual search demands.
Experiment 1

In this experiment a novel manipulation is introduced. The manipulation is a secondary visual search task designed to impair perceptual processing. Induction accuracy in this condition is then compared to induction accuracy in a single task, no manipulation, baseline condition.

Method

Participants

Fifty-six children (Baseline Condition: $N = 26, M_{\text{age}} = 5.35$ years, $SD = 0.18$; Visual Search Condition: $N = 30, M_{\text{age}} = 5.30, SD = 0.26$), recruited at local childcare centers, participated on the basis of returned permission slips. Childcare centers were primarily located in middle-class neighborhoods in a large Midwestern City. Each child was tested individually in a quiet room. Ten children (Visual Search = 10) were excluded due to low accuracy on the secondary task.

Materials

Both conditions used the same set of visual stimuli that consisted of 44 color photographs of animals on white backgrounds (see Figure 1 for examples) presented in the center of the screen. In addition, there were secondary task stimuli specific to the Visual Search (VS) condition. The VS condition used a set of visual stimuli that consisted of 16 red or black “+” and “o” symbols. These symbols were randomized and administered by Rapid Serial Visual Presentation, with items being presented for 250 ms
each with 250 ms inter stimulus intervals. Visual Search symbols were presented in the upper right hand corner of the screen with eccentricity of approximately 23° visual angle from the center of the monitor and subtending approximately 1.4° of visual angle. Sensitivity to both contrast and spatial frequency are greatly attenuated at such eccentricities (Strasburger, Rentschler, & Juttner, 2011), thus substantially reducing visual acuity with respect to the centrally presented stimulus. As a result, participants retain the ability to identify the basic-level category of the centrally presented stimuli, whereas their ability to perform detailed perceptual processing is attenuated (Strasburger, Rentschler, & Juttner, 2011; Thorpe, Gegenfurtner, Fabre-Thorpe, & Bülthoff, 2001).

Experiments were conducted on a Dell Inspiron laptop computer and stimuli were presented on a secondary 22” wide screen monitor. All experiments were programmed in E-Prime Professional 2.0 software.
Design and Procedure

The experiment had 2 between-subjects conditions: Baseline and Visual Search (VS). Whereas the primary task in both conditions was the same (i.e., to perform inductive generalization), the secondary task differed across the conditions. In the Baseline condition there was no secondary task, and in the VS condition the secondary task was to detect red “+” signs in a stream of red and black “+” and “o” signs.

The two conditions differed with respect to the secondary tasks (described above), whereas the same induction task was presented to all participants. In this task, each
participant saw 30 pictures of animals, one at a time, in random order. The animals were selected from 3 categories: 10 bears, 10 birds, and 10 cats. The pictures were presented centrally on a 22” wide screen monitor for 2750 ms each. This trial duration was selected by taking the average response time of 5-year-old children who participated in an untimed pilot version of the experiment. Participants were first shown a picture of a cat and told the cat had “beta-cells in its blood” (see Figure 2 for task sequence). On each trial, participants saw one picture of an animal and were asked if the presented animal also had beta-cells. Yes/No feedback was provided indicating that only cats had beta cells.

**Baseline Condition**

In this condition, participants were only presented with the induction task -- no secondary task was given in the Baseline condition. See Figure 2 for trial structures of each condition.
Figure 2: Trial structures for Experiment 1.
Notes: (a) Baseline Condition in which no secondary task was given, and (b) VS Condition in which a secondary visual search task is introduced instructing participants to monitor the upper right hand corner of the computer screen for a red “+” sign.

**Visual Search Condition**

This condition was similar to the Baseline Condition, with one exception: participants received a secondary Visual Search (VS) task. For the VS task, participants were initially shown randomly presented red and black “+” and “o” signs and were asked to detect a red “+” sign on each of the subsequent study phase trials. Verbal corrective feedback was provided to redirect attention to the visual search task if needed, and Yes/No feedback was provided to indicate whether participants correctly identified the red “+” signs. Fifty percent of the trials contained a red “+” sign and participants failing to reach 70% accuracy on the VS task were excluded from analyses. Simultaneously with the VS task, participants were presented with the same induction task as in the Baseline
Condition. The induction task was also accompanied by feedback which was identical to that in the Baseline condition.

Results and Discussion

In this experiment, participants were asked to perform induction under two different conditions: Baseline (where participants performed induction), and Visual Search (where participants performed induction with perceptual load). The goal of the latter condition was to impair the perceptual route to induction. If participants are able to use either semantic or perceptual information to perform induction, then induction accuracy should be well above chance in both conditions. However, if the task demands differentially affect induction, than accuracy in the VS condition may be reduced compared to the Baseline. Induction accuracies for both Experiment 1 conditions are reported in Figure 4.

![Figure 3: Average induction accuracy by condition. Note: error bars reflect standard errors of the mean.](image-url)
Data in Figure 3 were submitted to a between-subjects ANOVA. The analysis revealed a significant main effect of condition, $F(1, 44) = 30.1, p < 0.001$, such that children’s performance was significantly lower in the visual search condition ($M = 0.49$) than in the other condition ($M = 0.79, d = 1$). Furthermore, children’s induction performance in the Visual Search condition did not differ from chance, $p = 0.845$.

These findings suggest that impairing perceptual processing in children did attenuate induction. Although these are potentially important findings, there are alternatives that can possibly undermine their importance. That is, perhaps the attentional manipulation used in the VS condition did not actually impair perceptual processing as expected. It could be argued that the visual search task reduces visual acuity in children to such an extent that they are unable to either compute similarity between the target and test items (i.e., their perceptual processing is attenuated) or even determine the category of the test items (i.e., both perceptual and semantic processing is attenuated). If the latter is the case, then the visual search task impairs both the perceptual and the semantic routes to induction, thus leaving no basis for inductive inference. We address these possibilities in Experiments 2 and 3. If children in the VS condition can ably detect the category of each item, but do not use this information in their induction, this would present evidence that young children have difficulty performing induction only on the basis of self-generated category labels.
Experiment 2

This experiment was similar to Experiment 1 VS Condition, with the following critical difference. In order to examine children’s ability to self generate the category label for items under the Visual Search dual task demands, participants were asked to name the animal that was in the picture rather than to perform induction.

Method

Participants

Twenty-seven children ($M_{age} = 5.28; SD = 0.21$) participated at their childcare centers. Childcare centers were primarily located in middle-class neighborhoods in a large Midwestern City, and testing took place with each child individually in a quiet room. Seven children were excluded due to low accuracy on the visual search task.

Materials

Stimuli used in this experiment were identical to those used in the Visual Search Condition of Experiment 1. The experiment was conducted on a Dell Inspiron laptop computer, presented on a 22” wide screen monitor, and was programmed in E-Prime Professional 2.0 software.

Design and Procedure

The experiment was similar to the Visual Search condition from Experiment 1, except that instead of an induction task, children were presented with a categorization task (See Figure 4 for task structure). Specifically, participants were asked on each trial to name what kind of animal had been presented. This was done to determine whether
children were able to access category information when performing Visual Search and then self generate the basic-level category label. Obviously, if they could not, this would cast doubt on Experiment 1 because it would have to be concluded that visual search impairs both perceptual and semantic processing in young children, thus making them unable to perform induction.

Figure 4: Trial structure for Experiment 2.
Note: VS Categorization Condition in which participants are instructed to monitor the upper right hand corner of the computer screen for a red “+” sign.

Results and Discussion

In this experiment, children were asked to perform naming (which is a variant of a category identification task) rather than induction, with the goal of examining whether semantic information was available and could be self generated by children in the VS task. If it is indeed available and they can generate it (but children simply did not use it in Experiment 1), then naming accuracy should be high. In contrast, if children could not identify and label the category of an item, then VS disabled not only similarity
computation, but also access to semantic information. In the latter case, we would need to conclude that the task was simply too difficult to be informative.

Children’s naming accuracy in this condition was 81%, demonstrating that children were able to identify and label the category of the presented items under the Visual Search dual task demands. Importantly, their visual search accuracy ($M = 87\%$) did not differ from that in Experiment 1, $t(38) = -1.57, p = 0.124$. Therefore, whereas children in Experiment 1 could self-generate labels, they either did not do so or did not use this information in their induction.

To ascertain that children in the VS condition remember introductory information (i.e., what animal was introduced as having beta-cells), we replicated Experiment 1 VS Condition with 30 additional children. The procedure was identical to that in Experiment 1, except at the end of the induction task, we asked participants what kind of animal had beta-cells. Although neither their VS accuracy nor their induction accuracy differed from those in Experiment 1, their memory for introductory information was high (84%), demonstrating that children were able to maintain the information necessary for performing induction.

Taken together results of Experiments 1 and 2 indicate that a secondary VS task impairs induction, while leaving semantic processing unimpaired. In the previous experiments we failed to find evidence of 5-year-olds’ relying on semantic information in their inductions. This suggests that young children are more likely to rely on perceptual than semantic information when performing induction. It could be argued, however, that category identification and labeling are easier tasks than induction, and as such children’s naming accuracy in Experiment 2 was high, while induction accuracy in Experiment 1
was low. That is, perhaps the naming task in Experiment 2 does not address the difficulty of performing induction under the VS task demands. This possibility was addressed in Experiment 3.
Experiment 3

In order to determine whether children are able to use semantic information to perform induction under the visual search dual task demands, category-based induction training was introduced prior to children performing induction. Importantly, children were trained to perform category-based induction with categories different from those used in the experiment proper.

Method

Participants

Twenty-five children \((M_{\text{age}} = 5.33; \ SD = 0.20)\) participated at their childcare centers. Childcare centers were primarily located in middle-class neighborhoods in a large Midwestern City, and testing took place with each child individually in a quiet room. Two children were excluded due to low accuracy on the visual search task.

Materials

Stimuli used in this experiment were identical to those used in the Visual Search Condition of Experiment 1, and additional training stimuli were introduced. Training stimuli consisted of three black animal silhouettes on white backgrounds and seven color photographs on white backgrounds. Categories used in training were not used during the primary induction task and included rabbits, dogs, and horses. The experiment was conducted on a Dell Inspiron laptop computer, presented on a 22” wide screen monitor, and was programmed in E-Prime Professional 2.0 software.
Design and Procedure

The experiment was similar to the Visual Search condition from Experiment 1, except that training was conducted prior to the induction task. Training in this experiment was similar to that used by Fisher and Sloutsky (2005) and was designed to determine if children could use semantic information to perform induction when trained to do so. Prior to beginning induction, children were trained on three items of information: 1) animals with the same name are the same kind of animal, 2) animals that are the same kind have similar insides, and 3) animals with the same name have similar insides.

Training proceeded as follows: first, children were told that “animals with the same name are the same kind of animal.” Children were then shown the three animal silhouettes arranged in line on the bottom half of a computer monitor and were asked to name what kind of animal was in each silhouette. Next, six categorization trials consisting of photographs of animals from the same categories as the silhouette categories were displayed, one photograph at a time, on the top half of the monitor. Children were asked to point to the silhouette that was the same kind of animal as the one in the color photograph. Corrective yes-no feedback was provided after each trial.

Following categorization training, participants were given six induction training trials. Children were first reminded that animals with the same name are the same kind, and were then told “animals that are the same kind have the same stuff inside.” They were then shown a photograph of a target animal and told that the animal had some biological property (i.e., “this dog has think blood inside its body”). Next, children were shown pictures of other animals and asked to decide if they also had this property.
Corrective feedback was provided indicating that only target category items had the property because animals that are the same kind have the same stuff inside.

After categorization and induction training was complete children were reminded that “animals with the same name are the same kind of animal and have the same stuff inside.” All children successfully completed categorization and induction training and then proceeded to the Visual Search (VS) task. The VS task in this experiment was identical to that presented in Experiment 1.

**Results and Discussion**

In this experiment, participants were asked to perform induction following category-based induction training. If the demands of the dual task are such that semantic and perceptual information are inhibited, then accuracy in this task should not differ from that in the VS condition in Experiment 1. However, if visual search only attenuates perceptual processing and not semantic processing then accuracy in this task should be better than that in the VS condition of Experiment 1.

Accuracy in Categorization and Induction Training were both high ($M = 99\%, SD = .04$ and $M = 80\%, SD = .21$ respectively). Visual search accuracy was also high ($M = 87\%, SD = .10$) and did not differ from Experiment 1, $t (41) = -1.26$, $p = .21$. As predicted, induction accuracy in this condition was high ($M = 87\%, SD = .10$), and is presented in Figure 3 alongside data from Experiment 1. Furthermore, a comparison of the data from the two conditions in Experiment 1 and this experiment was conducted. A one-way ANOVA showed a main effect of condition on induction accuracy, $F (2, 66) = 32.74$, $p < .001$. Further analysis demonstrated that induction accuracy was significantly
higher in the VS Training condition than in the VS condition of Experiment 1, \( t(41) = 8.45, p < .001 \) and marginally higher than in the Baseline of Experiment 1, \( p = .07 \).

Findings of this experiment show that visual search does attenuate perceptual processing during induction while not attenuating semantic processing. Following training, children in this experiment were able to use semantic information to perform category-based induction under the VS task demands. These data demonstrate that task demands do not account for children’s low induction accuracy in Experiment 1.

**General Discussion**

The three experiments reported here introduced and tested a new paradigm for studying the mechanism of early induction. Experiment 1 attempted to impair perceptual processing by introducing a secondary Visual Search task. Experiments 2 and 3 assessed whether task demands alone can account for reduced induction accuracy in the VS task in Experiment 1. Results of Experiment 1 indicate that the visual search manipulation affected children’s induction performance. Furthermore, results of Experiment 2 show that children ably processed category information under the demands of the Visual Search condition, yet they failed to perform induction under those demands in Experiment 1. Lastly, results of Experiment 3 found that children can perform induction under the demands of the Visual Search task when they are trained to perform category-based induction.

Reported results indicate that impairing visual processing severely attenuated children’s ability to perform induction. The fact that even under the impaired visual processing condition, children could generate category labels (i.e., they ably named each item and performed category-based induction when trained to do so) suggests that they
do not spontaneously use category information when performing induction. These findings, in conjunction with other reports that under some conditions young children can perform category-based induction, strongly indicate that category-based induction is a product of development, whereas similarity-based induction is a developmental default.

While the results presented here are important, there are several questions that remain unanswered. First, as it has been demonstrated here that category-based induction is a product of development, what accounts for this development? And second, since this study addressed induction directly rather than inferring mechanism from memory, how can the memory results in previous studies be interpreted? Specifically, does memory in the ITR paradigm reflect differences between adults’ and children’s abilities to filter irrelevant information, or rather, does memory reflect underlying category representation and mechanism of induction? These questions will be addressed in the following chapter.
CHAPTER 3: ATTENTION AND THE DEVELOPMENT OF
INDUCTIVE GENERALIZATION: EVIDENCE FROM
RECOGNITION MEMORY

The results presented in Chapter 2 strongly indicate that category-based induction is a product of development, whereas similarity-based induction is a developmental default. It is proposed that the default similarity-based mechanism is not replaced by the emerging knowledge-based mechanism, rather the two mechanisms co-exist. As such, adults may use either mechanism, with the knowledge-based mechanism being the primary one. While adults’ use of a knowledge-based mechanism is not under debate, it is unclear what underlies its development. Thus, the goal of this chapter is to address the question, what develops?

One explanation for what develops could be taken form research in category learning. Considering that induction, like categorization, is a generalization process, it is possible that changes in induction and categorization are driven by the same developmental factor. For example, there is growing evidence that developmental changes in attention contribute in key ways to changes in category learning and representation. For example, 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. When new categories were introduced, adults continued to focus on the previously learned
category rule feature, and thus demonstrated a cost, or delay, in learning the new categories. 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 a similar cost of attention. Adults continued to attend to a category rule feature even when new categories with new rule features were introduced.

Further evidence of 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. During item classification and feature inference, older children and adults demonstrated an asymmetry in their responses. When classifying, these participants relied on a single deterministic feature, 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.

It is hypothesized that the distributed attention observed in infants and young children promotes forming a similarity-based category representation, as well as a similarity-based mechanism of induction. This hypothesis is also consistent with memory results in Induction-then-Recognition (ITR) tasks. That is, if distributed attention promotes similarity-based representations and induction, it would explain why memory for specific items (i.e., verbatim memory) would be high. Distributed attention to
multiple features would result in encoding the overall appearance of an item (Marks, 1991). In this case, children’s high memory, as compared to adults’, would be due to their inability to selectively attend to only task relevant information, such as a self-generated category label. Furthermore, attention focused to a single feature, such as a rule feature or category label (Deng & Sloutsky, 2013), would promote forming a knowledge-based representation and use of a knowledge-based mechanism during 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. In this case, adults’ poor memory when inferring properties across familiar categories would be due to their attention focused only on task relevant semantic information (i.e., the category label).

The current experiments were designed to examine the role of attention in the development of a category-based mechanism of induction, and to determine whether memory following an ITR task reflects the type of representation formed and the inductive mechanism used. In Experiment 4, children and adults were taught rule-based categories. After testing their categorization, participants were given an ITR 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 5 where adults and children learned similarity-based categories and were then presented with the same ITR task. If adults are merely more strategic at induction than young children, then adults’
memory for items in this condition should remain as low as in Experiment 4, and children’s should be equivalent across experiments. In contrast, if Experiment 4 reflects differences in how induction is performed, then adults in this experiment should exhibit better memory for items after induction than in Experiment 4.
Experiment 4

Method

Participants

Thirty-one adults (M_{age} = 20.3 years) and thirty-two 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.

Materials

Both experiments presented here used visual stimuli consisting of two categories of artificial insect-like creatures. 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 5). The remaining stimuli were constructed by exchanging probabilistic features between categories or introducing new probabilistic features.
### Category F

<table>
<thead>
<tr>
<th>P_{fep1}</th>
<th>P_{fep2}</th>
<th>P_{fep3}</th>
<th>P_{fep4}</th>
<th>P_{fep5}</th>
<th>P_{fep6}</th>
<th>D_{fep}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Body</td>
<td>Legs</td>
<td>Wings</td>
<td>Antenna</td>
<td>Claws</td>
<td>Tail</td>
</tr>
</tbody>
</table>

| Prototype | 0 | 0 | 0 | 0 | 0 | 0 |
| High      | 0 | 0 | 1 | 0 | 0 | 0 |
| Med Sim.  | 1 | 1 | 0 | 0 | 0 | 0 |
| Switch    | 1 | 1 | 0 | 1 | 1 | 1 |
| NP_{fep}D_{fep} | 0 | 0 | 0 | 0 | N0 | 0 |
| NP_{dax}D_{fep} | 0 | 0 | 0 | N1 | 0 | 0 |
| Low Sim.  | N1 | 1 | 1 | N2 | N0 | 0 |

### Category D

<table>
<thead>
<tr>
<th>P_{dax1}</th>
<th>P_{dax2}</th>
<th>P_{dax3}</th>
<th>P_{dax4}</th>
<th>P_{dax5}</th>
<th>P_{dax6}</th>
<th>D_{dax}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Body</td>
<td>Legs</td>
<td>Wings</td>
<td>Antenna</td>
<td>Claws</td>
<td>Tail</td>
</tr>
</tbody>
</table>

| Prototype | 1 | 1 | 1 | 1 | 1 | 1 |
| High      | 1 | 0 | 1 | 1 | 1 | 1 |
| Med Sim.  | 0 | 0 | 1 | 1 | 1 | 1 |
| Switch    | 0 | 0 | 0 | 0 | 1 | 0 |
| NP_{dax}D_{dax} | 1 | N1 | 1 | 1 | 1 | 1 |
| NP_{fep}D_{dax} | 1 | 1 | N0 | 1 | 1 | 1 |
| Low Sim.  | 1 | 1 | N1 | N2 | N0 | 1 |

Table 1: Example of stimulus structures used in Experiments 4 and 5.

Note: P = probabilistic feature; D = deterministic feature; 0 = dimension corresponding with Category F features; 1 = dimension corresponding with Category D features. Nn = new feature and the corresponding feature value.

---

**Figure 5:** Prototypes of Category F and Category D.

Note: Prototypes were not presented during the experiment.
Of the seven features present on each stimulus, one was deterministic and was never exchanged between categories. That feature (i.e., 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.

**Design and 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*

Instructions were provided prior to Category Training. Participants were first 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. Each block contained six High Similarity (High Sim.) items from each of the two categories.
High Sim. items contained the deterministic feature and five probabilistic features from within the category and one probabilistic feature from the alternate category (see Table 1 for example stimulus structure).

Category Testing

Participants were told to continue categorizing, as in Category Training phase. No feedback was provided in this phase. This phase contained two blocks. Block one presented the same twelve High Sim. items from Category Training, plus twelve Medium Similarity (Med. Sim.) items that had two probabilistic features from the alternate category. Block two presented twelve critical Switch items, six from each category. Switch items had the High Sim. probabilistic feature construction of one category (e.g., Category D), but the deterministic feature of the other category (e.g., Category F). The items could then be categorized as members of either category (e.g., the same item could be categorized as Category D if based on the probabilistic features, or as Category F if based on the rule feature). Following Category Testing all participants took a timed two minute break before proceeding to the ITR task.

Induction.

Participants were first shown an example of a High Sim. 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”). This phase contained one block of 36 trials. Items included twelve novel items from each category, each of which contained a new value for each feature (e.g., NP_{lep} D_{lep} items had one novel Category F
probabilistic feature, five Category F probabilistic features, and the Category F deterministic feature; \(\text{NP}_{\text{dax}} \ D_{\text{lep}}\) had one novel Category D probabilistic feature, five Category F probabilistic features, and the Category F deterministic feature). There were also twelve novel Distracter items. 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 which items were old and which were new. This phase contained one block of 36 trials. Items included the same twelve target category items from the Induction Phase (old Category F exemplars), twelve novel Low Similarity (Low Sim.) target category items (new Category F exemplars), six non-target category items from the Induction Phase (old Category D exemplars), and six novel Distracters. Low Sim. items contained five previously observed probabilistic features, one novel probabilistic feature that had not been used at any time in the preceding phases of the experiment, and the deterministic feature of the target category.

**Results and Discussion**

Accuracy in Category Training was high for both children (\(M = 94\%\)) and adults (\(M = 97\%\)) with both groups performing significantly better than chance (both \(p s < .001\)). Proportions of rule-based responses to High and Med. Sim. Items, as well as Switch items, from 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 \(p s < .001\)). Induction accuracies were equivalently high for
children \((M = 85\%)\) and adults \((M = 91\%)\), two-tailed \(t(61) = 1.89, p = .7\). The remaining analysis focused on results of the Recognition Memory Phase.

Memory discrimination was analyzed using signal detection \(d'\) scores. To calculate \(d'\) scores, each participants’ proportions of false alarms to new items (target category items not presented during induction) and hits to old items (target category items presented during induction) were converted to Z scores. The Z score for the false alarms was then subtracted from the Z score for hits, resulting in individual \(d'\) scores. If participants do not discriminate old from new target category 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 was marginally better than that of adults \((d' = 1.5 \text{ vs. } d' = 1.13 \text{ respectively}), t(61) = 1.75, \text{ one tailed } p = .09\).

Results of Experiment 4 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 during Category Testing was very high, suggesting that they (similar to adults) did learn a rule-based category. At the same time, children exhibited somewhat better memory than adults. This finding suggests that in the course of induction, children were likely attending to more than just the deterministic feature that defined the category. These findings are consistent with the theory that children rely on the overall similarity when performing induction. It could be argued however, that the observed differences simply reflect developmental differences in the efficiency of allocating attention during induction. Experiment 5 addresses this question.
Experiment 5

This experiment was similar to Experiment 4, with one exception: children and adults were trained on similarity-based (rather than rule-based) categories. If Experiment 4 simply reflects differences in the efficiency of attention allocation during induction, adults’ memory after performing induction in this experiment should remain low. In contrast, if memory for items is reflective of the mechanisms of induction, adults’ memory in Experiment 5 should be higher than that in Experiment 4, and children’s should be equivalent across experiments.

Method

Participants

Thirty-two adults (\(M_{\text{age}} = 20.35\) years) and twenty-five children (\(M_{\text{age}} = 5.2\) years) participated in this experiment. An additional three children were excluded from analysis for not responding reliably above chance to High and Med. Sim. items at Category Testing. One adult was excluded for responding more than two standard deviations below the mean at Recognition Memory.

Materials

Visual Stimuli were identical to those used in Experiment 4.

Design and Procedure

Procedures for this experiment were similar to those described in Experiment 4, 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 for both children ($M = 69\%$) and adults ($M = 86\%$) and both were significantly better than chance (both $ps < .001$). Proportions of rule-based responses to High and Med. Sim. items, and to Switch items, from Category Testing are reported in Table 2. The proportion of rule-based responses on High and Med. Sim. items was significantly better than chance for both age groups (both $ps < .001$), however, Switch item responses varied. Adults’ Switch responses in this experiment were lower than adults in Experiment 4 ($F(1, 62) = 497.65, p < .001$) and lower than chance ($t(32) = -10.36, p < .001$). Children’s Switch item responses were lower than children in Experiment 4 ($F(1, 55) = 31.25, p < .001$), but did not differ from chance ($p = .78$). Induction accuracy was high for children ($M = 71\%$) and adults ($M = 81\%$), with both groups perhaps somewhat lower than in Experiment 4. The remaining analysis focused on memory discrimination in the Recognition Memory Phase.
<table>
<thead>
<tr>
<th></th>
<th>High &amp; Med. Sim. Items</th>
<th>Switch Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults – Experiment 4</td>
<td>.98 (.03)</td>
<td>.97 (.07)</td>
</tr>
<tr>
<td>Children – Experiment 4</td>
<td>.88 (.16)</td>
<td>.86 (.23)</td>
</tr>
<tr>
<td>Adults – Experiment 5</td>
<td>.83 (.10)</td>
<td>.16 (.19)</td>
</tr>
<tr>
<td>Children – Experiment 5</td>
<td>.68 (.15)</td>
<td>.54 (.25)</td>
</tr>
</tbody>
</table>

Table 2: Mean Proportions of Rule-based Responses during Category Testing Phase
Note: Experiment 4 (Deterministic Instructions), Experiment 5 (Probabilistic Instructions). Standard deviations are in parentheses.

Memory discrimination $d'$ scores for Experiment 5 are presented in Figure 6, alongside $d'$ scores for Experiment 4. To further examine memory discrimination, $d'$ scores from both experiments were submitted to a 2 (Instruction Type: Probabilistic and Deterministic) X 2 (Age Group: Children and Adults) ANOVA. The analysis revealed a moderately significant interaction $F (3, 116) = 2.897, p = .09$, and a main effect of Instruction Type ($F (3, 116) = 12.053, p = .001$). Further analysis showed that adults in Experiment 4 had lower memory sensitivity scores compared to adults in Experiment 5 ($t (62) = 3.24, p < .01$), and children’s memory did not differ between Experiments 4 and 5 ($p = .24$).
Results of Experiment 5 clearly indicate that post-induction memory is reflective of the representation formed during category learning and how induction was performed. Adults’ high memory in this experiment, and children’s equivalent memory across experiments, indicates that results of Experiment 4 do not stem from adults’ having more efficient attention allocation than young children.

**General Discussion**

The two experiments reported here aimed to further understand the development of induction. Specifically, what is the role of attention in the development of inductive mechanisms, and what can we infer from memory following an induction task. To address these questions, 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 4, 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 5 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 4 and 5 correspond with the instructions and feedback provided during Category Training. Low memory in Experiment 4 was not due to more efficient induction, but rather a result of how attention was allocated during training. And, while children had high proportions of rule-based responses to Switch items in Experiment 4, 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 was distributed across multiple features of the stimuli regardless of the instructions and feedback. As such, children in both experiments formed similarity-based representations during category learning, used a similarity-based mechanism during induction, and had equivalent 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 support the hypothesis
that attention acts as a catalyst of representational and mechanistic change. It is proposed
that, 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.
CHAPTER 4: CONCLUSIONS

Recall that we considered two theoretical accounts of early induction: knowledge-based and similarity-based. According to the knowledge-based view, the inductive mechanism is stable across development. Children and adults first identify the category of an entity, and then perform induction on the basis of shared category (Gelman & Markman, 1986; Gelman, 1988). Category identification is accomplished by using a provided category label or by self-generating the label. Thus, induction is a category-based process, while categorization is a semantic process based on the label.

In contrast, according to the similarity view, early in development both categorization and induction are variants of the same process of similarity computation. Under this view, induction starts out as similarity-based and category-based induction develops gradually (Fisher & Sloutsky, 2005; Fisher, et al, 2015). Young children (and adults when categories are novel) first detect multiple similarities among presented entities, and then perform induction on the basis of similarity. Older children and adults identify the category of the entity, when categories are familiar, and then perform induction on the basis of shared category.

To adjudicate between these two accounts, Experiments 1 – 3 impaired visual processing, and thus similarity computation, by asking participants to perform Visual Search (VS) while performing induction. Results indicate that perceptual load in VS
conditions disrupted children’s ability to perform induction. At the same time, VS did not disable their ability to identify and label the category, or to perform category-based induction when trained to do so. Therefore, while the common category was available, young children did not spontaneously use it to perform induction. These findings suggest that in the absence of a provided label, full access to visual information is necessary for young children to perform induction.

In the above studies, appearance information is either partially (i.e., the Visual Search conditions) or fully (i.e., the Baseline condition) available, but labels are not provided. Therefore, in order to perform category-based induction, participants should self-generate the labels. Results indicate that without full access to visual information children failed to perform induction (see results of Experiment 1). This was despite the fact that they could access category information (see results of Experiment 2), and use category information to perform induction when trained to do so (see results of Experiment 3). These findings suggest that category-based induction is a product of development, whereas similarity-based induction is a developmental default. Given that the knowledge-based approach presumes no transition from similarity- to category-based induction, whereas the similarity-based account does, these findings provide support for the latter, but not for the former account.

If full access to appearance information is so important, why do 5-year-olds successfully perform induction when items are presented for very short periods (250 ms in Wilburn & Feeney, 2008)? Although, the precise time course of full perceptual processing is unknown, there is evidence that in adults such processing could require around 167 ms, whereas categorization requires only about 68 ms (Grill-Spector &
Kanwisher, 2005). Even if perceptual processing in 5-year-olds is 50% slower than that in adults, 250 ms should be enough for them to fully process each item.

At the same time, such brief presentation may not be enough to form a robust memory trace for the items (Potter, 1976): when a sequence of items was presented at 250 ms or even 333 ms per item, recognition memory for the items was quite low, even when testing was introduced immediately after the presentation of the sequence. Therefore, it is not surprising that when Wilburn and Feeney (2008) tested post-induction recognition memory in young children, their memory was low.

In addition, as argued by Sloutsky and Fisher (2004a), findings of low recognition memory are difficult to interpret in the absence of accurate recognition memory in the no induction baseline. It is only then can we conclude that performing induction (rather than other task demands) affected memory performance. Unfortunately, no such baseline was introduced in Wilburn and Feeney (2008), and Potter’s (1976) results strongly suggest that under the 250 ms presentation time recognition memory would be poor even in the baseline. Therefore, it is not clear that Wilburn & Feeney’s results present evidence against similarity-based induction early in development.

Results presented in Experiments 4 – 5 of this study further demonstrate that memory following induction is not due to children’s inability to inhibit perceptual processing, as suggested by Wilburn and Feeney (2008). Rather, memory reflects the category representation formed during learning and the mechanism used during induction. Experiments 4 – 5 systematically manipulated the category representation participants formed by directing their attention to either a category rule (see results of Experiment 4) or overall appearance (see results of Experiment 5). With attention
directed to the category rule, adults formed a category-based representation during category learning, and then used a category-based mechanism during Induction. This was evidenced in their memory accuracy following induction. Adults whose attention was directed to the category rule had poor memory discrimination following induction compared to children who received the same training instructions.

The pattern of memory results observed in Experiment 4 is similar to memory results with familiar categories (Sloutsky & Fisher, 2004a, 2004b, Fisher & Sloutsky, 2005) in that children exhibit better memory than adults. In contrast, when attention was directed to overall appearance in Experiment 5, adults’ memory was considerably higher compared to adults in Experiment 4, while children’s memory was equivalent across experiments. These findings support the account that memory discrimination reflects the inductive mechanism being used.

Results of Experiments 4 – 5 also support the hypothesis that the development of selective attention is a catalyst for the development of category-based induction. In Experiment 4, children’s responses during categorization were rule-based, as were adults’, however their memory following induction was not. This asymmetry between children’s categorization and memory discrimination could be explained by previous findings demonstrating that attentional and inhibitory processes develop sequentially (Klenberg, Korkman, & Lahti-Nuuttila, 2001). In that study with 3- to 12-year-olds, it was found that by the age of six children reached a mature level of task-specific motor and impulse control. However, not until ten years of age did children reach a mature level of task-specific visual attention. Thus it is likely that children in Experiment 4 reported here were able to make rule-based responses during categorization, but that their attention
remained distributed. This explanation is also consistent with the developmental trajectory of memory discrimination observed by Fisher and Sloutsky (2005). In that study with 5- to 11-year-olds, only 11-year-olds’ memory discrimination followed a mature pattern similar to that in adults.

In Experiment 4, children and adults were provided with the information and strategy necessary to perform knowledge-based categorization and induction (i.e., instructions and feedback directing attention to the rule feature during category learning). Despite this, children’s attention appears to have remained distributed throughout the task, as evidenced by their memory discrimination. Memory for exact items presented during induction is only possible if more than one feature is encoded. If children had encoded only the rule feature, by attending selectively to that feature, their memory would have been low, or at least not better than adults’.

Adults, on the other hand, appear to have attended selectively to the rule feature in Experiment 4, and thus, their ability to discriminate novel target category exemplars in the memory test was reduced. By attending primarily to the rule feature, only that feature would be fully encoded to memory, and discrimination would suffer. While adults’ memory was not zero, it was still marginally lower compared to children’s. Furthermore, the pattern of adults’ categorization and memory in Experiment 5 clearly demonstrates the effect of distributed attention. By attending to overall appearance, and thus encoding multiple features, adults in that study had much higher memory discrimination compared to adults in Experiment 4.

When learning a similarity-based category, adults’ memory following induction demonstrated use of similarity-based induction. In sum, the pattern of responses during
categorization in Experiments 4 - 5 are consistent with adults’ memory, but not with children’s. What is indicted by these data is that young children distribute attention regardless of task demands, while adults can either distribute or focus attention depending on task demands. This is inconsistent with the hypothesis that there is a dissociation between processing and mechanism (Wilburn and Feeney, 2008). Rather, it appears that the way children process the stimuli (i.e., by distributing attention) reflects how they learn categories, represent those categories, and use that representation to make inferences.

Additionally, the evidence presented here demonstrates that memory following induction is consistent with the type of attention used, as well as the category representation formed and the inductive mechanism used. It is not that children’s processing of perceptual information is independent from these mechanisms but rather that attention to perceptual detail is an essential aspect of how they perform generalization.

While the above findings are important to fully understanding the development of induction, many questions remain. For example, if selective attention is a catalyst of category-based induction, are there age differences in time spent attending to the rule feature? Furthermore, does time spent attending to the rule feature predict memory following induction? And last, do differences in instructions (i.e., probabilistic versus deterministic) predict the pattern of attention during induction? The next steps of the research presented here will be to address these questions directly in an eye tracking study.
Together, findings of these 5 experiments indicate that (1) similarity-based mechanism of induction is the developmental default, (2) category-based induction is a product of development, (3) the development of category-based induction can be attributed to improvements in selective attention, and (4) memory in the ITR paradigm reflects category representation and mechanism of induction.
References


