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Processing of perceptual information is more robust than processing of conceptual information in preschool-age children: Evidence from costs of switching

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ABSTRACT

Is processing of conceptual information as robust as processing of perceptual information early in development? Existing empirical evidence is insufficient to answer this question. To examine this issue, 3- to 5-year-old children were presented with a flexible categorization task, in which target items (e.g., an open red umbrella) shared category membership with one test item (e.g., a folded umbrella) and perceptual characteristics with another test item (e.g., a red mushroom). Participants were instructed to either categorize stimuli by the same dimension (i.e., perceptual similarity or category membership) in both phases of the task, or switch from categorizing by one dimension to categorizing by the other dimension. Results pointed to a strong asymmetry in switch costs: conceptual switch costs were higher than perceptual switch costs. These results suggest that processing of perceptual information remains more robust than processing of conceptual information at least until 5 years of age.

1. Introduction

The ability to generalize from the known to the unknown is a fundamental cognitive ability: As Steven Sloman succinctly put it "our knowledge that leopards can be dangerous leads us to keep a safe distance from jaguars" (Sloman, 1993, p. 321). Humans exhibit remarkable generalization abilities very early in development. By 3 months of age, infants can learn novel categories consisting of artificial as well as naturalistic objects (Bomba & Siqueland, 1983; Quinn, Eimas, & Rosenkratz, 1993), by 10 months of age infants can perform simple generalizations about object properties, such as the path of motion and sounds objects produce (Baldwin, Markman, & Melartin, 1993; Rakison & Poulin-Dubois, 2002), and by 24 months of age children readily extend known labels to novel objects (Booth & Waxman, 2002; Jones & Smith, 1998; Smith, Jones, & Landau, 1996). However, mechanisms of generalization early in development remain contested.

Generalization may be influenced by a variety of factors. Consider the generalization in the example above: On what basis might one decide to keep away from jaguars based on the knowledge that leopards are dangerous? Leopards and jaguars belong to the same animal family referred to as "big cats"; leopards and jaguars live in similar habitats (rainforest in Africa and South America, respectively); leopards and jaguars are both predators; leopards and jaguars look similar to each other. Researchers in the field commonly divide possible factors that can influence generalization into two broad categories: *perceptual* factors and *conceptual* factors (e.g., Booth & Waxman, 2002; Gelman & Markman, 1986; Sloutsky, 2010). Perceptual factors are those that are directly observable and readily perceived by the organism (e.g., that leopards and jaguars look similar); conceptual factors are characterized as those that

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cannot be observed directly and need to be learned or inferred from what is known (e.g., that leopards and jaguars belong to the same animal family).

There is little disagreement in the literature that perceptual factors influence both early and mature generalization (for review see Murphy, 2002). For example, when 3- to 4-months-old infants are presented with images of dogs and cats, under some conditions infants form a category representation for *cat* that excludes dogs and a category representation for *dog* that includes cats (Quinn, Eimas, & Rosenkratz, 1993). It has been shown that this pattern of categorization arises because the distribution of perceptual features in cats (e.g., length of head and ears, separation between eyes and ears, etc.) is subsumed by the distribution of perceptual features in dogs (French, Mareschal, Mermillod, & Quinn, 2004). Importantly, this asymmetry can be reversed or removed by varying the relationship between distributions of perceptual features in cats and dogs. These results convincingly demonstrate that young infants utilize perceptual information in the course of categorization. Other studies suggest that perceptual effects on categorization persist during toddlerhood (Rakison & Butterworth, 1998) and preschool years (Fisher & Sloutsky, 2005; Sloutsky & Fisher, 2004). Similarly, when children learn their first words, they extend new words to perceptually similar items (Huttenlocher & Smiley, 1987; Nelson, 1973) and when infants and preschoolers generalize properties of familiar items to novel items, they often rely on perceptual similarity (for review see Fisher, 2010).

Similarity effects are also well documented in mature generalization. For example, when adults were asked to evaluate the strength of arguments that were equally strong from the normative point of view, adults overwhelmingly chose the argument in which the conclusion category shared more features with the premise category (Sloman, 1993; Sloman 1998; for similarity effects in adults in other induction and categorization paradigms see Fisher & Sloutsky, 2005; Osherson, Smith, Wilkie, Lopez, & Shafir, 1990; Nosofsky, 1984; Rips, Shoben, & Smith, 1973).

There is also little disagreement that mature generalization is often influenced by conceptual factors, such as knowledge of taxonomic hierarchies, knowledge-based expertise, or knowledge of an object's function (Heit & Rubinstein, 1994; Proffitt, Coley, & Medin, 2000; Wisniewski, 1995). However, while conceptual effects in mature generalization are well documented, the developmental course of these effects remains unclear. One possibility is that early in development, generalization processes are driven primarily by the low-level mechanisms of perception, attention, and memory, with conceptual factors emerging as an important influence on generalization in the course of development and learning (McClelland & Rogers, 2003; Rakison & Lupyan, 2008, 2003; Samuelson & Smith, 2000; Sloutsky, 2003; Sloutsky & Fisher, 2004).

However, it has been argued that perceptual and attentional factors alone are insufficient to explain early generalization, and conceptual factors (e.g., knowledge of the ontological status of the object) permeate learning from early infancy (Booth & Waxman, 2008; Gelman, 2003). Proponents of this view suggest that from early in development children treat perceptual information as *peripheral* and conceptual information as *central* to learning object categories and names for these categories, and generalizing object properties (Booth & Waxman, 2008; Gelman & Coley, 1991; Keil, Smith, Simons, & Levin, 1998). Therefore, when perceptual and conceptual sources of information are in conflict, this conflict is resolved in favor of conceptual information; in other words, conceptual information takes "precedence" over perceptual information (Booth & Waxman, 2002, p. 20).

The question of whether young children ably process conceptual information and use it spontaneously in various cognitive tasks (such as word learning, categorization, and induction) has been hotly debated in the recent literature (for examples of such debates see Booth & Waxman, 2006; Gelman & Waxman, 2007; Sloutsky, Kloos, & Fisher, 2007a,b; Sloutsky & Fisher, 2004; Smith, Jones, Yoshida, & Colunga, 2003; Smith & Samuelson, 2006). However, this debate remains unresolved: as Smith and Samuelson (2006, p. 1342) put it, "proponents of both sides can conduct nearly identical experiments and see the same results as being for and against" a particular theoretical account (for a review of different theoretical interpretations of the same empirical evidence see Fisher, 2007). Therefore, available empirical evidence is insufficient to distinguish between the alternative theoretical possibilities.

The goal of the present research was to develop a paradigm that can help elucidate how 3- to 5-year-old children process conceptual and perceptual information. To address this issue, I used a flexible categorization task inspired by the task-switching paradigms used with adults (Allport, Styles, & Hsieh, 1994; Berg, 1948; Koch, 2001; Meiran, 1996; Spector & Biederman, 1976) as well as children (Blaye, Chevalier, and Paour, 2007; Cepeda & Munakata, 2007; Deák, 2003; Jacques & Zelazo, 2001; Kirkham, Cruess, & Diamond, 2003; Zelazo, Frye, & Rapus, 1996). Task-switch paradigms have been widely used to investigate executive control by presenting participants with a task in which performance demands change in the middle of the task. For example, in the Dimensional Change Card Sort task (DCCS; Zelazo et al., 1996), which is a child-friendly analogue of the Wisconsin Card Sort test (Berg, 1948), children are presented with a set of cards depicting familiar objects that differ on two dimensions, such as color and shape (e.g., red and blue flowers, and red and blue boats). Children are first asked to sort cards according to one dimension, for example shape (in this case they need to group blue flowers with red flowers, and blue boats with red boats). Upon completing this task, children are asked to sort cards according to a different dimension, for example color (in this case they need to group red boats with red flowers, and blue boats with blue flowers). A considerable amount of evidence suggests that despite understanding and remembering the instructions, children younger than 4 years of age often perseverate in sorting by the original dimension (for review see Zelazo, Muller, Frye, & Marcovitch, 2003). It is important to note that children are equally likely to perseverate if they start sorting by shape and switch to sorting by color, and if they start sorting by color and switch to sorting by shape.

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Perseveration errors described above are one type of *switch costs* – robust decrease in performance after a task switch. It has been well-established that switch costs manifest themselves as increased error rate in young children, and increased error rate and reaction time in adults (e.g., Diamond & Kirkham, 2005; Koch, 2001; Meiran, 1996; Zelazo, Frye, & Rapus, 1996). There are several factors that influence switch costs; the most relevant of these for the present research is the strength of the pre-switch task set compared to the post-switch task set.

Within the developmental literature it has been reported that when children switch from a weaker task set to a stronger task set, switch costs are relatively low (Blaye et al., 2007; Cepeda, Kramer, & Gonzalez de Sather, 2001; Deák, Ray, & Pick, 2004; Fisher, 2011; Yerys & Munakata, 2006). For example, Yerys and Munakata (2006) developed a version of the DCCS task in which the pre-switch dimension was represented by novel colors or novel shapes, which were referred to by novel labels (e.g., "this is a dax one" or "this is a flirp"). The reasoning behind this manipulation was that novel colors and shapes referred to by novel labels would have a weaker representation in short-term memory than familiar colors and shapes referred to by familiar labels. Consequently, costs of switching were predicted to be lower when children were switching from a weaker task set to a stronger task set (e.g., from sorting by a novel color to sorting by a familiar shape) than when children were switching from a stronger task set to a weaker task set (e.g., from sorting by a familiar color to sorting by a novel shape). These predictions were confirmed in a series of experiments.

Similarly, Fisher (2011) developed a version of the DCCS task in which saliency of the pre-switch dimension was manipulated relative to the post-switch dimension. Specifically, in this study perceptually similar values were used for the dimension of color (i.e., red and pink) and dissimilar values were used for the dimension of shape (i.e., stars and flowers) to achieve differential saliency of dimensions. Effectiveness of this manipulation was confirmed in a separate calibration experiment: while all dimension values could be correctly discriminated by young children, in a speeded discrimination task children were faster to respond that the cards matched or differed on the dimension of shape than on the dimension of color. When the DCCS task involved switching from a stronger task set (i.e., shape in this case) to a weaker task set (i.e., color in this case), switch costs were high. However, when the task involved switching from a weaker task set (i.e., color) to a stronger task set (i.e., shape), switch costs were practically eliminated. Importantly, studies with children overwhelmingly find that switch costs are not limited to the first post-switch trial: children either fail on most post-switch trials (i.e., the majority of 3-year-olds show this pattern) or succeed on most post-switch trials (i.e., the majority of 4-year-olds show this pattern) (Zelazo et al., 1996).

Within the adult literature there have been mixed findings with regards to whether switch costs are higher when switching to a stronger task set or a weaker task set (Allport, Styles, & Hsieh, 1994; Allport & Wylie, 2000; Monsell & Yeung, 2003; Monsell, Yeung, & Azuma, 2000). Regardless of the direction of switch costs asymmetry in adults, it has been shown that switch costs are confined entirely to the first post-switch trial (see Gilbert & Shallice, 2002 for discussion).

It is difficult to directly compare the findings on switch cost asymmetries in children and adults due to different ways of calculating switch costs (based on response latency in adults and based on response accuracy in children) and differences in research design (i.e., studies with adults typically involve 23–35 task switches and studies with children typically involve 1–2 task switches). All studies that reported switch cost asymmetries in the developmental literature (Blaye et al., 2007; Cepeda, Kramer, and Gonzalez de Sather, 2001; Deák, 2003; Deák et al., 2004; Fisher, 2011; Yerys & Munakata, 2006) suggest that children are more successful in switching from a weaker task set to a stronger task set. Therefore, this pattern of results reported across multiple studies with young children will be used to formulate predictions and motivate interpretation of the experiments reported in this paper. Specifically, if conceptual information is central to categorization early in development (i.e., is more salient than other kinds of information), whereas perceptual information is peripheral (and thus less salient), then conceptual categorization should represent a stronger task set than perceptual categorization. Consequently, children should have lower switch costs when switching from categorizing by perceptual information to categorizing by conceptual information. However, if perceptual information is more salient and represents a stronger task set than conceptual information, the opposite pattern of performance should be observed.

To test these possibilities, 3- to 5-year-old children were presented with a flexible categorization task, in which participants were asked to categorize the same set of objects twice and the categorization rule was changed in the middle of the task. Much of the previous research examining the relative importance of different sources of information early in development (e.g., category knowledge vs. appearance similarity) presented children with ambiguous visual images referred to by either identical of different labels (Gelman & Markman, 1986; Jaswal, 2004; Sloutsky & Fisher, 2004). Therefore, category information was often communicated by linguistic labels in prior research. Such paradigms pose interpretation problems, as some researchers consider labels to be proxies of categories for children as young as 2 years of age (Gelman & Coley, 1991; Gelman & Markman, 1986; Jaswal, 2004), whereas other researchers suggest that labels are treated as object features at least until 4 years of age (Napolitano & Sloutsky, 2004; Sloutsky & Fisher, 2004; Sloutsky & Lo, 1999; Sloutsky, Lo, & Fisher, 2001). Thus, according to the former view, label-based generalization is one and the same as category-based generalization, whereas according to the latter view, generalization can be label-based without being category-based.

To avoid this problem of distinguishing between label-based and category-based generalization, no labels were provided to communicate category membership in the studies presented below. Instead, children were presented with iconic images of well-known objects (familiarity with the stimuli was confirmed by the results of familiarity

checks described below); these images were organized into triads in order to put category membership information in conflict with perceptual similarity. For example, an open red umbrella was paired with a folded blue-and-yellow umbrella to create a category match and with a red mushroom to create a perceptual match. In Experiment 1 some children were asked to use different sorting rules in different phases of the task (i.e., Perceptual-to-Conceptual and Conceptual-to-Perceptual conditions); other children were asked to use the same sorting rule in both phases of the task (i.e., Perceptual-to-Perceptual and Conceptual-to-Conceptual conditions). Proportions of correct responses in each task were then used to calculate perceptual and conceptual costs of switching. Experiment 2 was conducted to examine whether children's performance in Experiment 1 could stem from difficulty in understanding or remembering the instructions.

2. Experiment 1

2.1. Method

2.1.1. Participants

To effectively analyze switch costs, the sample in each condition had to include at least 10 children who passed the pre-switch phase by providing at least 6 out of 8 correct responses (or 75% correct). Testing continued until this criterion was met in each age group in each condition. The final sample consisted of 101 3-year-old children ($M = 3.54$, $SD = .25$ years; 54 females and 47 males), 89 4-year-old children ($M = 4.52$, $SD = .29$ years; 42 females and 47 males), and 62 5-year-old children ($M = 5.43$, $SD = .32$ years; 32 females and 30 males). All participants were recruited from child-care centers and preschools in a large Midwestern city.

2.1.2. Materials

Materials consisted of eight experimental triads in which a target object (e.g., an open red umbrella) belonged to the same basic-level category as one test item (e.g., a folded blue-and-yellow umbrella, i.e., a Conceptual match) but looked similar to the other test item (e.g., a red mushroom, i.e., a Perceptual match). The location of the Conceptual matches and Perceptual matches (i.e., to the left or to the right of the target object) was counterbalanced across triads. Object triads used in Experiment 1 are presented in Fig. 1. Additionally, there was one instructional triad depicting a lemon (target), half of a lemon slice (a Conceptual match) and a tennis ball (a Perceptual match).

2.1.3. Design and procedure

The experiment had a 2 (Initial task: Perceptual vs. Conceptual categorization) by 2 (Switch condition: Switch vs. No-Switch) by 3 (Age group: 3-, 4-, and 5-year-olds) between-subjects design. Therefore, within each age group there were four between-subject conditions: Perceptual-to-Perceptual, Perceptual-to-Conceptual, Conceptual-to-Conceptual, and Conceptual-to-Perceptual conditions. Children were randomly assigned to one of these four conditions and interviewed individually by a hypothesis-blind experimenter in a quiet room at a day-care center.

In the Perceptual-to-Conceptual condition, children were first asked to group together objects that "look similar" and then switch to grouping together objects that are "the same kind of thing". At the start of the experiment, children were presented with the instructional triad and the task was explained. For example, in the Perceptual-to-Conceptual condition, children were first told: "*In this game you have to decide which objects go together. The rule of the game is that objects that look similar go together. For example, this lemon is yellow and round and this tennis ball is yellow and round, therefore they go together, because they look similar. Can you show me which objects go together in this game?*" At the end of the first phase of the task, participants were again presented with the instructional triad and the new rule was explained: "*Now we are going to play a different game. In this game, objects that are the same kind*[1] *of thing go together. For example, this is a lemon and this is a lemon slice; they go together because they are the same kind of thing. Can you show me which objects go together in this game?*" The order of these instructions was reversed in the Conceptual-to-Perceptual condition. Instructions for perceptual and conceptual categorization were identical in the no-switch conditions (i.e., Perceptual-to-Perceptual and Conceptual-to-Conceptual conditions); however, instead of presenting instructions for the switch task, the experimenter repeated the rule before the second block of trials.

Object labels were provided only during the instructional trial but not during experimental trials: during the experiment proper children were only asked to point to objects that "go together". The experiment was administered on a laptop computer using SuperLabPro software, and the order of trials was randomized for each participant. After completing the task, all children were presented with a familiarity check: they were shown all pictures used in the experiment proper, one by one, and asked to identify the depicted objects. The goal of the familiarity check was to ensure that all objects used in this study were familiar to children.

2.2. Results

Accuracy scores in both phases of the task produced a uni-modal non-normal distribution: Kolmogorov–Smirnov D Phase I = .133, $p < .0001$; Kolmogorov–Smirnov D Phase II = .128, $p < .0001$. In both phases of the experiment the distributions of responses were positively skewed, skewness was .173 and .172 in Phases I and II, respectively.

It has been suggested that ANOVA is robust to the violations of the normality assumption (Glass, Peckham, & Sanders, 1972; Harwell, Rubinstein, Hayes, & Olds, 1992). Furthermore, a recent Monte Carlo simulation study by Schmider, Ziegler, Danay, Beyer, and Bühner (2010) provided strong empirical evidence for robustness of ANOVA with regards to non-normally distributed data. Finally,

[1] Prior research has established that preschool-age children understand both the request to find the one that "looks similar" and the request to find the one that is "the same kind of thing" (see Sloutsky & Fisher, 2004; Experiments 1–3).

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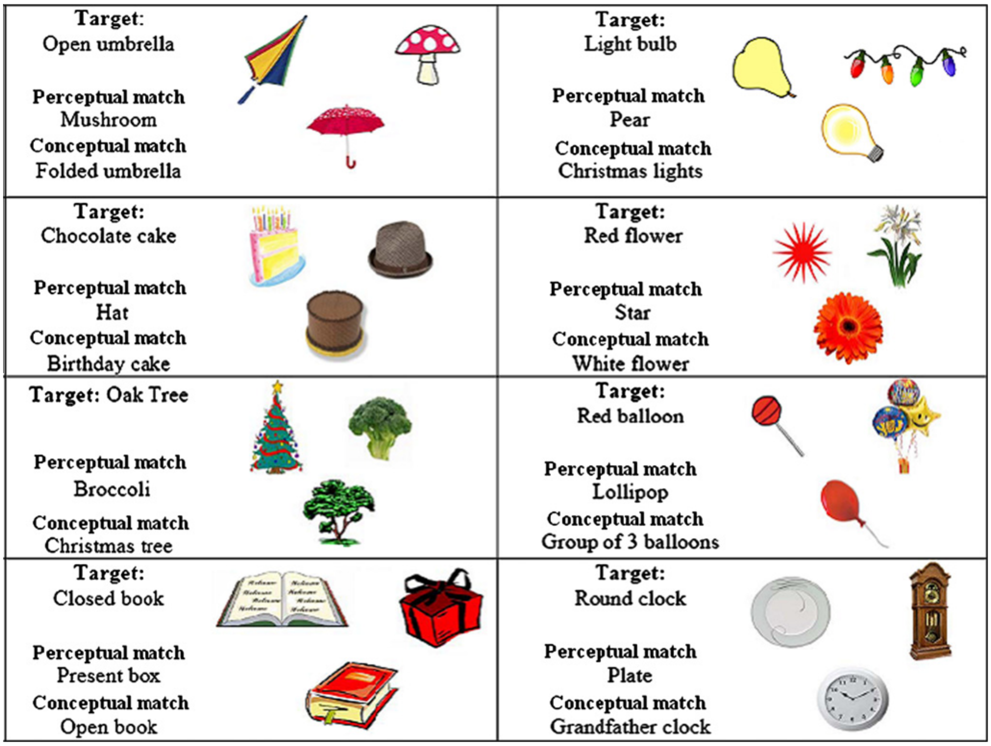

Fig. 1. Experimental triads used in Experiment 1 (In the Oak/Broccoli/Christmas Tree triad all three items match on color, unlike in the rest of the triads. Therefore, it could be argued that in the Perceptual Categorization task some children decided to match on shape, whereas others decided to match on color. To control for this possibility, a separate group of 3-year-olds ($N = 11$; $M = 3.44$ years) and 4-year-olds ($N = 12$; $M = 4.49$ years) were presented with the Perceptual Categorization task and a modified "oak" triad. Specifically, the Christmas Tree test item was replaced with Green Peas. The finding indicated that in the Perceptual Categorization task children were far more likely to match on both shape and color than on color alone: Among 3-year-olds, 10 children out of 11 chose the Broccoli test item; among 4-year-olds, 10 out of 12 children chose the Broccoli test item. In both age groups the probability of choosing this test item was greater than chance, both binomial $ps < .02$.).

some statisticians caution against the use of non-parametric alternatives to ANOVA due to (1) the loss of precision stemming from transformations into rank data and (2) reduced power of non-parametric tests (Edgington, 1995; Tanizaki, 1997). Therefore, for the data reported in this paper ANOVA was used for omnibus analyses and chi-square tests were used for analyzing individual patterns of responses.

2.2.1. Categorization accuracy

Table 1 summarizes the number of children in each condition who passed and failed Phase I of the task (children were required to provide at least six correct responses on eight trials to pass Phase I) and proportions of correct categorization responses in Phases I and II. The first analysis examined the rates of passing Phase I by age group and initial categorization condition. The initial task in the Conceptual-to-Perceptual condition was identical to that in the Conceptual-to-Conceptual condition; similarly, the initial task in the Perceptual-to-Conceptual condition was identical to that in the Perceptual-to-Perceptual condition. Therefore, for the purpose of this analysis the number of children passing and failing Phase I was collapsed across conditions with identical initial tasks.

Overall, there was no association between the number of children passing and failing Phase I and the type of the initial categorization task (i.e., Perceptual or Conceptual categorization). There were 49 3-year-old children who participated in the initial Perceptual Categorization task and 21 (43%) of them passed Phase I; there were 52 3-year-old children who participated in the initial Conceptual Categorization task and 20 (38%) of them passed Phase I; $\chi^2(1) < 1$. There were 39 4-year-old children who participated in the initial Perceptual Categorization task and 23 (59%) of them passed Phase I; there were 50 4-year-old children who participated in the initial Conceptual Categorization task and 24 (48%) of them passed Phase I; $\chi^2(1) < 1$. There were 33 5-year-old children who participated in the initial Perceptual Categorization task and 22 (67%) of them passed Phase I; there were 27 5-year-old children who participated in the initial Conceptual Categorization task and 22 (81%) of them passed Phase I; $\chi^2(1) < 1$.

At the same time, the association between age and rate of passing Phase I was significant, $\chi^2(2) = 14.22$, $p < .001$. A total of 101 3-year-old children participated in Experiment 1 and 41 of them (41%) passed Phase I; 89 4-year-old children participated and 47 of them (53%) passed Phase I; 62 5-year-old children participated and 44 of them (71%) passed Phase I. Follow-up analyses indicated that performance of 5-year-old children was different from that of 3- and 4-year-old children, both $\chi^2(1) > 5.03$, $ps < .05$;

Table 1
Number of children passing and failing Phase 1 in Experiment 1, proportions of correct responses in Experiment 1 by, and standard deviations (in parentheses).

	Switch conditions				No-switch conditions			
	Perceptual-to-Conceptual condition		Conceptual-to-Perceptual condition		Conceptual-to-Conceptual condition		Perceptual-to-Perceptual condition	
	Phase I (perceptual)	Phase II (conceptual)	Phase I (conceptual)	Phase II (perceptual)	Phase I (conceptual)	Phase II (conceptual)	Phase I (perceptual)	Phase II (perceptual)
Participants who passed Phase I								
3-Years-olds	***n* = 10**		***n* = 10**		***n* = 10**		***n* = 11**	
	.86* (.11)	**.37** (.28)	**.82*** (.11)	**.58** (.33)	**.84*** (.08)	**.81*** (.15)	**.86*** (.12)	**.83*** (.17)
4-Years-olds	***n* = 13**		***n* = 13**		***n* = 11**		***n* = 10**	
	.86* (.13)	**.39** (.35)	**.85*** (.11)	**.76*** (.23)	**.87*** (.11)	**.84*** (.19)	**.87*** (.12)	**.79*** (.26)
5-Years-olds	***n* = 11**		***n* = 11**		***n* = 11**		***n* = 11**	
	.91* (.08)	**.60** (.36)	**.92*** (.10)	**.85*** (.14)	**.87*** (.11)	**.91*** (.09)	**.89*** (.12)	**.83*** (.22)
Participants who did not pass Phase I								
3-Years-olds	***n* = 19**		***n* = 16**		***n* = 16**		***n* = 9**	
	.42 (.15)	**.56** (.16)	**.34*** (.19)	**.61** (.26)	**.38*** (.21)	**.43** (.29)	**.44** (.11)	**.51** (.18)
4-Years-olds	***n* = 8**		***n* = 8**		***n* = 18**		***n* = 8**	
	.48 (.14)	**.53** (.25)	**.38** (.21)	**.42** (.21)	**.36*** (.23)	**.35*** (.24)	**.48** (.15)	**.50** (.19)
5-Years-olds	***n* = 7**		***n* = 3**		***n* = 4**		***n* = 4**	
	.52 (.19)	**.69±** (.25)	**.42** (.14)	**.58** (.07)	**.34** (.21)	**.52** (.34)	**.41** (.19)	**.65** (.28)

* Means that are different from chance (50%; $p < .05$) are marked with an asterisk (*); means marginally different from chance ($p < .10$) are marked with ±symbol.

whereas performance of 4-year-old children was only marginally different from that of 3-year-old children, $\chi^2(1) > 2.84$, $p = .09$.

As shown in Table 1, post-switch accuracy of children who did not pass Phase I was often not different from chance (50%), with the exception of 4-year-old children who responded at below chance level during Phase II of the Conceptual-to-Conceptual condition (*M* post-switch = .35), one-sample $t(17) = 2.65$, $p < .05$. Note that 3-year-old children responded at below chance level during Phase I in the Conceptual-to-Perceptual condition (*M* pre-switch = .34) and Conceptual-to-Conceptual condition (*M* pre-switch = .38), and 4-year-old children responded at below chance level during Phase I of the Conceptual-to-Conceptual condition (*M* pre-switch = .38), all one-sample *ts* > 2.05, *ps* < .05. Taken together, these findings may indicate a possible bias towards perceptual categorization in 3- and 4-year-old children. This possibility is discussed further in the General Discussion section. In 5-year-old children post-switch accuracy in the Perceptual-to-Conceptual condition was marginally greater than chance (*M* post-switch = .69), one-sample $t(6) = 2.01$, $p = .08$. This could indicate a possible bias towards conceptual categorization in older children; however, no further evidence of this bias was observed in the Conceptual-to-Conceptual condition (*M* pre-switch = .34, *M* post-switch = .52) both one-sample *ts* < 1.5, *ps* > .23.

A different pattern of results emerged for children who successfully passed the pre-switch phase. In all three age groups post-switch accuracy was lower in the Perceptual-to-Conceptual condition than in the Conceptual-to-Conceptual condition (*M* post-switch = .37 vs. *M* post-switch = .81 in 3-year-olds, *M* post-switch = .39 vs. *M* post-switch = .84 in 4-year-olds, and *M* post-switch = .60 vs. *M* post-switch = .91 in 5-year-olds), all independent-sample *ts* > 2.71, *ps* < .02, all Cohen's *ds* > 1.18. In contrast, when post-switch accuracy was compared between the Perceptual-to-Perceptual and Conceptual-to-Perceptual conditions, decrease in post-switch accuracy was observed only in 3-year-old children (*M* post-switch = .83 vs. *M* post-switch = .58, independent-samples $t(19) = 2.25$, $p < .05$, Cohen's $d = .95$); whereas there was no decrease in post-switch accuracy in older participants (*M* post-switch = .79 vs. *M* post-switch =. 76 in 4-year-olds and *M* post-switch = .83 vs. *M* post-switch = .85 in 5-year-olds, both independent-samples *ts* < 1, *ns*).

2.2.2. Costs of switching

The central analyses focused on the costs of switching. Costs were calculated based on the data from participants who successfully passed Phase I. The formula for calculating costs can be summarized as follows: cost = (Post – Mean(pre)). For instance, to calculate Perceptual Switch Costs, the mean proportion of correct responses on the perceptual categorization task in Phase I was subtracted from each individual score on the perceptual categorization task in Phase II. Conceptual switch costs, Perceptual no-switch costs, and Conceptual no-switch costs were calculated in a similar way. Switch costs are presented in Fig. 2A and No-Switch costs are presented in Fig. 2B.

To analyze costs a 3 (Age: 3-, 4-, and 5-year-olds) × 2 (Condition: Switch vs. No-Switch) × 2 (Costs Type: Perceptual vs. Conceptual costs) ANOVA was performed. This analysis indicated a main effect of the switch condition, $F(1, 118) = 35.68$, $p < .0001$, $\eta^2 = .23$, and a main effect of the type of costs, $F(1, 118) = 7.19$, $p < .01$, $\eta^2 = .06$. These main effects were qualified by the switch condition by costs type interaction, $F(1, 118) = 14.05$, $p < .0001$, $\eta^2 = .11$. The effect of age was not significant, $F(1, 118) = 2.05$, $p > .13$, and interactions involving age were also not significant, all *Fs* < 1.18, *ps* > .31.

The switch condition by costs type interaction was further explored through a series of planned comparisons. Collapsed across age groups, Perceptual No-Switch Costs

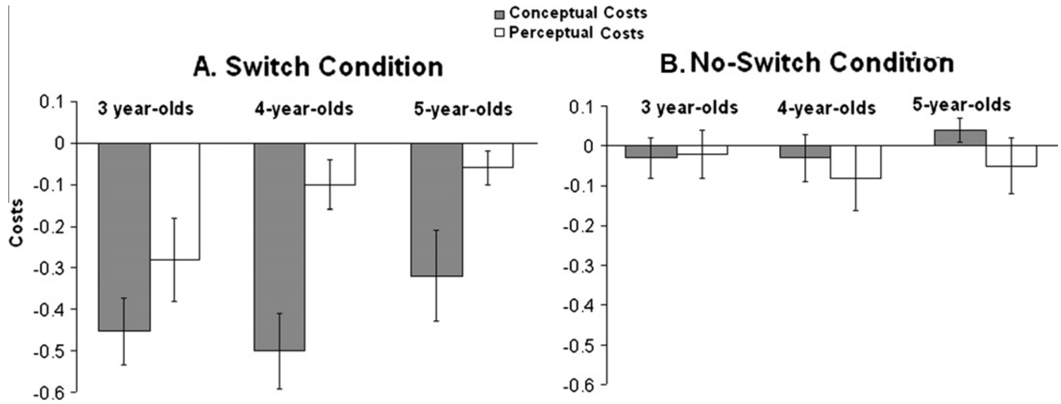

Fig. 2. Perceptual and Conceptual costs in Experiments 1 (panel A) and Experiment 2 (Panel B). Error bars represent the standard errors of the mean.

were not statistically different from Conceptual No-Switch Costs ($M = -.05$ and $-.01$, respectively), independent-sample $t(61) = 1$, *ns*. Both types of No-Switch Costs were not different from zero, both one-sample $ts < 1.34$, $ps > .19$.

In contrast, both Perceptual and Conceptual Switch Costs exceeded zero, both one-sample $ts > 3.21$, $ps < .005$. However, Conceptual Switch Costs ($M = -.41$) were significantly greater than Perceptual Switch Costs ($M = -.14$), independent-samples $t(66) = 3.69$, $p < .005$; the effect size for this difference was large, Cohen's $d = .90$.

When explored within each age group, this difference in the magnitude of Perceptual and Conceptual Switch Costs was not significant in 3-year-old children, independent-samples $t(18) = 1.07$, $p = .29$. However, in 4- and 5-year-old children Conceptual Switch Costs were significantly greater than Perceptual Switch Costs, both independent-samples $ts > 2.21$, $ps < .05$, Cohen's $d = 1.38$ and .95 in 4- and 5-year-old children, respectively.

2.2.3. Familiarity check

In addition to the labels provided in Table 1, the following types of responses were scored as correct: (1) semantically similar labels (e.g., "pie" instead of "cake", "bowl" instead of "plate"); (2) super-ordinate labels substituted for basic-level labels (e.g., "fruit" instead of "pear", "candy" instead of "lollipop"); and (3) substitutions from the same basic-level category (e.g., "apple" instead of "pear", "cauliflower" instead of "broccoli", "popsicle" instead of "lollipop").

Substitutions from the same basic-level category comprised less than 5% of responses and were scored as correct only if the child correctly identified the other two pictures in the corresponding triad. This was done because confusing "broccoli" for "cauliflower", given that the child knows that the other objects in the triad are trees, should lead to the same pattern of sorting in both conditions as correct identification of the object as "broccoli".

Children in all age groups exhibited high accuracy during the familiarity check, averaging 90%, 93%, and 95% of correct responses in 3-, 4-, and 5-year-olds, respectively. There were no significant differences in accuracy on this task among the three age groups, all independent-sample $ts < 1.7$, all $ps > .11$. Across the age groups, children exhibited near-ceiling accuracy when identifying Target objects (98% correct) and Conceptual Matches (97% correct); accuracy in identifying Perceptual Matches was 83%, significantly lower than accuracy for Targets and Conceptual Matches, both independent-samples $ts > 3.15$, $ps < .01$.

The latter effect was driven by children's relatively low accuracy in identifying images depicting a *mushroom* (63% correct) and a *plate* (68% correct). The most common response for *mushroom* was "marshmallow"; however, no child identified this image as an umbrella. The most common responses for *plate* were "circle" and "mirror"; however, no child identified this image as a clock.

Across all three age groups children were more accurate when identifying the objects used as Conceptual Matches than the objects used as Perceptual Matches; yet, the pattern of switch costs observed in Experiment 1 favored switching to perceptual categorization over switching to conceptual categorization. Furthermore, children's naming accuracy of Perceptual Match items was not related to their post-switch accuracy on individual trials in either Conceptual-to-Perceptual switch condition, $r = .29$, $p > .16$, or Perceptual-to-Conceptual condition switch condition, $r = .10$, $p > .63$. Therefore, children's naming accuracy cannot explain the switch cost asymmetry observed in Experiment 1.

2.3. Discussion

Overall, findings of Experiment 1 suggest an asymmetry in costs of switching in preschool-age children: costs of switching are larger when children switch to categorizing by conceptual information than when children switch to categorizing by perceptual information. These findings indicate that perceptual information is more readily processed than conceptual information in preschool-age children.

It could, however, be argued that the reverse is the case. For instance, one could argue that in the Perceptual-to-Conceptual switch condition children had to inhibit the dominant response (i.e., conceptual categorization) and this inhibition carried-over to the next task, thus leading to poor performance on the dominant task (Gilbert & Shallice, 2002). Similarly, children could have found it

relatively easy to inhibit the less-dominant response (i.e., perceptual categorization) in the first phase of the Conceptual-to-Perceptual switch condition; therefore there was little inhibition carry-over and children performed relatively well in the less-dominant task.

However, findings in the no-switch conditions are inconsistent with the inhibition carry-over hypothesis. In particular, if asymmetry in switch costs in Experiment 1 stemmed from greater difficulty in inhibiting conceptual information during the pre-switch phase, then children should have exhibited a large decrease in accuracy in the second phase of the Perceptual-to-Perceptual condition (due to fatigue from inhibiting the dominant response) and little decrease in accuracy in the Conceptual-to-Conceptual condition (due to relative ease of inhibiting the non dominant response). Yet, there was no asymmetry in costs in the no-switch conditions: both perceptual and conceptual no-switch costs were not different from each other or from zero.

One important finding stemming from Experiment 1 is that many children (59% of 3-year-olds, 47% of 4-year-olds, and 29% of 5-year-olds) found it challenging to categorize pictures by a single dimension when there was a strong conflict between perceptual and conceptual information. The difficulty that many children experienced during Phase I of the task might seem surprising given the reports that young children are able to resolve conflict between perceptual and conceptual information in tasks that are substantially more difficult than sorting (e.g., property induction; Gelman & Markman, 1986). However, it has been demonstrated that children can do so only when conflict is low or absent; when conflict between different attributes is high, 4-year-old children perform at chance level in induction as well as categorization tasks (Sloutsky & Fisher, 2004; Sloutsky et al., 2001). The findings of Experiment 1 are consistent with those reported by Sloutsky and colleagues; however, I deemed it important to examine directly whether the difficulty many children experienced in the pre-switch phase of Experiment 1 stemmed from their difficulty in resolving conflict between perceptual and conceptual information.

This issue was addressed in Experiment 2, in which participants were presented with the same pictures as in Experiment 1, but these pictures were re-organized into triads such that the conflict between perceptual and conceptual information was removed. If the high proportion of participants who failed the first phase of the task in Experiment 1 stemmed from children's difficulty in resolving conflict between conceptual and perceptual information, then removing this conflict should result in the majority of participants successfully passing the first phase of the task in Experiment 2.

Another goal of Experiment 2 was to examine whether results observed in Experiment 1 could be, at least partially, attributed to children's difficulty in understanding or remembering the instructions. If understanding and remembering the instructions posed significant difficulty, then removing conflict between conceptual and perceptual information should not affect this difficulty; therefore, relatively low levels of pre-switch performance may be observed in Experiment 2. If however, children's difficulty during the pre-switch phase of Experiment 1 stemmed from resolving the conflict between perceptual and conceptual information, then removing conflict in Experiment 2 should lead to successful performance even with exactly the same instructions.

3. Experiment 2

3.1. Method

3.1.1. Participants

Participants were 24 3-year-old children ($M = 3.68$, $SD = .25$ years; 16 females and eight males), 23 4-year-old children ($M = 4.45$, $SD = .31$ years; 12 females and 11 males), and 22 5-year-old children ($M = 5.72$, $SD = .35$ years; 7 females and 15 males). All participants were recruited from child-care centers and preschools in a large Midwestern city and none of them participated in Experiment 1.

3.1.2. Materials and procedure

Materials in Experiment 2 consisted of the same pictures used in Experiment 1; however, the triads were re-arranged to remove conflict between category membership and appearance. To achieve this, two different sets of eight triads were created, one for the pre-switch phase and one for the post-switch phase. Every triad consisted of a target item, an unrelated lure, and a matching item that could be either a Perceptual match or a Conceptual match. For example, if the target item was an open red umbrella, then a clock served as an unrelated lure, a folded umbrella served as a Conceptual match in one phase of the task and a red mushroom served as a Perceptual match in the other phase of the task. In other words, the target and unrelated lure were kept constant, but the matching picture varied according to task (i.e., conceptual vs. perceptual categorization). As in Experiment 1, there were eight experimental trials and one instructional trial in each phase of the experiment. Instructions to participants were identical to those in Experiment 1.

The experiment was administered on a laptop computer using SuperLabPro software, and the order of trials was randomized for each participant. Participants were randomly assigned to the Conceptual-to-Perceptual Switch or the Perceptual-to-Conceptual switch conditions, and interviewed individually by a hypothesis-blind experimenter in a quiet room at a day-care center.

3.2. Results and discussion

All participants in Experiment 2 passed the pre-switch phase (i.e., provided at least 75% of correct responses). Proportions of correct responses by age group and condition are presented in Table 2. As is shown in the table, children in all three age groups performed significantly above chance in both phases of the task in both experimental conditions, all one-sample $ts > 3.75$, all $ps < .005$.

To analyze costs of switching when conflict between dimensions is removed, cost scores were calculated using the same procedure as in Experiment 1: cost =

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Table 2
Proportions of correct responses in Experiment 3 by age group and condition.

	Perceptual-to-Conceptual condition		Conceptual-to-Perceptual condition	
	Pre-switch phase	Post-switch phase	Pre-switch phase	Post-switch phase
3-Year-olds	.92*	.76*	.86*	.75*
4-Year-olds	.96*	.84*	.97*	.88*
5-Year-olds	.96*	.93*	.99*	.98*

* Means that are above chance (50%; $p < .05$) are marked with an asterisk (*).

(Post – Mean(pre)). These data are presented in Fig. 3. Costs of switching scores in Experiment 2 were submitted to a 2 (Type of costs: Perceptual vs. Conceptual) × 3 (Age: 3-, 4-, and 5-year-olds) ANOVA. This analysis revealed a main effect of age, $F(2, 63) = 3.57$, $p < .05$, $\eta^2 = .10$. The main effect of type of costs and the cost type by age interaction were not significant, both $Fs < 1.7$, $ps > .19$. Tukey post hoc tests indicated that overall switch costs were higher in 3-year-old children ($M = -.13$) than in 5-year-old children ($M = -.1$), $p < .05$; switch costs in 4-year-old children ($M = -.10$) were not statistically different from switch costs in the other two age groups, $ps > .15$.

One-sample t-tests were performed to analyze whether costs in Experiment 2 exceeded zero. Both Perceptual and Conceptual costs were either significantly or marginally greater than zero in 3- and 4-year-old children, all one-sample $ts > 2.07$, $ps < .062$ (see Fig. 3 for details). In 5-year-old children Conceptual costs were marginally greater than zero, $t(10) = 1.91$, $p = .085$, and Perceptual costs were slightly (3%) smaller then zero, $t(10) = 2.52$, $p < .05$.

These findings suggest that some proportion of the costs (with the exception of Perceptual costs in 5-year-olds) observed in Experiment 1 could be due to the memory demand of remembering the post-switch instructions. It needs to be noted that this proportion is likely to be relatively small, as the magnitude of costs in Experiment 2 (in which costs ranged between +3% and −16%) was considerably smaller than in Experiment 1 (in which costs ranged between −6% and −50%). This intuition was supported by a one-way ANOVA conducted on all switch scores collapsed across type (Perceptual vs. Conceptual) with conflict condition (Present/Experiment 1 vs. Absent/Experiment 2) as an independent factor, $F(1, 135) = 18.77$, $p < .0001$, $\eta^2 = .12$. Most importantly, the absence of the effect of cost type in Experiment 2 suggests that there was no-switch cost asymmetry; therefore memory demands of the task should have contributed evenly to switch costs in both switch conditions in Experiment 1.

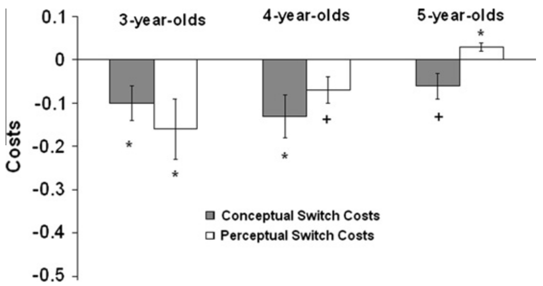

Fig. 3. Perceptual and Conceptual switch costs when conflict between perceptual similarity and category membership is removed (Experiment 2). Error bars represent the standard errors of the mean. Asterisks [*] indicate differences significantly different from zero, $ps < .05$; plus signs [+] indicate differences marginally different from zero, $ps \leqslant .085$.

Overall, Experiment 2 provided direct evidence that the low pass rate on the pre-switch tasks in Experiment 1 stemmed from children's difficulty in resolving the conflict between conceptual and perceptual information rather than from difficulty in understanding the instructions: not a single participant failed the pre-switch phase when conflict was removed in Experiment 2, even though instructions were identical to those used in Experiment 1. Additionally, children's above-chance performance in both phases of the task in Experiment 2 makes it highly unlikely that children experienced difficulties in Experiment 1 because they did not perceive Perceptual matches as looking similar to the target objects or Conceptual matches as belonging to the same kind as the target objects. Finally, the most important finding of Experiment 2 is that asymmetry in costs of switching was not observed when conflict between perceptual and conceptual information was removed.

4. General discussion

The current experiments yield several novel findings. First, when perceptual and conceptual sources of information were in conflict, many 3-, 4-, and 5-year-old children failed to resolve this conflict successfully when asked to group stimuli on a single dimension (i.e., perceptual or conceptual similarity; Experiment 1). This finding is unlikely to stem from children's difficulty in understanding the instructions, as not a single child failed to correctly categorize these stimuli when conflict between perceptual and conceptual information was removed in Experiment 2. As mentioned above, the difficulty of 4-year-olds in resolving conflict between different sources of information – such as perceptual similarity and category labels – is well documented (Sloutsky & Fisher, 2004; Sloutsky et al., 2001). The current findings extend previous research because they show that this difficulty may persist beyond the age of 5 and that there is a gradual increase in the proportion of children able to resolve such conflict between 3 and 5 years of age.

Second, the data reported in this paper suggest that by 3 years of age children ably process both perceptual and conceptual information when presented with well-known objects, as evidenced by equivalent proportion of children failing to pass the pre-switch Perceptual categorization task and the pre-switch Conceptual categorization task in Experiment 1. These data support theories emphasizing the importance of conceptual information early in development (Booth & Waxman, 2002, 2008; Gelman, 2003; Gelman & Markman, 1986). However, analysis of performance in the second phase of the task suggests that although by 3 years of age children spontaneously process

conceptual as well as perceptual information, processing of conceptual information remains considerably more fragile than processing of perceptual information at least until 5 years of age. In particular, findings of Experiment 1 demonstrate that costs of switching to categorizing by conceptual information were markedly higher than costs of switching to categorizing by perceptual information. In other words, children who successfully resolved the conflict between perceptual and conceptual information during the pre-switch phase were more successful in switching to categorizing by perceptual similarity than by category membership. These findings provide direct evidence that conceptual information is unlikely to take precedence over perceptual information early in development. If anything, the pattern of switch costs reported here points to the opposite possibility.

4.1. Mechanisms of category learning early in development

How do children acquire categories? This question has fascinated several generations of researchers; yet, there is still no consensus in how this question should be answered. One answer to this question suggests that conceptual knowledge is central for category learning from infancy (Booth, Waxman, & Huang, 2005; Gelman, 2003; Gelman & Waxman, 2007; Jaswal, 2004; Markman, 1991). Whether innate or acquired in early infancy, conceptual knowledge is thought to constrain and guide learning of categories and category labels in toddlerhood and beyond.

However, the data presented in this paper are largely inconsistent with this theoretical possibility. In particular, even 5-year-old children exhibited a strong asymmetry in their switch costs, such that switching to conceptual categorization was more challenging than switching to perceptual categorization. At the same time, these data are consistent with (and were predicted from) the alternative theoretical possibility. The alternative account suggests that category learning proceeds from learning categories based on multiple commonalities in the input to eventual acquisition of more abstract conceptual knowledge that is not directly available from the input (e.g., plants are alive, umbrellas protect us from rain, clocks are for telling time, etc.) (McClelland & Rogers, 2003; Rakison & Lupyan, 2008; Sloutsky, 2010; Sloutsky & Fisher, in press).

It has been suggested that there are two systems that support category learning. The *compression-based* system supports category learning by reducing information available in perceptual input (Sloutsky, 2010; see Ashby, Alfonso-Reese, Turken, & Waldron, 1998; and Seger & Cincotta, 2002 for similar proposals). Rich perceptual information is thought to be compressed into a more basic and less detailed representation as processing proceeds from primary sensory cortical areas to more central brain regions. Features idiosyncratic to each exemplar are unlikely to survive this compression, whereas features common to many exemplars are likely to survive the compression and become a part of the category representation. Support for the compression-based system of category learning comes from the findings suggesting that projections from visual neurons in the inferotemporal (IT) cortex onto the neurons in the tail of the caudate nucleus are organized in a many-to-one fashion, which is "ideal for extracting commonalities across a range of stimuli" (Nomura et al., 2007, p. 40; Wilson, 1995).

The brain regions involved in the compression-based system mature relatively early in life. For example, there is evidence that physiological properties and connectivity of visual IT neurons in macaques reach adult levels of maturity by 6 months of age, with some properties of the IT neurons reaching full maturity as early as 6 weeks of age (see Gross & Rodman, 1992 for review). Therefore, learning via the compression-based system seems to be a plausible explanation of category learning early in life.

The other putative system of category learning, the *selection-based* system, supports category learning by selectively tuning attention to a small number of relevant features (Sloutsky, 2010). This tuning may occur, for instance, if a particular feature is more perceptually salient than other features available in the input. With regards to visual input, saliency of a particular location is determined by how different this location is from its surroundings in terms of color, orientation, motion, and depth (Koch & Ullman, 1985). Detection of saliency is thought to involve the visual cortex and some thalamic structures – the lateral geniculate nucleus and the pulvinar nucleus (Koch & Ullman, 1985; Li, 2002; Robinson & Petersen, 1992). These brain regions also mature relatively early in life (for review see Nelson & Dukette, 1998). For instance, structures and connections within the layers of the human visual cortex reach maturity by 15 months of age (Bourne & Rosa, 2006; Burkhalter, Bernardo, & Charles, 1993); studies with macaques show that the lateral geniculate nucleus reaches functional maturity by 8 months of age (Kiorpes & Kiper, 1996; Movshon, Kiorpes, Hawken, & Cavanaugh, 2005).

However, selective tuning of attention to specific features can be also guided by conceptual knowledge (e.g., color is not important for categorizing toys, but it is important for categorizing foods). It has been suggested that deployment of conceptual knowledge is supported by a network of brain areas consisting of the temporoparietal junction, the temporal poles, and the prefrontal cortex (Lambon Ralph, Pobric, & Jefferies, 2009). Herein lays the problem: prefrontal cortex is known to exhibit remarkably protracted maturation and is generally believed to be one of the last brain areas to mature (Casey, Giedd, & Thomas, 2000; Luna, 2009; Nelson & Dukette, 1998). Protracted maturation of the prefrontal cortex seems inconsistent with the possibility that category learning in infants and toddlers can be guided by conceptual knowledge. Findings presented in this paper provide further support to the theoretical account advocating perceptually-driven category learning early in development, by demonstrating that even at 5 years of age perceptual information exerts a greater pull on attention than conceptual information.

4.2. Flexible categorization task vs. DCCS

An important aspect of the findings presented above is that the outcome of Experiment 1 is seemingly in conflict with the large body of research on the DCCS task. In

particular, a large number of 3- to 5-year-old children did not pass the first phase of the task in Experiment 1, although 3-year-old children typically have no difficulty passing the pre-switch phase in the DCCS task (Zelazo, Muller, Frye, & Marcovitch, 2003). However, this conflict is apparent rather than real. It is important to keep in mind that the flexible categorization task used in Experiment 1 is different from the classic DCCS task in two important ways. First, in the DCCS task children are presented with stimuli that are considerably less variable than stimuli in the flexible categorization task. For example, if a blue bunny and a red boat are used to mark sorting trays in the DCCS task, then on each trial children are presented with either a red bunny or a blue boat. In contrast, the stimulus set was much more diverse in the flexible categorization task, in which each triad depicted a unique set of objects. Second, because each trial in the flexible categorization task depicted a unique set of objects, it was impossible to formulate sorting rules based on specific *dimension values* as in the DCCS task (e.g., "blue things go here"). Instead, rules in the flexible categorization task are formulated in such a way that children need to abstract the relevant dimension values on each trial (e.g., "things that look similar go together"). Based on these two factors, it is likely that the flexible categorization task is a more demanding task than the classic DCCS task; the findings of Experiment 1 provide evidence that this is indeed the case.

5. Conclusion

Overall, the findings presented in this manuscript suggest that conflict between conceptual and perceptual information poses a significant challenge to young children, and the proportion of children capable of resolving this conflict increases gradually between three and 5 years of age. Importantly, by 3 years of age children spontaneously process perceptual as well as conceptual information of familiar objects; however, processing of conceptual information remains considerably more fragile than processing of perceptual information, at least up until 5 years of age.

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