Cake or Hat? Words Change How Young Children Process Visual Objects

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Abstract

A large literature shows that language influences cognition. Yet, we know very little about when and how linguistic influences on cognition become important in development. Here we test the proposal that one pathway by which language affects cognition is by activating category information which influences visual processing, and that this influence starts early. Across two experiments, we show that category information affects visual processing and that words can activate category information in young children.

Keywords: language; attention; cognitive development; vision.

Introduction

A large literature has documented that linguistic information changes other cognitive processes. Evidence for this comes from laboratory tasks in which people perform differently if they experience the same event associated with different kinds of linguistic information (Feist & Gentner, 2007; Loftus & Palmer, 1974) or associated with linguistic information vs. information presented in another modality (Lupyan & Spivey, 2010; Lupyan & Thompson-Schill, 2012), and from cross-linguistic research that shows influences of language on presumably non-linguistic processes (Fausey & Boroditsky, 2011; Levinson & Haviland, 1994). Taken together, these results show that language – and words, in particular – changes how adults perform on a wide variety of tasks, and that these cognitive processes are permeable to linguistic information.

Despite this wealth of evidence, we know very little about when and how linguistic influences on cognition become important in development. Understanding the development of linguistic effects on cognition is essential to understand the development of human cognition and the nature of individual differences in cognitive abilities – differences that start early and have downstream consequences into later development (Morgan, et al., 2015; Stanovich, 1986). One possibility is that language influences cognition by activating information about the objects or events to which it refers, and this information changes how visual information is processed. This hypothesis is plausible for three reasons. First, there is evidence supporting the link between language and visual processing. For example, adults listening to spoken sentences look at possible visual referents even when the visual array is irrelevant to the task (see Huettig, Rommers & Meyer, 2011), and when adults hear a word (e.g. "snake") they are likely to look at objects that share aspects with the referent of the word (e.g. a rope, similar shape, Huettig & Altmann, 2007). Similarly, adults' ability to detect a visual item is boosted by labeling the item (Lupyan & Spivey, 2008), and children's ability to find a target in a cluttered display is boosted by hearing the spoken name of the target object (Vales & Smith, 2015).

Second, word learning and object recognition are two related developmental achievements. Children's ability to identify visually degraded objects (Pereira & Smith, 2009), to attend to the configuration among the parts of a novel object (Augustine, et al., 2011), and to recognize sparse versions of known object categories (Smith, 2003), all are positively related to the number of words a child knows. Object recognition continues to be coordinated with word comprehension into adulthood (Huettig et al., 2011).

Third, there is evidence suggesting that words activate knowledge about the categories to which they refer. Words – object names in particular – do not refer to a specific item but rather to more abstract knowledge. Empirical results have shown that, relative to other cues (e.g. environmental sounds), words activate more decontextualized, categorical knowledge (Edmiston & Lupyan, 2015; Lupyan, 2008).

Taken together, this evidence supports our proposal that one pathway by which language affects human cognition is by activating category information which then influences visual processing, and that this pathway likely starts in early childhood. To directly test this proposal, in Experiment 1 we asked whether visual processing can be influenced by visual category information, and in Experiment 2 we examined whether category information activated by words can also influence visual processing. We tested 3-year-old children, who know several hundreds of object names and are at the start of the long developmental course in visual object recognition and in language development.

Rationale for the experiments

A large literature on categorical perception suggests that categorical information activated through visual means can change how adults process visual stimuli (Beale & Keil, 1995; Daoutis, Pilling & Davies, 2006; Goldstone, 1995; Goldstone, Lippa & Shiffrin, 2001; Livingston, Andrews & Harnad, 1998). By hypothesis, having learned that items belong to the same category changes in-task perceived similarity, making within-category discriminations harder than between-category discriminations. This idea that within-category comparisons are more difficult than between-category comparisons has been conceptually replicated with multiple kinds of tasks and stimuli (Jonides & Gleitman, 1972; MacKain, Best & Strange, 1981; Newell & Bülthoff, 2002), including some with infants and children (Eimas, Siqueland, Jusczyk & Vigorito, 1971; Jusczyk, Rosner, Cutting, Foard & Smith, 1977; Massaro, 1984).

To test if categorical information influences visual processing in young children, the present experiments tested children's ability to find a target in a cluttered array. The visual arrays were composed of items of the same category as the target (Within-Category search) or items of a different category than the target (Between-Category search). In Experiment 1, the category information was instantiated via visual information, and in Experiment 2, the category information was instantiated via linguistic information. In both experiments, we used two categories that share visual similarity but minimal conceptual similarity, and that children are likely to be familiar with: cakes and hats.

Experiment 1

If categorical information instantiated by visual information changes children's ability to visually process a visual array, then searching for a target amidst items of the same visual category should be more difficult than searching for that target amidst items of a distinct visual category.

Methods

Participants. Thirty-two children (15 females, M_{age}=36 months, SD=1.92) were randomly assigned to either the Within- or the Between-Category condition. Children had no developmental disorders, and English was the main or only language spoken by all families. Two additional children were recruited but not included due to experimenter error and being unable to follow task instructions during the familiarization phase. Parental consent was obtained for all participants, and all children received a toy for participating.

Apparatus and Stimuli. Stimuli were presented on a 17" touchscreen monitor. E-Prime (PST, Pittsburgh, PA) was used to present the stimuli and to record participants' responses. The stimuli were placed in 16 possible locations. The stimulus set is depicted in Figure 1A; four hats and four cakes were selected in pairs and recolored in red scale, such that a hat and a cake in the same pair were similar to each other in color appearance, overall shape, and details (e.g. in pair 1, both items have stripes and a smaller component at the top). The Within- vs. Between-Category manipulation was realized by changing target/distractor assignments; for instance, for pair 2, the Within-Category search array was composed of hat 2 as the target and hats 1, 3, and 4 as distractors; for the Between-Category search, cake 2 served as the target amidst the same (i.e. 1, 3, and 4) hat distractors.

To ensure that young children could recognize the items used, 12 children who did not participate in the main experiments (7 females, M_{age}=36 months, SD=2.67) were tested in a 4-alternative forced choice recognition task; on each trial, children were asked to select the picture that matched the heard word (e.g. "Where is the cake?"). Each child was asked to recognize all the items in the stimulus set twice, with target category (hat vs. cake) blocked, order of block presentation counterbalanced across children, and items presented in random order. On average, children selected the correct item on 81% of the trials (SD=0.22). No differences in accuracy were found across the two category of items ($t(11)$=1.11, p=0.29), or time taken to respond to cakes vs. hats items ($t(11)$=1.92, p=0.08).

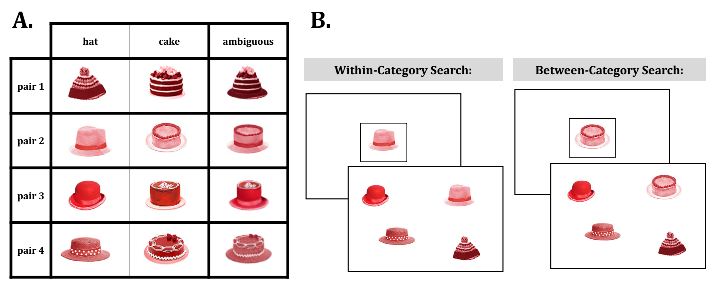

Figure 1, **A:** Full stimulus set. The *hat* and *cake* stimuli were used as targets and distractors in Experiment 1. The *ambiguous* items were used as targets in Experiment 2. **B:** Experiment 1, Trial structure.

Because the visual search task requires participants to discriminate the items in the search array from each other, 8 additional children (2 females, M_{age}=36 months, SD=1.04) were tested in an immediate match-to-sample task that probed their ability to discriminate pairs of stimuli. On each trial, children were presented with a sample object at the top center of the screen and then asked to indicate which of two options at the bottom matched the sample; if children could discriminate the two stimulus pictures, then they should be able to correctly select the option that matched the sample. All possible combinations of items that would be presented as targets and distractors in the visual search were tested. Each child was asked to discriminate one hat and one cake from the remaining items; this was done so that, for each child, a foil never became a target and vice-versa. The target category (hat vs. cake) was blocked, order of block presentation was counterbalanced across children, and items were presented in random order. Each child was tested on a given contrast (e.g. hat 1 vs. hat 2) twice. On average, children selected the correct option on 89% of the trials (SD=0.19). No differences were found in children's ability to discriminate Between- vs. Within-category items ($t(7)$=1.07, p=0.32) or time taken to respond to cakes vs. hats items ($t(7)$=0.41, p=0.69).

Design and Procedure. Each trial started with a "fixation" slide that encouraged children to rest their hands on the table. The experimenter made sure the child was looking at the screen before displaying a preview of the target. After 1s, the search array was automatically displayed and the child was asked to find the target picture and touch it; the trial ended once a manual response was detected (see Figure

1B). Children had up to 15 secs to make a response, and were encouraged to find the picture as fast as possible. Across test trials, the target was displayed equally often on the left and right side of the screen. Prior to the test phase, children were familiarized with using the touch screen and with the idea of searching for the object that matched the visual preview as fast as possible. Each child was assigned to one target, and searched for that target for 24 trials. None of the objects were labeled. The experimenter gave general encouragement (e.g. "thanks for your help finding the pictures") but no feedback was provided. Children received stickers to maintain their interest in the task.

Results and Discussion

Initial inspection of the data suggested that participants were, on average, both faster and more accurate in the Between-Category condition than in the Within-Category condition. Traditional analysis of variance would require analyzing response time and accuracy separately, which implicitly assumes that these two variables are independent (e.g. Davidson & Martin, 2013). Instead, we analyzed RT and accuracy together by comparing the relationship between RT and accuracy across the two conditions. Figure 2A depicts this relation and shows that the two conditions differ in how time taken to respond (plotted as quantiles) influences the likelihood of correctly identifying the target; accuracy in the Between-Category condition was overall higher and less influenced by response time. A generalized linear mixed effects analysis was performed using the geepack package (Højsgaard, Halekoh & Yan, 2006) in the R environment. The model was fit with a logit link function, a binomial variance function, a scale parameter fixed at 1, and an independent correlation structure. The variables Condition (Between-Category vs. Within-Category) and RT (as a continuous variable) were included as fixed effects with the interaction term, and participant was included as a random effect; RT was centered to decrease the differences in the scales of the model parameters. Odds Ratios were calculated by exponentiating the model estimates.

The model showed that Condition (Odds Ratio, OR=0.2, $p<0.001$) and the interaction between condition and RT (OR=0.43, $p<0.05$) were significant predictors of accuracy. RT was marginally predictive of accuracy, OR=1.8, $p=0.08$. This suggests that processing the visual information in the within-category condition is challenging, and when children are asked to find a target amidst distractors of the same visual category they either cannot maintain the target active for more than a few seconds, or they disengage with the task if they fail to find the target within a few seconds. Notice that visual category information affected visual processing even though children could discriminate pairwise presentations of within- and between-category items equally well in the calibration study, even though children searched for the same visual target across all trials and thus should be able to remember the particular visual target, and even though the visual properties of the items were equated as best as possible across the two conditions.

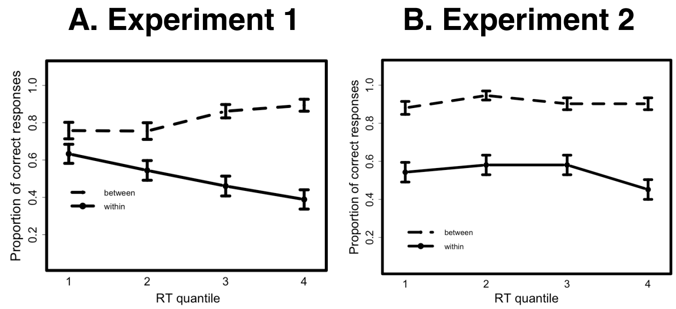

Figure 2, Mean proportion of correct responses per Reaction Time quantiles. Dashed line: Between-Category, Solid line: Within-Category.

These results show that category information presented through *visual* means influences visual processing in young children; this is, to the best of our knowledge, the first demonstration that visual categories directly influence visual processing in young children. This result adds to past research showing that infants, children, and adults (e.g. Eimas, Siqueland, Jusczyk & Vigorito, 1971; Goldstone, Lippa & Shiffrin, 2001; Massaro, 1984) are sensitive to category information, showing that category information matters for how children visually process a scene. When children encoded, for example, a hat target and saw the other hats in the within-category search array, that same-category information seems to have disrupted their ability to find the target hat. In sum, Experiment 1 shows that categorical information perceived in a visual scene can directly influence visual processing, as predicted by our proposal. In Experiment 2 we test the hypothesis that words, through activating categorical information, should also change the perceived target-distractor similarity, and therefore change visual processing.

Experiment 2

The goal of Experiment 2 was to test the hypothesis that hearing the spoken name of an object activates information about that object's category, which influences visual processing. This hypothesis predicts that, for example, if an ambiguous target is labeled as a *hat* and is placed amidst other hat distractors, it should be more difficult to find than when that target is labeled as a *cake* and is placed amidst the same hat distractors. In other words, when presented with the same visual information in the search array, children should be better able to find a target if it was labeled as a category other than the distractors.

Methods

Participants. Thirty-two children (18 females, M_{age}=36 months, SD=2.12) were randomly assigned to either the Within-Category or the Between-Category condition. These children did not participate in Experiment 1. Four additional children were recruited but not included due to refusal to participate (N=3) and failure to follow task instructions.

Stimuli and Procedure. Four ambiguous items were created by blending together the two items (cake and hat) of each pair (see Figure 7, rightmost column); the ambiguous items included aspects of both the cake and the hat of the pair (e.g. the frosting and the ribbon), and were edited to look like a plausible visual object (e.g. smooth surface, even coloring, even edges). The Within- vs. Between-Category manipulation was realized by changing how the target object was labeled during the visual preview. For instance, in the Within-Category condition, children would preview the ambiguous item #2 and hear it labeled as *hat*, and then be asked to find it amidst hats 1, 3, and 4. In the Between-Category condition, children would preview the same ambiguous item #2, but hear it labeled as *cake* and then be asked to find it amidst hats 1, 3, and 4. Notice that the visual information presented in the preview and in the search array is *exactly the same* in both conditions – the difference between the two conditions is whether the ambiguous target is labeled a member of the same vs. a different category as the distractors while it is previewed prior to search. All other aspects of the procedure for the visual search were the same as Experiment 1.

To ensure that the ambiguous stimulus pictures were equally likely to be recognized as hats and cakes, 8 additional children (6 females, M_{age}= 36 months, SD=2.62) were tested in a 4-alternative forced choice recognition task similar to the one used in Experiment 1. Each child was tested with all the ambiguous items, two of them as "cake" and the other two as "hat"; across children, each ambiguous item was equally likely to be tested as "hat" and as "cake". The target category (hat vs. cake) was blocked for each child, the order of block presentation was counterbalanced across children, and the presentation order of the items was randomized within each block. On average, children selected the ambiguous items as "cake" on 81% (SD=0.40) of the trials, and as "hat" on 84% (SD=0.35) of the trials (paired $t(7)$=0.16, p=0.88) – suggesting that the ambiguous items were equally likely to be recognized as hats and cakes. Children took a similar amount of time to respond to cakes vs. hats trials ($t(7)$=0.45, p=0.67). In addition, to ensure that children were not selecting the ambiguous items merely because they looked more unfamiliar or novel than any of the foils, children were presented with 4 "catch" trials (2 after each block) where they were asked to find a balloon; on these "catch" trials, one of the foils was a novel-shaped object and the other two foils were known objects. Children correctly identified the balloon on 91% (SD=0.18) of the trials, suggesting that they were not relying on novelty to respond in this task.

Results and Discussion

Similar to Experiment 1, initial data inspection suggested that participants were both faster and more accurate in the Between-Category condition than in the Within-Category condition. Figure 2B shows that the relationship between RT and accuracy is the same across conditions, in that participants' accuracy does not depend on time taken to respond, but participants in the Between-Category condition were more accurate than participants in the Within-Category condition. A generalized linear mixed effects model (fit in the same way as in Experiment 1) showed that Condition was the only significant predictor of accuracy, OR= 0.12, $p<0.001$. Time taken to respond [OR=1.1, p=0.8] and the interaction between Condition and RT [OR=0.8, p=0.4] were not predictive of accuracy. This suggests that hearing the name of an object activates visual information about that objects' category, which affects visual processing. When presented with *the same* visual information, children's ability to find a visual target in a cluttered array depended on how that visual target had been labeled while it was being previewed. This is a robust demonstration of the effect of language on visual processing – encoding an ambiguous object as a hat or as a cake changed children's ability to find that object amidst the same set of distractors.

General Discussion

The experiments presented here support our proposal that language affects human cognition by activating category information, which in turn influences visual processing. In Experiment 1, children's ability to find a visual target was hindered by the presence of same-category distractors; this influence of categorical information on visual processing was instantiated through visual means. Experiment 2 extended those results by showing that words can also activate categorical information which influences visual processing. Together, these results show that visual processing is influenced by categorical information, and that heard words can instantiate categorical information.

How does categorical information – through visual or linguistic means – influence visual processing? Past research on categorical perception suggests that categorical information changes the perceived similarity among the items, with items that belong to the same category being perceived as more similar to one another than items that belong to different categories (Goldstone & Hendrickson, 2010; see also Sloutsky & Fisher, 2004 for a related developmental model). This perceived similarity could influence visual processing in multiple ways. One possibility is that perceiving an item as a member of the same category as the distractors – and consequently as more similar to the distractors – lowers the threshold for accepting an item in the array as the target (e.g. Elman, 1979). Another possibility is that perceiving all the items as items of the same category influences children's ability to bind all the features of the target object together (Treisman & Schmidt, 1982); there is evidence that object feature binding is still developing in late childhood (Lorsbach & Reimer, 2005) and that children are prone to making conjunction errors (Dessalegn & Landau, 2008). Through increasing the perceived similarity between the target and the distractors, category information might lead children to incorrectly bind features of the target and the distractors, increasing the likelihood of making an incorrect selection. Interestingly, language has been suggested to play a role in the binding of visual features in young children (Dessalegn

& Landau, 2008; 2013), perhaps through the activation of categorical information.

These are empirically testable possibilities that merit future research. But notwithstanding the specific process by which children's ability to find a target was impaired by the presence of distractor items of the same category as the target, the point is that *it was impaired* – both when the categorical information was presented through visual means (Experiment 1) and through language (Experiment 2). The current results support the idea that words influence visual processing by highlighting information about the objects' category. This idea has important consequences to conceptualize the pathway by which words change visual object processing in young children, proposing that words activate categorical information that may change how objects are perceived and processed. Future research should examine what specific aspects of the objects' category are being activated when a word is heard. The ability to recognize the components of an object, and how those components relate to each other, is one critical aspect of visual object recognition (Tarr & Bülthoff, 1998), and the developmental literature on visual object recognition suggests a long and protracted development on the ability to use configural information (Augustine et al., 2011: Jüttner et al., 2013). Given the strong links between word learning and visual object recognition in early childhood (Augustine, et al., 2011; Pereira & Smith, 2009; Smith, 2003), it is possible that language comes to change what aspects of the objects children attend to.

These results also highlight the importance of understanding the nature of visual processing in young children. Contemporary accounts of visual processing in adults propose a reciprocal interaction between the short-term encoding of visual information and long-term visual representations (e.g. Brady, Konkle, & Alvarez, 2011). Research across levels of analysis suggest that both processes might be permeable to top-down influences (e.g. Hemmer & Steyvers, 2009; Olsson & Poom, 2005), but we have very little understanding of how these develop. That is, what information do children use to visually process objects in the moment, what do those visual representations include, and what factors influence the long-term encoding and fidelity of those visual representations? All these processes are likely to mature and improve with age (e.g. Burnett Heyes et al., 2012; Simmering & Perone, 2012) and might be weak in children (Riggs, McTaggart, Simpson & Freeman, 2006; Zhang, Shen, Tang, Zhao & Gao, 2013). Importantly, visual processing and visual working memory have been shown to be immature in children with language impairments (Collisson et al., 2015), further underscoring the importance of understanding the development of these processes.

In sum, we documented that words influence visual processing, likely by highlighting information about the objects' category. This fits with our proposal that one pathway by which language influences human cognition is by activating category information, which influences visual processing, and that this pathway likely starts in early childhood.

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