Perceptual and linguistic category formation in infants

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Abstract

It is known that infants are aware of the category of objects in daily life before explicit vocabulary acquisition starts. It has been suggested that the ability of categorization is likely to play an essential role in its overall cognitive development. In this study, we conducted a series of experiments using stimuli that have various attributes in order to understand the process of such a categorization in an infant's pre-linguistic development. We consider two possible cognitive processes of linguistic categorization. One possible scenario is that certain members of the categories are derived from similarity with the most representative members of a category (prototypical members). Alternatively, the coupling of each category member-ship with relevant labels can be traced to the symbol grounding problem. Our results are consistent with an interpretation that the cortical systems involved in language development is inseparably linked with prototype effects in categorization.

1. Introduction

The human linguistic system is complex and arbitrary. Nevertheless young children become fluent speaker of the native language in a short period. Acquiring this complex linguistic system in a fairly short time is an absolute marvel, reflected in the characteristic human cognitive development [1]. It has been known that young children are able to master the use of the native language without any special training. An environment where they can participate in the usual social exchange is sufficient. During the development in the period from 1.5 to 6 years after birth, infants add new words to their vocabulary at an average rate of 8 words a day. In this period, the infants aren't provided with a definition of the meaning or the usage of the new words. Infants learn by an inference from the conversations that they encounter.

It is unacceptable to explain the learning of language in a way that is dependent on a solid and formal acquisition of each word. If the acquisition of the name of an object is done in a one by one examination of the unique properties of the objects in relation to all the other objects in the world, vocabulary acquisition should take an enormous time. It is a logical impossibility to make reasonable inferences from only a limited amount of information on the objects that a particular word is apparently referring to. Despite these seeming theoretical impossibilities, children can acquire a particular meaning from the enormous possible set of meanings of the words referring to the objects [2].

At least one thing is clear in the children's word learning. When children listen to a new word, they never explore the whole domain of the logically possible meaning of the particular word in question. In the majority of cases children "guess" the meaning of the words which they listen to for the first time and assign a temporary meaning to that word after making proper reasoning. Such a temporary assignment of the meaning of the word has been called "fast mapping" [3].

As a possibly effective method of dissolving the apparent difficulty in coming to an understanding of an infant's language acquisition, and accounting for the seemingly effortless way in which children conduct fast mapping, recently the concept of cognitive constraint has entered the mainstream approach.

The cognitive constraint here refers to the conceptual scheme that children retain internally when they encounter a new word. The cognitive constraint effectively narrows the range of search that needs to be done in the acquisition of new words [4, 5]. This concept is introduced in a marked contrast with the philosophy of behavioral psychology in which children's learning and development are attained through the inputs and feedbacks from the outside. The cognitive constraints are metaphors with which the cognitive linguists try to account for an infant's inherent ability of language development in the pre-linguistic period.

The specific nature of the cognitive constraint that has been advocated up to the present can be classified roughly into the following two classes. One is the knowledge on how a word can be made to represent a general concept. Another is the knowledge on the structure of the vocabulary such as what kind of meaning a word can possibly have.

It is known that infants are aware of the category of objects in daily life before explicit vocabulary acquisition starts [6]. Infants only a few months old are able to separate complex visual stimuli into generic object categories [7]. For instance, infants are able to recognize the various "cars" - pictures of cars in books, real cars running on the street etc., as belonging to a single category. Even though the various attributes such as color, texture, size are not the same for a real car and a picture car, they are able to perceive them as belonging to a single category. As a result of this categorization process, children as young as 30 months old can be markedly different in their abilities at the perceptual level [8]. It has been suggested that the ability of categorization is a meta-knowledge tightly coupled with an infant's language acquisition [9], and is likely to play an essential role in its overall cognitive development. For example, a familiar object such as an apple can take various forms, when it is cut and dressed. The child is apparently able to recognize these physically different entities as belonging to the same category.

Based on the hypothesis that knowledge for the perceptual category representations of objects exists before explicit verbal ability appears [10, 11], we conducted a series of experiments in order to understand the process of such a categorization in an infant's pre-linguistic development.

2. Phonological Association Task

When infants in the pre-linguistic period encounter various situations where the usage of language is involved, how do they make the word-object association? In order to clarify this point, we conducted a series of experiments.

2.1. Method

Twenty 14 to 24 month-old infants (M=21m0d) participated in the study.

Infants sat facing the screen. As the two pictures in different categories were shown on the screen, the name of one of the categories was given as an auditory stimulus. Each pair of pictures was presented for 10 seconds. Stimulus design is given in Figure 1. 9 trials were conducted.

By measuring the mean looking time, we investigated the ability of the infants to generalize over image variations in associating the images with audio stimulus.

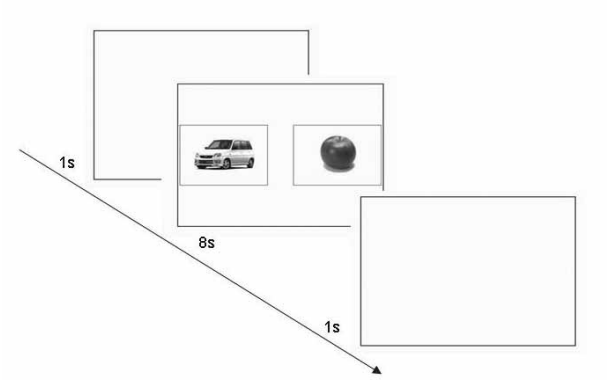

Figure 1: Stimulus design.

Pictures of target objects were varied in the salient features such as color, form, and size. For example, the apple was given either as a whole, cut half, or dressed as a rabbit (given in Table 1). Presented stimuli belonged to one of categories (food, creature, and artifact). Word familiarity and word length were matched based on the database of Japanese words [12].

Table 1: Stimulus Objects

Category-apple	Whole apple photo Half apple picture Rabbit-shaped apple photo
Category-fish	Line drawing fish Goldfish photo Cloth fish photo
Category-car	White car photo Red car picture Woody toy car photo

2.2. Results

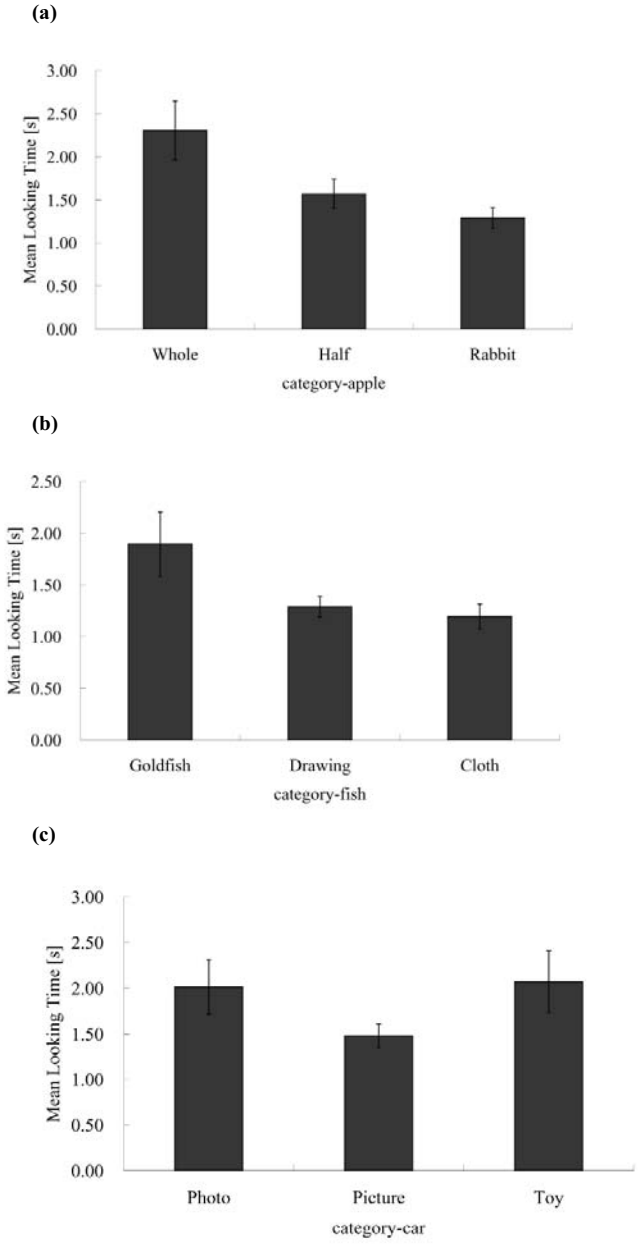

Figure 2: Preference Scale in various forms.
(a) category apple, (b) category fish, (c) category car.

Significant effects of the physical shape of the object were observed; except for category-car (artifact) (food: $F(2, 31) = 5.690$, $p=0.008$ (Fig2.a), creature: $F(2, 30) = 4.116$, $p=0.026$ (Fig2.b), artifact: $F(2, 34) = 1.561$, $p = 0.225$(n.s.) (Fig2.c), total: $F(2, 105) = 7.734$, $p<0.001$). Though a repeated-measure ANOVA with pairing objects (target vs. other) revealed a significant difference (food: $F(1, 72) = 67.21$, $p<0.001$, creature: $F(1, 66) = 64.46$, $p<0.001$, artifact: $F(1, 72) = 83.28$ $p<0.001$, total: $F(1, 214) = 205.9$, $p<0.001$) (given in Figure 3).

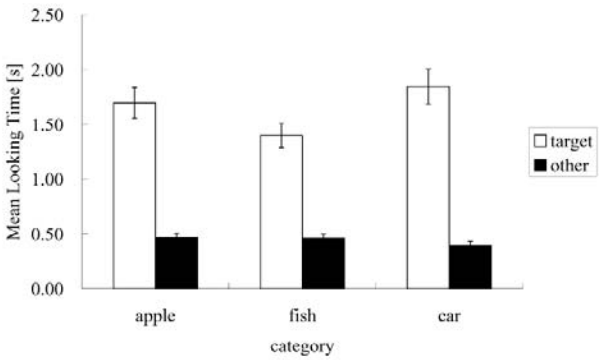

Figure 3: Preference Scale (target vs. other)

These results are consistent with the interpretation that the infant is able to recognize the physically different forms of object as belonging to the single category, even before explicit verbal ability emerges.

The experiment is based on a preferential looking paradigm, and does not address the explicit abilities of the infants to use the acquired category in a linguistic or pre-linguistic context. With that limitation in mind, these results are consistent with the interpretation that the infants are apparently able to perceive physically different objects as belonging to a single category. These results are also indicative of the developmental process in the infants to perceive the various objects in the environment as belonging to specific categories.

This experiment alone does not tell us how the infants are able to conduct this pre-linguistic categorization. There could be two major ways of realizing the categorization. Firstly, the infants could use the perceptual similarities between the various forms of apple. Even when the apple is cut in half or dresses as a rabbit, there are visual similarities (such as the color or the texture) that the infant could utilize in the categorization process.

Alternatively, the infants can use the single auditory label as common to the various appearances of each category. The first strategy is more perceptually based, whereas the second strategy is tightly coupled with the linguistic maturity to come. The infants could utilize these different strategies to a varied extent at different stages of development.

In order to clarify this point, we conducted a second series of experiments, where we presented two different age groups of infants with several pictures of different objects in a contingent context.

3. Naming and Visual-Pairing Task

In this experiment, we investigated whether there are significant changes in the ability for categorization and naming in formative stage. The key question was whether the infants depended on visual information or linguistic information when they perceived the different forms of an object (e.g. apple) as belonging to the same category.

3.1. Method

Twenty infants of two age groups participated in the study. They were fallen into two groups of the same number. 10 of them were aged round 15 months (M = 15m6d), and the remaining 10 were aged 21 months (M = 21m3d). Each infant was tested individually. The infant was seated on a mother's lap across a table from the experimenter.

In the test phase, the two pictures in different categories were given as the picture on the drafting paper as same as previous experiment.

The experimenter presented the infants with pairs of pictures and asked them a series of questions. In the naming task, the experimenter asked (in Japanese) "'Ringo' [object's name] wa dotti?" Which is (an) apple?]. In the visual-pairing task, the experimenter presented another visual stimulus as the prototypical member of the target categories and asked the question (in Japanese) "Kore to onaji mono wa dotti?" [Which is the same thing as this?]. The infants answered by pointing to a picture. Both procedures were repeated for the seven sets of pictures.

The stimuli were the same as in previous experiment, except that now they are printed on the drafting papers.

3.2. Results

The results of the naming task and the visual pairing task were analyzed separately. For each trial, infants were given a score of 1 when they chose the correct object, and a score of 0 when they chose the other. Mean total scores per age and task are given in Table 2. Repeated-measure ANOVAs were conducted to determine whether infants were choosing the correct picture significantly above the chance level. In the naming task, significantly high correct rates above chance were revealed in both the younger group ($M = 5.63$, $SD = 0.92$, $F(1, 14) = 43.04$, $p<0.001$) and the elder group ($M = 6.43$, $SD = 0.98$, $F(1, 12) = 63.04$, $p<0.001$). In the visual-pairing task, these analyses revealed that infants of the younger group were responding at chance ($M = 3.75$, $SD = 1.83$, $F(1, 14) = 0.15$, $p=0.71$), while infants of the elder group were responding above chance level ($M = 5.14$, $SD = 0.69$, $F(1, 12) = 39.68$, $p<0.001$).

Table 2: Mean numbers of correct responses

	Naming	Visual
Younger (15 month)	5.63*	3.75
Elder (21month)	6.43*	5.14*

* $p < 0.001$

The marked difference in the correct rate for the visual and naming tasks is interesting. These results are consistent with the interpretation that infants give priority to linguistic information over the visual information when the presented stimuli are well known to them.

4. Discussion

Within cognitive psychology and cognitive linguistics, categorization has become a major field of study and prototype effect is focused as the characteristic features of categorization [14, 15]. The results from experiment of phonological association task showed significant effects of the physical shape of the object.

In the present study, phonological association task was conducted to study the association between the linguistic

labels given as auditory stimuli with the visual stimuli through the cognitive process involving the prototypical member as inner representations within each individual. From the aspect of prototype effects, we may conclude that the relatively more representative members in the category are easier to invoke the prototypical member in the inner representation. Thus, infants were able to find appropriate objects out of the stimuli presented and to associate them with the auditory labels. The different behavior observed in category-car (artifact) might be due to the familiarity with common categories such as "car" and "toy" for children.

In addition, we may consider a kind of symbol grounding problem. In the visual-pairing condition, test stimuli given with the question were treated as one of the most typical member of the target categories that evoked the prototypical member. It is suggested that their similarity enabled to analogize other members from these stimuli.

Finally, the linguistic labels given in the naming task made it easier to recall the prototype within each category than the similar members in the visual-pairing task. The different strategies used in categorization are expected to vary according to children's stage of development.

It has been much debated whether children weigh shape similarity more heavily than conceptual similarity, invisible to the eye, such as taxonomic relatedness or functional commonality [13]. Through several developmental phases, conceptual similarity seems to take precedence over shape similarity. On the other hand, it is possible that the infants apply both of these principles to word-object association and perceptual categorization as the situation demands. The higher correct rate for the naming task compared to the visual task in experiment of naming and visual-pairing task is consistent with the interpretation that infants are more conceptually driven than visual driven in the judgment of categories.

The ability to identify as belonging to the same category objects which bears no or little resemblance, and to judge objects which bears a strong resemblance to each other as belonging to different categories, are formed through the stages of the development [8, 10]. The understanding of the concept of identity plays the prominent role in perceptual categorization.

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6. References

[1] Obler, L. K. and Gjerlow,K., *Language and the Brain.* Cambridge University Press, Cambridge, UK, 1999.

[2] Soja, N. N., Carey, S., and Spelke, E. S., “Ontological categories guide young children's inductions of word meaning: Object terms and substance terms”, Cognition, 38, 179-211, 1991.

[3] Carey, S. and Bartlett, E., “Acquiring a single new word”, Papers and Reports on Child Language Development, 15, 17-29, 1978.

[4] Markman, E. M. and Hutchinson, J. E., “Children's sensitivity to constraints on word meaning: Taxonomic versus thematic relations”, Cognitive Psychology, 16, 1-27, 1984.

[5] Landau, B., Smith, L. B., and Jones, S. S., “The importance of shape in early lexical learning”, Cognitive Development, 3, 299-321, 1988.

[6] Eimas, P. D. and Quinn, P. C., “Studies on the formation of perceptually based basic-level categories in young infants”, Child Development, 65, 903-917, 1994.

[7] Quinn, P. C. and Eimas, P. D., “Perceptual cues that permit categorical differentiation of animal species by infants”, Journal of Experimental Child Psychology, 63, 189-211, 1996.

[8] Gelman, S. A. and Markman, E. M., “Categories and induction in young children”, Cognition, 23, 183-209, 1986.

[9] Nazzi, T. and Gopnik, A., “Linguistic and cognitive abilities in infancy: when does language become a tool for categorization?”, Cognition, 80, B11-B20, 2001.

[10] Gelman, S. A. and Markman, E. M., “Young children's inductions from natural kinds: the role of categories and appearances”, Child Development, 58, 1532-1541, 1987.

[11] Stager, C. L. and Werker, J. F., “Infants listen for more phonetic detail in speech perception than in word-learning tasks”, Nature, 388, 381-382, 1997.

[12] Amano, S. and Kondo, T., *Nihongo-no Goitokusei (Lexical properties of Japanese).* SANSEIDO Co.,Ltd. Tokyo Japan, 2003.

[13] Soja, N. N., Carey, S. and Spelke, E. S., “Discussion: Perception, ontology, and word meaning”, Cognition, 45, 101-107, 1992.

[14] Rosch, E. and Mervis, C. B., “Family Resemblances: Studies in the Internal Structure of Categories”, Cognitive Psychology, 7, 573-605, 1975.

[15] Lakoff, G., Women, Fire, and Dangerous Things: What Categories Reveal about the Mind. The University of Chicago Press, Chicago, 1987.