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Ten-month-olds' selective use of visual dimensions in category learning

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Abstract

There is now general consensus that infants can use several different visual properties as the basis for categorization. Nonetheless, little is known about when and whether infants can be guided by contextual information to select the relevant properties from amongst those available to them. We show here that by 10 months of age infants can be biased, through observational learning, to use one or the other of two object properties for classification. Two groups of infants watched an actress classifying objects by either shape (the Shape group) or surface pattern (the Pattern group). When subsequently presented with two test trials which contradicted either one or the other of the classification rules, infants in the two groups looked longer to the classification event that was incompatible with the rule that group had been familiarized to. These results are discussed with reference to the development of selective feature processing in infancy.

Keywords: Categorization; Context dependence; Observational learning; Selective attention

By 12 months, human infants can group objects into perceptual categories based on a variety of common dimensions such as colour (Bornstein, Kessen, & Weisskopf, 1976), shape/form (Colombo, McCollam, Coldren, Mitchell, & Rash, 1990; Quinn, Slater, Brown, & Hayes, 2001), surface patterns (Eimas & Quinn, 1994) or movement (Casasola, Bhagwat, & Ferguson, 2006; Hirsh-Pasek, Golinkoff, Pruden, & Salkind, 2006). However, objects encountered in their every day lives have many different dimensions (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), not all of which are informative for assigning the objects to specific categories. As adults, we have little problem selectively extracting the relevant dimensions when relevance is defined either by explicit instruction, implicitly, by the context in which an object is seen or by prior knowledge (Flanagan, Fried, & Holyoak, 1986; Lin & Murphy, 1997; Murphy, 2001; Schyns & Oliva, 1999)

Older children can also selectively use a subset of visual features to categorize objects. For example, 3- to 4-year olds will take into account object domains (i.e. food or tools), when attending to either shape or colour. Similarly, toddlers transfer their new found tool knowledge to objects that can be used to reach and pull another object, but not to objects that share a common colour or pattern with the demonstration object (Landau, Smith, & Jones, 1998), whereas they will consider colour as relevant when transferring information about food items (Lavin & Hall, 2002; Santos, Hauser, & Spelke, 2001). Additional evidence for the onset of selective feature processing comes from the domain

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of language acquisition, where studies have shown that during their second year of life infants learn that syntactic categories are associated with certain visual dimensions. Between 11 and 14 months infants learn that common nouns refer to object kinds and not to surface properties (Waxman & Booth, 2001) and later, around 21 months, that adjectives have the opposite property (Waxman & Markow, 1998). Interestingly even after this age infants maintain their capacity to flexibly switch between a shape-based or a material-based generalization, depending on the dimension highlighted by the task (Samuelson and Horst, 2007).

Despite this evidence of context-dependent selective processing of object features during early childhood, few studies have directly examined the onset of this capacity in infancy. One possibility is that selective attention will develop along with, and in close relation to, language acquisition. Possibly it is by discovering that different object properties are associated with different labels that infants learn to selectively attend to them. Indeed, labels have been shown to help object categorization, even in 6-month olds (Fulkerson & Waxman, 2007; Waxman & Braun, 2005). However, there is also evidence that even non-linguistic instruction can direct infants' attention towards a subset of object properties during categorization. For example, Ellis and Oakes (2006) found that 13-month olds, who spontaneously categorized a group of objects as cubes versus balls, could be induced to group these same objects on the basis of their material properties (i.e. soft versus hard), if these less visually obvious properties were demonstrated prior to the categorization test. A link between selective feature processing and language acquisition was found in this study as well, those infants who manifested flexibility being also those who had larger receptive vocabularies.

Does language set a lower limit to the emergence of these capacities? It is possible that before linguistic categories are being learned, infants' categorization is rigidly determined by whichever property they find most salient. For example, 2-month olds scan the external contour of objects more than their interior (Maurer & Salapatek, 1976). Thus, it is possible that shape or form might capture younger infant's attention and prevent them from learning categories that cut across this dimension. Indeed, 9-month-olds categorization of two natural categories (mammals versus vehicles) does not seem to be affected by the presence of colours or textures which cut across these categories (Pauen, 2002). Nonetheless, natural categories constitute a special case of entrenched knowledge, which might make them less susceptible to flexible reorganization. If novel categories are being learned, young infants may show the ability to use a range of dimensions depending on the classification task and context. Thus, even if form is dominant in their spontaneous attractiveness they could overcome this, if necessary.

The current study explores this issue. We use an observational category-learning task in an attempt to modulate whether 10-month olds attend to either the shape or the surface pattern of the same set of objects, depending on the prior context. We chose 10-month olds because we know that at this age infants can create categories based on various visual properties while at the same time they have not yet discovered the links between linguistic categories and different object properties.

Infants watched a series of categorization events that followed either a *Shape rule*, in which triangles were grouped together and separately from rectangles, independent of their surface patterns, or a *Pattern rule*, in which objects with stripes were grouped separately from objects with dots, independently of shape. During the test trials all infants were presented with two novel categorization events, one that violated the Shape rule, while conforming to the Pattern rule, the other that violated the Pattern rule, while conforming to the Shape rule. We were interested in seeing whether infants' judgements of these sequences depended on their prior familiarization. Specifically, we predicted that if 10-month-old infants are able to selectively use different stimulus dimensions then they should look longer at the test trial that contradicts the rule with which they had been familiarized. Finally, because a number of studies have shown that a communicative context enhances infants' processing of object properties (Striano, Reid, & Hoehl, 2006; Yoon, Csibra & Johnson, personal communication) the classification event involved a woman placing the objects in one group or the other. It was hoped that the introduction of an agent in the event would help the infants recognize the different dimensions relevant for the categorization.

1. Methods

1.1. Participants

Forty infants took part in this study: 20 in the Shape condition (8 girls and 12 boys), with a mean age 307 days (range 291–315 days) and 20 in the Pattern condition (12 girls and 8 boys), with a mean age of 310 days (range 301–317 days). A further seven babies were excluded from the Shape group (four for fussiness, two for looking only at the actress in

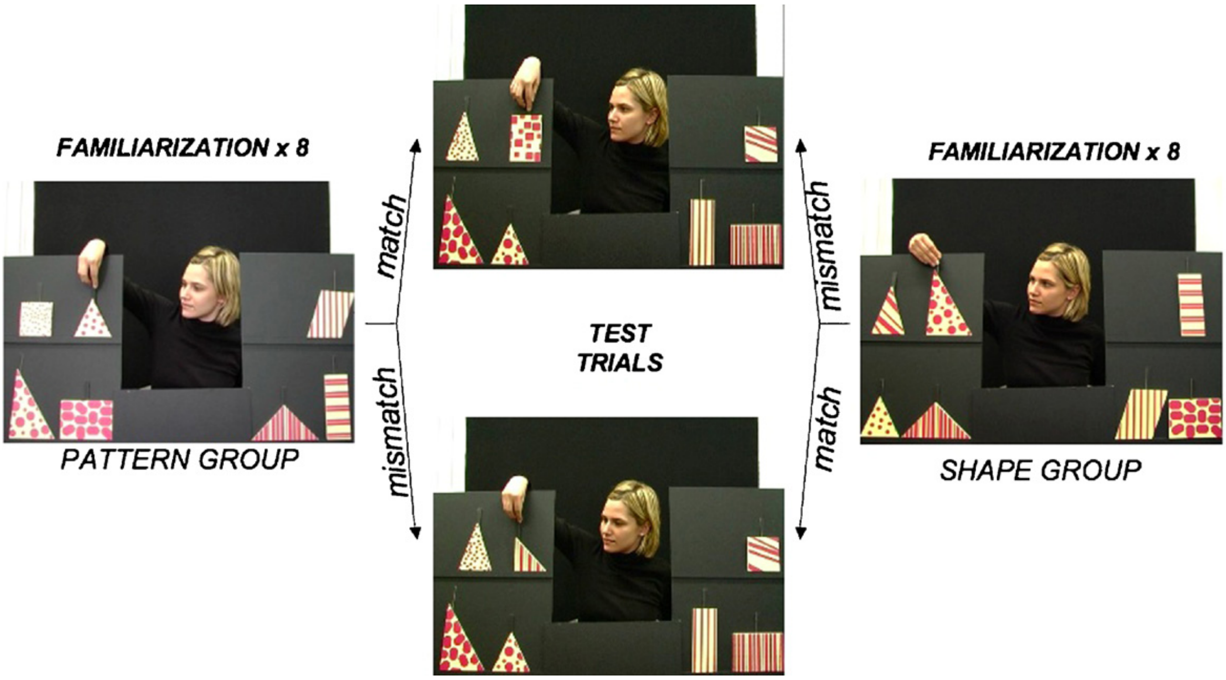

Fig. 1. Selected frames from the video clips used in this study. After placing the object, the actress withdrew her hand and maintained her gaze direction until the end of the sequence.

the test trials, and one because of experimenter error) and a further four babies were excluded from the Pattern group (three for fussiness and one for looking only at the actress, in the test trials).

1.2. Stimuli

The Familiarization and Test stimuli consisted of digitally edited video sequences depicting an actress interacting with eight objects (see Fig. 1). The objects were cardboard cut-outs of four differently shaped triangles and four rectangles. Two of the triangles and two of the rectangles were covered with different stripe-patterned paper and the other two with different dot-patterned paper. In each trial, infants would only see seven of these objects. Six of the objects were stationary, located on two lateral boards, three triangles on one side and three rectangles on the other (the Shape context) or three striped objects on one side and three dotted objects on the other (the Pattern context). The seventh object was manipulated by an actress who placed it onto one of the boards. Each sequence started with the actress happily exclaiming "Hello baby" and waving towards the camera. She then took the seventh object from behind a central small occluder, raised it, looked at it and then placed it on one of the two lateral boards (Fig. 1). After she placed the object she maintained her gaze averted to that side, until the end of the trial. We created eight such sequences in which each of the eight objects was in turn the one that was placed on the boards. When on the boards the objects had a visual angle of 7–9°, horizontally and vertically.

1.3. Procedure

Infants were seated on their parents lap, 60 cm away from a 85 cm plasma screen. The infants were first shown eight Familiarization trials. In each of these trials a different object was placed on one of the boards. The order in which the objects were placed, as well as the hand used for the placement, was randomised. Two different sequence orders of the eight trials were generated for use with each group (Shape and Pattern contexts). Immediately after Familiarization all infants saw the same two Test trials in which two new objects were introduced: (1) a new triangle having a new striped pattern, and (2) a new rectangle having a new dotted pattern (see Fig. 1). For any particular baby the two objects were placed on the same board, which led to one of the trials being a *Match trial* (corresponding to the familiarized rule) and the other a *Mismatch trial*. What counted as a Match or a Mismatch trial depended on the type of Familiarization received (e.g., the striped triangle placed on the left side constitutes the Match trial for the Shape group and the dotted rectangle placed on the same side constitutes the Mismatch trial for this group). For the Pattern group the same sequences would have an opposite value. This procedure ensures that the category learning was assessed for both categories within a dimension. The side on which the test objects were placed, right or left, was counterbalanced. The order of presentation of the Match and Mismatch trials was also counterbalanced across infants.

All the trials were of fixed duration, 17 s for the familiarization trials and 26 s for the test trials. An attention getting stimulus, a spinning flower accompanied by a sound, was presented between each two successive trials. A new trial was started only if the baby was looking at the screen.

Finally, pilot work for the Pattern context (six infants) initially revealed that infants appeared to have little sensitivity to the pattern information. Therefore, in the Pattern context we added an extra sensitization sequence, prior to the events described above, in which full screen patterned textures, similar to the ones covering the experimental object were shown in alternation (eight slides, 2 s each) and side by side (four slides, 2 s each). The purpose of this was to heighten the relevance of texture information for infants in this group. The eight familiarization trials followed immediately.

1.4. Data analysis

Video recordings of the infant's looking behavior were coded with 40 ms accuracy. Gaze direction was coded from the beginning of each sequence until the end of the trial. The gaze direction was coded as towards (1) the left board, (2) the right board or (3) the person or (4) outside the screen. We then calculated the total time spent looking at each of these locations. The recordings of 35% of the participants (seven in each group) were also coded by a second coder, who was blind to the experimental hypothesis, to check reliability. The looking times to the side where the object was placed were correlated between coders with $r = 0.948$.

2. Results

2.1. Familiarization trials

To compare infants' attention to the familiarization sequences in the two contexts, the looking time at the whole screen, and the looking time at the lateral boards, averaged across the eight familiarization trials, were evaluated separately for the Shape and Pattern Groups using *t*-tests. Infants in the Shape group looked less than those in the Pattern group at the whole screen (14.3 versus 15.8, respectively) but more at the sides (3.5 versus 2.9, respectively). However these differences were only marginally significant (whole screen: $t = -1.85$, $p > 0.07$; sides: $t = 1.90$, $p > 0.06$). Thus, while infants in the two contexts accumulated comparable amounts of experience with the two contexts, because differences in looking time to the sides where categorization can be observed did approach significance we chose to include this looking time measure as a covariate when analysing the test trials.

2.2. Test trials

Because much of the early part of the test event unfolds without involving a category decision, coding was started from the time point in the video sequence when the actress begins to place the object on one of the lateral boards. This corresponds to when a category decision has been made. As with the Familiarization trials, this coding scheme yielded measures of looking times to left, right and middle parts of the screen. An inspection of the looking time to the different parts of the screen showed that infants spent most of the time looking at the actress. Infants looked approximately 70% of the time to the actress, approximately 20% to the side where the object was placed, and the rest of time to the opposite side. We were first interested in seeing whether these locations were equally influenced by the test trial condition. Therefore we carried out an ANOVA with Screen Side (Side where object was placed, Center and Opposite side) and Condition (Match, Mismatch) as within subject variables. This revealed a significant interaction of Screen Side and Condition ($F(2,30) = 5.15$, $p = 0.01$; Table 1). This effect was due to longer looks towards the side of the screen where the test object was placed, when the placement violated the familiarized rule (Mismatch condition).

To analyse further the effect of Condition on the test trials three separate ANOVAs were run on the looking time measures for each location, with the between subjects factors: Familiarization type (Shape, Pattern), Side on which the test object was placed (Left, Right), test trial Order (Match first, Mismatch first), and the within-subject factor Condition (Match, Mismatch). The time each infant spent looking at the familiarization trials was also entered as a

Table 1
Looking time measures at the three parts of the screen, depending on the experimental condition

	Side where object is placed	Center	Opposite side
Match (S.D.)	3.74 (0.432)	12.83 (0.966)	1.00 (0.247)
Mismatch (S.D.)	4.28 (0.480)	12.78 (0.999)	1.00 (0.251)

covariate (Famtime). This analysis revealed a main effect of Condition $F(1,25) = 4.18$, $p = 0.05$) on the looking time to the side receiving the test object. There were no other significant main effects of Familiarization type, Side Order, or Famtime or significant interactions between these factors and Condition. No significant main effects (including of Condition) were found on the looking time to the other two parts of the screen (i.e., Center and Opposite side).

3. Discussion

We have shown that 10-month olds can selectively use one of two object properties, shape or surface pattern, for categorization. Both test trials that infant saw in this study contained a mismatch between the features of the test objects and the objects with which the test item was classified, yet infants better detected the violation within the dimension that had been highlighted by the classification observed during the induction trials. In an earlier study Ribar, Oakes, and Spalding (2004) showed that the variability of exemplars affects whether infants can learn a novel category. While these results already showed flexibility in accepting different dimensions as a basis for categorization, our study goes well beyond this. We show that, while maintaining the feature distribution, infants' categorization is affected by the rules that govern the classification of those objects. To our knowledge this is the first evidence of this kind in infants as young as 10-month old.

The need for a longer familiarization for the Pattern group implies that this dimension might initially have been more difficult to use than the objects' shape. This can be the result of a processing bias. Indeed when natural categories are involved shape is often being preferred to texture in category membership judgements (Pauen, 2002; Rakison & Butterworth, 1998). Even in adulthood shape extraction is believed to be a fast and obligatory processing step, texture and colour adding little to initial object recognition (Biederman & Cooper, 1991). It is also possible that the difference between stripes and dots was simply less psychophysically potent than the difference between triangles and rectangles. As in adulthood, the features that infants use for categorization will depend on both the visual context and the features' availability to perception (Schyns, 1998). Infants' success in category learning, independent of the dimension used, proves that, in the present study, they could go beyond perceptual biases or limitations.

Two further aspects of our study are worth highlighting. Firstly, within each primed dimension infants succeed in finding the inconsistency in classification for both of the displayed categories. This is indicated by the fact that they looked longer in, for example, the Shape condition, when either a triangle was joining the rectangles or a rectangle was joining the triangles. Thus the infants succeeded in creating two categories within each dimension, suggesting a good allocation of attention and memory abilities at this age. Presenting them with two contrasting categories might actually have helped the category learning, as has been shown under certain conditions (Quinn, 1987; Waxman, 2004 but see also Mareschal, Quinn, & French, 2002 for different findings). Secondly, we used an actress to induce the classification because we believed that this would increase infants' attention to the scene and thus help their learning. However, it is possible that his choice of presentation worked against us since infants spent the majority of their time looking at the agent and less at the classified objects. It is therefore remarkable that, despite the demands of our study, infants succeeded in the category-learning task.

The present results support the existence, early in life, of mechanisms that allow selective use of object features in the particular case of object categorization. They also contribute to the wider topic of the development of selective attention in infancy by demonstrating that before infants become sensitive to grammatical categories they can use non-linguistic prior experience to selectively process shape or texture. Similarly, Wilcox and Chapa (2002) showed that priming 5-month olds to a functional distinction between differently patterned objects helped them use pattern in a subsequent occlusion event. Without this priming infants did not detect the pattern change of the object, after occlusion, while still detecting a shape change (Wilcox, 1999). This study joins ours in showing that prior experience can modulate infant's attention to surface features, even at a younger age. The primacy of shape processing in occlusion events, as well as in our own study, could stem from a general bias to process object shape. Alternatively, in Wilcox's study, it could be the result of context-specific learning. Shape, along with size, is a relevant feature in predicting the outcome of occlusion event (Wang & Baillargeon, 2006). Future studies will address how the context-modulation of attention to features interacts with pre-existing biases, throughout development.

Fewer infant studies have investigated the development of feature-based attention as opposed to spatial attention (Colombo, 2001). One reason for this may be the fewer available methods for modulating attention to features in a non-verbal way. We showed here that, through observational learning of classification events, we can induce feature-selective processing in infants. We hope to thus encourage more extensive studies addressing the development of feature-based attention in the future.

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