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On the Acquisition of Pattern Encoding Skills

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These experiments evaluated two potential sources of developmental changes in pattern encoding: advances at a perceptual level enabling better representation of the spatial relations among elements, and acquisition of metaperceptual knowledge supporting a deliberate search for distinguishing features. Children 6, 10, and 12 years old, as well as adults encoded high level distortions of random dot configurations. These materials were originally used by Posner and Keele (1968). In the first experiment, subjects matched exemplars to their prototypes. In two other experiments, subjects learned to categorize distortions under two different training conditions—one designed to focus attention on individual exemplars, the other designed to facilitate comparison of exemplars within and across categories. Following training, subjects classified new instances into the learned categories. The same pattern of developmental change was found in the matching task and in the classification task: major gains between ages 6 and 12 and continued gains to adulthood. Several aspects of the results identify change at a perceptual level after age 10 as a source of this development, independent of possible contributions from metaperceptual advances.

Performance on a variety of pattern encoding tasks improves dramatically during childhood. Developmental changes have been observed in the ability to encode faces (Blaney & Winograd, 1978; Carey & Diamond, 1977; Flin, 1980; Goldstein & Chance, 1964; Kagan & Klein, 1973), structured scenes (Mandler & Robinson, 1978), and abstract patterns (Boswell, 1976; Boswell & Green 1982; Gibson & Gibson, 1955; Mendelson & Lee, 1981; Paraskevopoulos, 1968). The source of these advances has not been identified. There are three general possibilities. First, with experience, children would gain knowledge of the objects to be encoded. Such content-specific knowledge would enable the distinguishing

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features of materials such as faces and scenes to be encoded more successfully (Chi, 1983). Two other sources of developmental change in encoding efficiency would be content-general, applying to all types of material, including abstract patterns. Children might acquire metaperceptual knowledge supporting strategies such as a search for common and distinguishing features among groups of patterns. The final possibility for content-general development would be a change in perceptual ability. For example, children might become better able to represent the full set of spatial relations among the elements of any pattern.

The classic study of Gibson and Gibson (1955) provided evidence of developmental differences in the ability to encode abstract patterns. Subjects were given coil-like nonsense forms to be studied briefly and then discriminated from distractors varying in numbers of turns, horizontal extent, and orientation. At ages 6 to 8, children were less accurate than at ages 9 to 11. In addition, the older children were inferior to adults. These changes in sensitivity to pattern features have been attributed to either perceptual or metaperceptual development. However, the features that individuate the Gibson and Gibson figures overlap with those that individuate alphanumeric characters. Increasing familiarity with letters and numbers could enhance sensitivity to those distinguishing features, suggesting that the acquisition of content-specific knowledge could also have contributed to these results. More recent studies have demonstrated developmental changes in the encoding of abstract patterns in which the transfer of knowledge gained with familiar materials is not a possibility (Boswell & Green, 1982; Chipman & Mendelson, 1975, 1979; Mendelson & Lee, 1981; Mendelson, 1984).[1]

In this article we evaluate two potential sources of content-general developmental changes that would affect the encoding of abstract patterns. The first is metaperceptual: improved general strategies for finding common and distinguishing features. The second is perceptual: increased ability to encode spatial relations. Posner and Keele's prototype extraction paradigm (Posner & Keele, 1970) seems ideally suited to this purpose. Subjects are shown distortions of randomly generated patterns and must identify those exemplars generated from the same prototype. There is no knowledge acquired outside the task that could be relevant to learning to distinguish the categories. The distinguishing features are configural (deriving from the spatial relations of elements in the prototype) and the use of high-level distortions as training exemplars ensures that their representation places great demands on a pattern encoder. By studying generalization of the learned categories to new patterns, the adequacy with which this configural information has been represented can be assessed. Finally, the influ-

[1] The study by Bowell and Green (1982), will be discussed at length here. Using a wide variety of tasks, Chipman and her colleagues showed that young children make less use than older children and adults of such pattern features as internal repetitions and symmetries. These differences could reflect either perceptual or metaperceptual development.

ence of encoding strategies can be examined by varying the conditions under which the categories are learned.

The adult capacity to extract the configural information that underlies a category is revealed by successful generalization to new instances. Adults typically categorize the prototype (which they have never seen) as reliably as they categorize the exemplars on which they were trained. New distortions of the prototype are not as well classified as the training exemplars; their accuracy decreases as the level of distortion of the prototype increases. It has also been observed that idiosyncratic features of the training exemplars are forgotten more rapidly than the prototypical information (Homa, Cross, Cornell, Goldman, & Schwartz, 1973; Posner & Keele, 1970; Strange, Kenney, Kessel, & Jenkins, 1970). These findings have been taken as evidence for a particular form of representation of the categorical information in memory, namely, the existence of a summary representation, in addition to representation of the features of the training exemplars. However, it has been shown that the same pattern of results could emerge from a model of memory in which only the training exemplars themselves are represented (Hintzman & Ludlam, 1980; Smith & Medin, 1981). The issue has not been resolved and alternatives to both the summary representation and individual–exemplar views have also been suggested (e.g., Elio & Anderson, 1981; McClelland & Rumelhart, 1985). We are primarily interested here in understanding developmental changes in the adequacy with which the prototypical information is encoded, rather than its representational format.

There is already evidence of developmental changes in the encoding of random patterns of the Posner type. Boswell and Green (1982) presented such a task to adults and children (ages 4–6 years) and subsequently assessed recognition of the training exemplars (olds) and classification of new exemplars, under two conditions. In the first condition (Categorize), subjects were given the standard instructions to identify all exemplars, old and new. In the second condition (Remember), subjects were asked to indicate only those items they had seen during training, that is, only the olds. There were three interesting developmental differences:

1. Children required many more trials to learn to classify the training exemplars.
2. In the Categorize condition children were inferior to adults in classifying new exemplars. Although children and adults were comparable in accuracy on prototypes, children classified prototypes less accurately than olds whereas adults showed the reverse pattern.
3. In the Remember condition, when explicitly asked to distinguish olds from prototypes, children could do so, but adults could not.

Boswell and Green suggest that these developmental differences result from strategic differences between children and adults. In their view, children learn the categories by focusing attention on idiosyncratic features of the training exemplars, presumably attempting to form an association between the category label and each instance. In contrast, these investigators suggest, adults focus attention on the features shared by members of each category, resulting in limited acquisition of exemplar-specific knowledge. The children's exemplar-based encoding strategy would account for their slower learning, less adequate generalization, and ability to discriminate olds from new category members. Although Boswell and Green argue that for the children a summary representation coexists with exemplar-specific knowledge, their account is consistent with the formation of a summary representation only in adults.

There is some evidence that the learning task given adults can influence later classification. Medin & Smith (1981) showed that subjects who were instructed to "learn the categories" generalized better to new instances than those who were instructed to abstract a rule plus exceptions, or to form a general impression and use it in later decisions. Using patterns of the Posner type, Metcalfe and Fisher (1986) showed that generalization to new instances was better when subjects had studied exemplars to prepare for a categorization task than when they had studied them to prepare to discriminate those patterns from others. However, this does not alter the basic profile of adult generalization. Even when adults attempted to learn to identify particular exemplars, they were successful at categorizing new instances. Their performance reflected the prototypical basis of category membership.

Evidence that the adult generalization profile emerges automatically from exposure to members of a category sharing prototypical information also comes from studies in which subjects are unaware that there are several categories of patterns or in which there is no learning task (e.g., Evans, 1967), suggesting a limited role for encoding strategies. However, it is possible that the relative automaticity with which prototypical information is encoded by adults does not hold for children. If this were so, children might benefit more than adults from conditions supporting the utilization of strategies for finding the features that category members share and those that distinguish one category from another. This hypothesis is consistent with Boswell and Green's interpretation of their results, and the studies to be reported here will address it.

We suggest, however, a different interpretation of Boswell and Green's data. First, we hypothesize a metamemorial difference between children and adults that is distinct from their suggestion of age differences in attention to common features. Learning to label patterns with category names involves the formation of paired associates. It is well known that strategies for forming arbitrary associations and for monitoring one's progress in a task of this kind are acquired between age 5 and adulthood (Kail, 1984). The difference in learning speed between Boswell and Green's children and adults could derive, in part, from these metamemorial advances. Second, we propose that children have less ability than adults to perceive the spatial relations among the elements of these patterns, and thus have a less complete representation of the prototypical information upon which category membership depends. This would mean that children find a set of distortions of the same prototype phenomenally less similar than do adults. This could contribute to both their slowness in learning to attach the same label to the members of a category and to their poorer generalization to new exemplars. It might also account for children's ability to discriminate old and new exemplars when asked to do so.

Our hypothesis that children are actually inferior to adults in ability to encode configural information predicts developmental differences in classifying the prototype, as well as in classifying new distortions. While the latter was found to be true, the children and adults in Boswell and Green's study did about equally well in recognizing the prototype as a member of the category. We suggest that this equality might have been a ceiling effect reflecting the use of training exemplars, 2- and 5-bit distortions, which differed only slightly from the prototype.[2] Our studies utilized more difficult materials on which adults were predicted to show an advantage over young children in generalization to the prototype as well as in generalization to other new instances.

The experiments in this article continue the work on developmental changes in pattern encoding begun by Boswell and Green. We will examine the evidence for changes at a metaperceptual level and for changes arising directly from increased ability to perceive and encode spatial relations among pattern elements. In Experiment 1 a simple matching task is used to evaluate our hypothesis that young children are limited in the ability to see the similarity between distortions and the prototypes from which they are derived.

EXPERIMENT 1

Method

Subjects. Subjects were 24 undergraduate volunteers and 24 children aged 6, 10, and 12. The children were recruited from an upper-middle-class suburban public school system. There were an equal number of males and females in each age group. The undergraduates were paid $5.00 each and the children were given a small gift.

Materials. Materials were constructed as described by Posner and Keele (1968). Three prototypes were formed by placing nine dots randomly in a 30 × 30 cell matrix. For each prototype a total of ten distortions were generated, four at the 5-bit level and six at the 7.7-bit level. Examples of the materials are shown in Figure 1. The dots were about 1 mm in diameter, printed in black, with the patterns centered on squares of white paper 17 cm × 17 cm.

[2] The number of bits represents the degree of randomness imposed on the location of dots in the prototypical pattern.

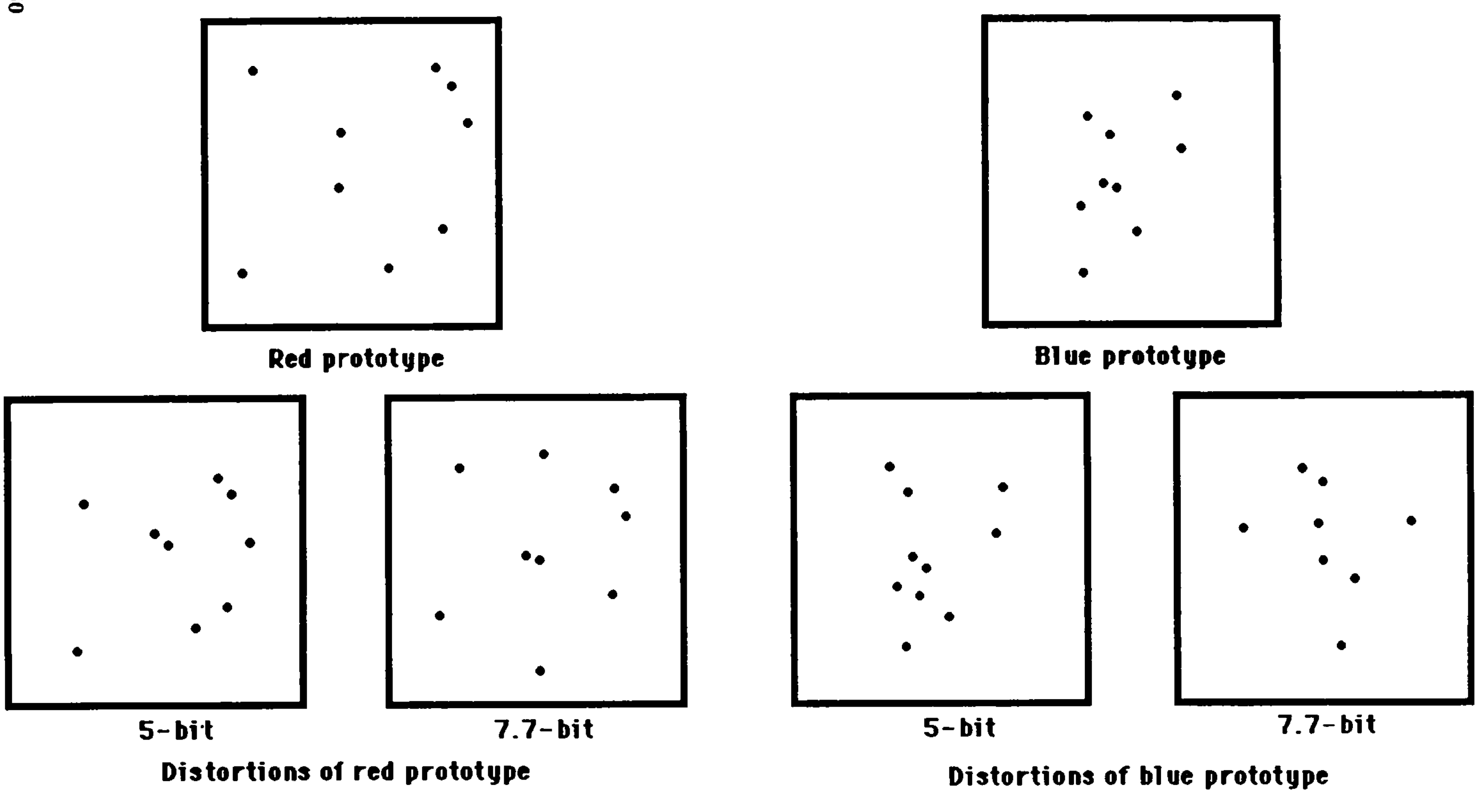

Figure 1. Materials used in these experiments: two of the prototypes and a 5-bit and 7.7-bit distortion of each.

Procedure. Three small black platforms were placed before the subject with one of the three prototypes displayed on each. The left-to-right arrangement of the three prototypes was randomized across subjects in each age group. Subjects were presented a randomly ordered series of 30 patterns comprised of the 10 distortions of each prototype. The task was to indicate to which prototype each distortion was most similar by placing it beneath the appropriate platform. Patterns already placed were no longer visible. Subjects were told to look at all three prototypes before deciding where each pattern belonged and were reminded of this if they appeared not to be doing so. Participants were told that they were doing well but no direct feedback was given. This short procedure required less than 10 minutes from even the youngest children.

Results and Discussion

Table 1 shows the accuracy of each age group in percentage-correct assignments.

Performance at all ages was significantly above the chance level of 33% correct. At each age items closer to the prototype (5-bit distortions) were assigned more accurately than those farther from the prototype (7.7-bit distortions). Both of these results indicate sensitivity at all ages to the configural features that distortions share with their prototypes.

These data were entered into an ANOVA with age and sex as between-subject variables and item type (5-bit vs. 7.7-bit distortions) and category (the three different prototypes) as within-subject variables. There were no significant main effects or interactions involving sex. Significant main effects were found for age, $F(3, 88) = 9.87$, $p < .001$, item type $F(1, 88) = 120.13$, $p < .001$, and category, $F(2, 176) = 25.09$, $p < .001$.[3] There were no interactions involving age.

A Newman-Keuls test for differences among means examined the source of the main effect for age. At the .05 criterion level there were no differences in overall accuracy between 6- and 10-year-olds or between 12-year-olds and adults. Adults were more accurate than either of the two youngest groups at the .01 criterion level, and the advantage of 12-year-olds over 6-year-olds just failed to reach the .05 criterion level.

Despite evidence of sensitivity to the configural properties of the patterns at all ages, there is thus a clear developmental advance in the adequacy with which

[3] Although formed by the same rule, the three categories differed with respect to the actual distance between their exemplars and the prototype, as given by summing over metric distance between each point and the corresponding point on the prototype. In the present experiment, exemplars of the most tightly clustered category were easier to sort than exemplars of the other two categories. In some of the other tasks using these materials which we will present in this article, main effects of category also emerged, along with complex patterns of interactions of category with variables such as age and item type. All of these effects were attributable to differences in category difficulty resulting from the idiosyncratic structural differences noted above. Because these effects have no bearing on the arguments presented in this article they will not be discussed.

Table 1. Mean Percentage Correct Sorting of Exemplars into Categories

	Item Type	
Age Groups[a]	5-bit Distortions	7.7-bit Distortions
6-year-olds	76	62
10-year-olds	78	63
12-year-olds	85	68
Adults	91	77

[a] $n = 24$ for each group

this information is encoded. The emergence of developmental differences in a task that does not involve learning militates against Boswell and Green's hypothesis that the differences they observed between young children and adults reflect a shift in learning strategy. Any adult superiority in abstracting a summary representation from training exemplars would be irrelevant to this matching task. However, other metaperceptual skills are relevant to matching tasks as well as to the traditional learning and generalization task. Adults might be more systematic than children in their efforts to find features that distinguish prototypes or more likely to examine the whole pattern before making a match.

The likelihood of a metaperceptual contribution to the development of pattern encoding can be evaluated by attempting to influence subjects' encoding strategies and determining how the developmental function is affected. To accomplish this we turned to a learning paradigm and devised two acquisition conditions. The first, the copy procedure, was designed to ensure that young children would actually examine the entire pattern. Subjects copied each training exemplar several times, forcing attention to all of the dots. Each exemplar had to be correctly categorized before another new exemplar was presented. This method should facilitate attempts to remember individual exemplars. The second training method, the array procedure, was designed to facilitate a search for common and distinguishing features of the categories. All the patterns were viewed at once, grouped into their categories. The subject was instructed to study them to see how those in each category were alike and how those in the three categories differed. This procedure should facilitate deliberate attempts to form a summary representation.

Both the copy and array training procedures were used in the context of a categorization task, that is, subjects were explicitly asked to learn to distinguish the categories so that new members could be classified. The literature suggests that given this common orientation, adults were likely to encode the stimuli similarly in the two training conditions. Experiment 2 tested the prediction that adults would show the standard generalization profile following both procedures.

EXPERIMENT 2

Method

Subjects. Subjects were 48 male and 48 female undergraduate volunteers, paid $5.00 each for their participation. Equal numbers of men and women were assigned to each of the two training procedures (copy and array). Within each procedure and sex, half of each group of subjects were assigned at random to one of two training/generalization lists so as to provide an internal replication.

Materials. The materials were the prototypes and distortions used in Experiment 1. Two different learning lists were assembled, each consisting of four randomly selected 7.7-bit distortions of each prototype (the training exemplars). An appropriate generalization list was constructed for each learning list consisting of two of the training exemplars for each category (olds), the prototypes of each of the three categories, two 5-bit distortions of each prototype, and two 7.7-bit distortions of each prototype that had not been used as training exemplars. Three different semi-random sequences of each generalization list were prepared. In each sequence no more than two successive items came from the same category and items from all three categories and of all types (olds, prototypes, 5-bit distortions, new 7.7-bit distortions) were evenly distributed. Each subject was given two generalization trials with a different sequence used for each trial.[4]

Training Procedure. Our adult subjects were informed that the procedures were those we intended to use with young children. Both the copy and array procedures began with the same set of general instructions:

> We have made three different kinds of patterns: the red kind, the blue kind, and the green kind. The colors are only names for the different kinds; the patterns have nothing to do with color. We have made lots of each kind. We want you to be able to tell which kind each pattern is. This is how you'll learn the different kinds of patterns. I'll teach you four red ones, four blue ones, and four green ones. After you learn them I'll show you some new reds, blues, and greens that you have never seen before and ask you to say what kind each one is. It doesn't matter how long it takes you to learn the reds, blues, and greens I give you. The important thing is to know them well so that later you'll be able to tell which kind some new ones are.

When the patterns were actually shown, subjects were told that they should be viewed in the orientation in which they were presented. Subjects were also told that all the patterns had the same number of dots and that they should look at the entire pattern rather than at just a part of it.

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[4] A pilot study using these materials in the standard Posner and Keele (1970) procedure produced a generalization pattern similar to that of their subjects.

Copy Training Procedure. The first three items shown always consisted of one red, one blue, and one green. After these three exemplars had been presented and the required number of copies of each had been made (see below), the first classification trial was given. Three small platforms whose tops were covered with red, blue, and green felt cloth were placed before the subject (with left-to-right arrangement of the colors varied across subjects). The set of three items was presented one at a time (in random order) as many times as needed to classify all three on a single trial without error, placing them beneath the appropriate platform. Items already placed were no longer visible. Subsequently, items were added one at a time in a semi-random order (balanced for category) with the subject required to classify the cumulated set correctly in a single trial before each addition.

When each exemplar (including the first three) was presented for the first time, the subject was told its color name and then required to complete several partial copies of it. The exemplar to be learned was composed of black dots. The subject was given, alongside the exemplar, an incomplete copy of it with a number of randomly selected dots missing. He or she used a felt-tipped pen of the appropriate color (red, blue, green) to go over the black dots already on the partial copy and to add the dots that were missing. For the first three patterns learned, four partial copies were completed: copies lacking 3 dots, 4 dots, 5 dots, and 6 dots. For the next three items learned, the copy lacking 3 dots was eliminated. For the last six items, the copy lacking 4 dots was also eliminated. The experimenter removed each colored copy immediately after it was produced.

At the beginning of each classification trial the stimuli were removed from under the platforms and shuffled. The experimenter handed each exemplar to the subject who responded with a color name. In the case of an incorrect response, the experimenter said the correct color immediately and the subject then placed the pattern under the corresponding platform. The learning criterion was correct classification of all 12 exemplars on a single trial.

Array Training Procedure. Three pieces of cardboard, 32 cm × 32 cm, covered by red, blue, and green felt cloth were placed horizontally edge-to-edge before the subject. The left-to-right arrangement of the colors varied across subjects. The experimenter set out all 12 training exemplars, placing the four members of each category on the appropriate board. The items were laid out in mixed sequence with regard to category. The subject was told that it did not matter where each exemplar was placed on its board. Subjects were given 2 minutes to look at the patterns and told to try to learn which were the red, which were the blue, and which were the green. The items were then taken up, shuffled, and presented one at a time for the subject to give a color name. Errors were corrected immediately by the experimenter. Each exemplar was removed from view as soon as it had been classified. After an error, all the patterns were again laid out on the colored boards and the subject was given another 2-minute period to view them, followed by another test trial. This study and test process was repeated until all 12 exemplars had been classified correctly on a single trial.

Generalization Procedure. The first generalization trial was given immediately after the learning criterion had been met. Subjects were told that they would now see a mixture of some of the patterns they already knew, along with some reds, blues, and greens they had never seen before. The experimenter handed each stimulus individually to the subject for classification. Subjects trained in the copy procedure were required to complete (in black) a copy of each pattern in which 6 dots were missing before giving the exemplar a color name and placing it under the corresponding platform. The copying step was designed to reinforce attention to the entire pattern. Subjects trained in the array procedure simply provided a color name for each stimulus and the experimenter removed that item before presenting the next. The second generalization trial followed immediately. All subjects simply provided a color name for each exemplar and the experimenter then removed the pattern. During generalization, subjects were encouraged and told they.were doing well, but no direct feedback was given.

Results and Discussion

Learning. Given that the copy procedure required subjects to make several copies of each pattern, it is not surprising that it took longer (about 30 min per subject) than the array procedure (about 10 min per subject). Mean errors during learning were 4.69 (SD = 1.99) in the copy procedure and 3.85 (SD = 0.50) in the array procedure. An ANOVA was carried out on the errors data with procedure, sex, and learning list as between-subject variables, and category (red, blue, green) as within-subject variables. There were no significant main effects of procedure and no significant interactions of procedure with any other variable. Thus, the opportunity to view all of the patterns at once did not appreciably improve the ability of the adults to learn to distinguish the categories. Error rate was also unaffected by any of the other variables.

Generalization. Between the first and second generalization trial there was a decrease in total errors, the magnitude of which did not approach significance. Therefore, for all further analyses, errors were collapsed over the two trials. Table 2 shows the percentage of correct classification of items of each type.

The most important result is the replication of the standard pattern found in the literature: Prototypes are classified as well as olds and accuracy on other new distortions decreases with increasing distance from the prototype. The generalization data were entered into an ANOVA with procedure (copy vs. array), sex, and learning/generalization list as between subject variables, and category (red, blue, green) and item type (olds, prototypes, 5-bit distortions, new 7.7-bit distortions) as within-subject variables. There were no significant main effects of

Table 2. Mean Percentage Correct Classification During Generalization; Adult Subjects

	Item Type			
	Olds	Prototypes	5-bit	7.7-bit
Training procedure[a]				
Copy	94	90	85	68
Array	94	92	85	75

[a]$n = 48$ for each training procedure

procedure, sex, or learning/generalization list. As expected, there was a significant main effect of item type, $F(2, 184) = 11.54, p < .001$. A Newman-Keuls analysis showed that performance on olds and prototypes did not differ at the .05 criterion level; performance on each of these two types of items was better than that on 5-bit distortions which was, in turn, better than that on new 7.7-bit distortions (all differences at the .01 criterion level).

Although there was no main effect for procedure, there was a significant interaction between procedure and item type, $F(3, 276) = 2.87, p < .05$. A Newman-Keuls analysis revealed that this was due to better performance by subjects trained in the array procedure on one type of item, new 7.7 bit distortions, a difference that reached the .05 criterion level.

The copy and array conditions offer a striking contrast to a subject learning to classify patterns. The copy procedure seems likely to facilitate memory of particular aspects of individual training exemplars, whereas the array procedure seems likely to encourage the subject to find a way to distinguish the three categories with less precise knowledge of each exemplar. However, in terms of number of errors during training, the two procedures were comparable. Subjects trained in the two procedures performed at the same overall level of accuracy and showed the same generalization profile—the ability to identify the prototype as a member of the category is at the same level as recognition of the exemplars on which learning occurred, and accuracy in classifying 5-bit and new 7.7-bit exemplars shows the slope associated with increasing distance from the prototype. Experiment 2 confirms our prediction that any strategic differences induced by the two training procedures would have little or no effect on adults' ability to encode prototypical information.

In Experiment 3 we examine children's performance in both the copy and array procedures. Three issues will be addressed. First, if the comparability of children and adults in identifying prototypes found by Boswell and Green is indeed attributable to a ceiling effect, the more difficult materials used here should reveal an adult superiority in classifying prototypes as well as in classifying other new exemplars. Second, if a change in ability to encode configural information is the source of the developmental differences in the matching task of

Experiment 1, the same developmental function should emerge in generalization to new exemplars of learned categories. Finally, we will bring evidence to bear on Boswell and Green's hypothesis that a shift from a learning strategy based on encoding exemplars to one based on forming a summary representation is an important source of the differences they found between children and adults. If this were the case, young children and adults trained in the array procedure might be expected to differ less than those trained in the copy procedure, both in learning rate and in performance during generalization.

EXPERIMENT 3

Method

Subjects. Thirty-two children ages 6, 10, and 12 participated. They were drawn from the same upper-middle-class suburban public school system as those in Experiment 1 and equal numbers of boys and girls were included at each age. Data from 32 of the adult subjects of Experiment 2 were used for comparison. Four males and 4 females were chosen at random from among those trained on each list of exemplars in each procedure.

Procedure. At each age, half the children of each sex were assigned at random to the copy procedure and half to the array procedure for training. Both procedures were administered just as they had been to the adults in Experiment 2, except that in the array procedure some prompting was given to those 6-year-olds whose attention during the study periods appeared unfocused. In these cases the experimenter would say, "Look at the patterns on each color board and try to see how they are all alike; try to see how the reds, blues, and greens are different." These prompts were used sparingly.

The length of a single day's training session was limited to 45 minutes. If the learning criterion had not been met within that time, training was discontinued and completed on the next day. For children trained in the copy procedure, each day after the first began with presentation of the set of items last used, whether or not all of those items had been responded to correctly. When an errorless trial was attained with this set an item was added in the usual way and training resumed. There was always at least one training trial on the day that the generalization list was presented; that is, there was never a break between the day on which the learning criterion was met and the day of generalization. All 12-year-olds and 10-year-olds completed training and generalization in 1 day. Among 6-year-olds, 9 children trained in the copy procedure and 3 trained in the array procedure required 2 days to complete the task, and 1 child trained in the array procedure required a third day. One 6-year-old (in the copy procedure) made no progress in learning the task and was replaced by another subject.

Table 3. Mean Numbers of Errors During Training

	Training Procedure	
Age Groups[a]	Copy	Array
6-year-olds	18.0	16.6
10-year-olds	9.6	4.4
12-year-olds	2.3	2.6
Adults	3.2	2.8

[a]n = 32 for each group

Results and Discussion

Learning. Table 3 shows the number of errors to criterion at each age in each procedure. These data were entered into an ANOVA with age (6, 10, 12, adult), sex, procedure (copy, array), and learning list as between-subject variables.

There were marked age differences, $F(3, 96) = 20.79, p < .001$. A Newman-Keuls analysis with a criterion level of .01 showed that 6-year-olds made more errors than all other groups and that 10-year-olds made more errors than 12-year-olds or adults. Twelve-year-olds made as few errors as adults. There was a main effect of sex, $F(1, 96) = 4.80$, $p < .05$, with males making fewer errors, an effect that did not interact with age.[5]

Thus, the developmental function for the learning phase of this task shows major gains between ages 6 and 10, further improvement between ages 10 and 12, and no further change to adulthood. These data confirm Boswell and Green's finding that young children require more trials than adults to learn to categorize this type of abstract pattern. They also fill in the developmental function between these two end points. In our task, 10-year-olds are inferior to 12-year-olds, whereas the latter have reached the learning speed of adults.

There were no main effects or interactions involving learning list. More importantly, there were no main effects or interactions involving training procedure. The absence of a main effect of procedure replicates what was found in Experiment 2 with adults. The lack of a significant interaction of age and procedure indicates that the opportunity to view all the patterns at once does not appreciably affect learning efficiency at any age. This is of particular interest because it suggests that strategies for finding common and distinctive features play a negligible part in learning to categorize these patterns. This result militates against Boswell and Green's hypothesis that the superiority of adults to young children in

[5] As in other cases of sex differences in spatial abilities (c.f. Linn & Petersen, 1985), the effect size (d = .33) may be considered small (Cohen, 1977). Note also that no sex difference emerged in Experiments 1 and 2, or in the generalization data of Experiment 3.

learning efficiency in a task of this kind reflects adults' deliberate attempts to form a summary representation of the categories.

Initial pilot work using the standard Posner and Keele procedure (successive exposure of the full set of exemplars with feedback after each response) indicated that the learning rate of 6-year-olds was excruciatingly slow, and that many would fail to master the task. Both the copy and array procedures, therefore, may be credited with enabling even our youngest subjects to reach criterion. Both procedures engendered a good deal of interaction with the experimenter, and this aspect undoubtedly contributed to successful learning, especially in the youngest group.

Despite the absence of a significant interaction of age and procedure, the difference between error rates in the copy and array conditions appears substantial at age 10 and small at any other age, as shown in Table 3. A t test on the number of errors during training among 10-year-olds in the two procedures yielded $t(30) = 1.99, p < .10$. An ANOVA comparing just the two youngest age groups failed to show an interaction of age group and procedure, $F(1, 60) = 0.51, p = 0.48$. Variability among 6-year-olds trained in the array procedure was unusually high. Taken together, these observations suggest that some 6-year-olds and most 10-year-olds find it easier to learn to label the training exemplars in the array procedure than in the copy procedure. This might reflect acquisition of metaperceptual knowledge during this period, supporting a deliberate search for distinguishing features. The array condition would facilitate such a search and the copy procedure would minimize it, producing the suggestion of an effect of procedure seen at age 10. However, other differences between the copy and array conditions might also account for this effect. In any case, by age 12 learning errors have dropped equally in both procedures. This might indicate that encoding in terms of distinguishing features has become so readily executed that the two training conditions no longer have different effects.

Another possible metaperceptual source of greater learning efficiency at age 10 than at age 6 is support for the strategy of looking at the entire pattern rather than at a part of it. Although in both training procedures subjects were advised by the experimenter to look at the whole pattern, the copy procedure actually enforced attention to all the dots during initial presentation of each training exemplar. It would therefore be expected that any advantage of 10-year-olds attributable to having acquired the "look at the whole pattern" strategy would be diminished in the copy procedure relative to the array procedure. Thus, acquisition by 10-year-olds of this strategy and/or a strategy to search for distinguishing features would tend to increase their advantage over 6-year-olds in the array procedure relative to the copy procedure. Therefore, the absence of an interaction of age and procedure in the learning data for these two groups argues against a sizeable contribution from either source. These results encourage us to look elsewhere to explain the greater learning efficiency of 10-year-olds. In the general discussion we will suggest an alternative possibility.

The superiority of 12-year-olds and adults to 6-year-olds and 10-year-olds in learning efficiency is consistent with the evidence from Experiment 1 of a developmental advance between ages 10 and 12 in ability to represent configural information. Further evidence on this point is provided below by the results for the generalization phase of this task.

Generalization. The overall pattern of performance during generalization was examined with an ANOVA on the errors data. Age, sex, training procedure and learning/generalization list were between-subject variables, and generalization trial (first, second), category (red, blue, green), and item type (olds, prototypes, 5-bit distortions, new 7.7-bit distortions) were within-subject variables. Most important, the main effects for age and item type expected on the basis of the results of Experiments 1 and 2, were confirmed: for age, $F(3, 96) = 15.27$, $p < .001$; for item type, $F(3, 288) = 114.33$, $p < .001$. There was also a significant interaction between these two variables, $F(9, 278) = 3.28$, $p < .01$, which will be discussed in the following section.

There was a main effect of generalization trial, $F(1, 196) = 18.41$, $p < .001$, reflecting a small but consistent improvement on the second trial. The advantage for the second trial did not interact with age or item type. There were no other significant main effects or interactions involving any other variable of interest. Most important, there was no main effect of procedure nor any significant interaction involving this variable. Table 4 shows that, for the generalization data as distinct from the learning data, there is no suggestion of an interaction of procedure with age.

The main effect for item type resulted from an advantage for olds over new exemplars and, among new exemplars, the standard relation between level of distortion and classification accuracy. A Newman-Keuls analysis showed that performance levels on each of the item types differed at the .01 criterion level.

Our primary interest in these results is to assess development of the ability to represent the configural features that distinguish the three categories. Pertinent

Table 4. Mean Percentage Correct Classification During Generalization: All Subjects

	Training Procedure	
Age Groups[a]	Copy	Array
6-year-olds	73.8	73.8
10-year-olds	73.0	73.0
12-year-olds	78.2	81.2
Adults	86.5	90.0

[a]$n = 32$ for each group

data are overall performance and pattern of errors at each age. Planned t tests were used to compare adjacent age groups in terms of overall success. Ten-year-olds (73.0% correct) were no more accurate than 6-year-olds (73.8% correct). Twelve-year-olds (79.8% correct) were significantly more accurate than 10-year-olds, $t(62) = 34.11$, $p < .001$ and adults (88.2% correct) were significantly more accurate than 12-year-olds, $t(62) = 10.41$, $p < .001$.

Figure 2 shows performance at each age on each type of item. Accuracy on olds was not affected by age, indicating that a suitable learning criterion had been adopted. That is, despite developmental differences in learning rate, during generalization the training exemplars were classified equally well by all subjects. At every age, performance on new exemplars declined as distance from the prototype increased.[6] As is clear in Figure 2, however, the two older groups displayed a different classification profile than the two younger groups. The developmental difference shows most clearly with respect to prototypes. Apparently, a ceiling effect accounts for Boswell and Green's observation of equal performance on prototypes by young children and adults. This effect probably arose from use of training exemplars much closer to the prototype than those used here. In our data the two older groups classified prototypes just as accurately as they classified olds whereas the two younger groups classified prototypes less accurately than they did olds.[7] Thus, performance of the youngest two groups was nearly identical in profile, as well as in overall accuracy. Both aspects of performance change significantly by age 12, and development appears to continue between age 12 and adulthood.

To summarize: The generalization data show 6- and 10-year-olds performing at the same level with 12-year-olds superior to both younger groups and adults superior to 12-year-olds. There is no indication of any effect of training procedure on the ultimate representation of prototypical information in memory. These results contrast with those of the learning phase of this experiment in which 10-year-olds were more efficient than 6-year-olds. The learning data also differ from the generalization data in hinting at an effect of procedure at age 10, suggesting that strategic gains might contribute to faster learning at this age than in younger children.

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[6] A Newman-Keuls analysis showed that at each age prototypes were classified more successfully than new 7.7-bit distortions (at the .01 criterion level). At ages 12 and 6 (at the .01 criterion level) and at age 10 (at the .05 criterion level) prototypes were classified better than 5-bit distortions. Although all subjects found 5-bit distortions easier than new 7.7-bit distortions, the difference was significant only for adults (at the .01 criterion level) and at age 6 (at the .05 criterion level).

[7] A Newman-Keuls analysis showed that both older groups were more accurate on prototypes than the two younger groups. Adults were more accurate than all other groups on 5-bit distortions and more accurate than either 6-year-olds or 10-year-olds on 7.7-bit distortions. All of these differences reached the .01 criterion level; no other differences reached the .05 criterion level.

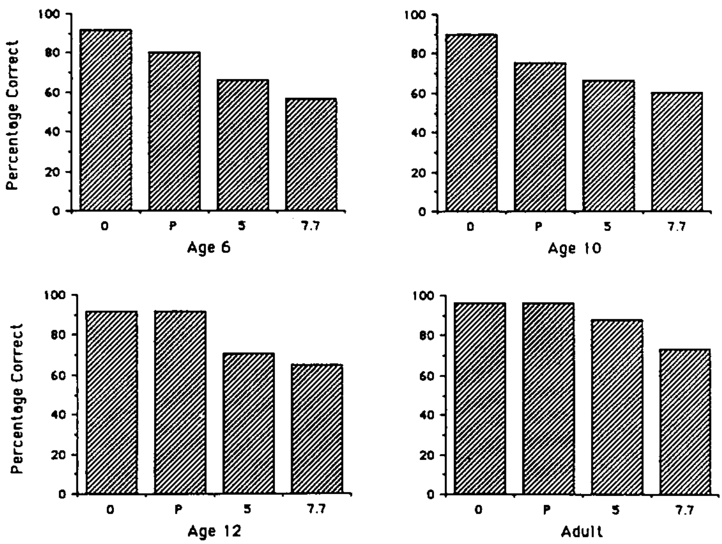

Figure 2. Mean percentage correct classification at each age of each type of item presented during the generalization phase of Experiment 3.

General Discussion

The intent of these experiments was to disentangle two potential sources of developmental changes in the encoding of abstract patterns: gains in metaperceptual knowledge that might support a deliberate search for common and distinguishing features, and increases in perceptual ability that would permit a more complete representation of the spatial relations among pattern elements. Several aspects of our results identify developmental change at a perceptual level as underlying the major advance in pattern encoding seen after age 10, independent of possible contributions from metaperceptual advances.

Data from two of the tasks used in these studies provide the most direct measure of ability to represent configural information: success in matching exemplars with their prototypes in Experiment 1, and accuracy in classifying exemplars into previously learned categories in Experiment 3. The same developmental function emerged in both—no change between ages 6 and 10, marked improvement between ages 10 and 12, and continued gain between age 12 and adulthood. Figure 3 shows that at each age, ability to classify 5-bit and new 7.7-bit distortions in Experiment 3 parallels ability to sort these items in Experiment 1.

Experiment 1 has no learning task, therefore, possible developmental differences in learning strategies (such as in deliberate attempts to form a summary representation) cannot be relevant to age changes in matching accuracy. In the generalization phase of Experiment 3 there is no opportunity consciously to compare one pattern with another, therefore, possible developmental differences

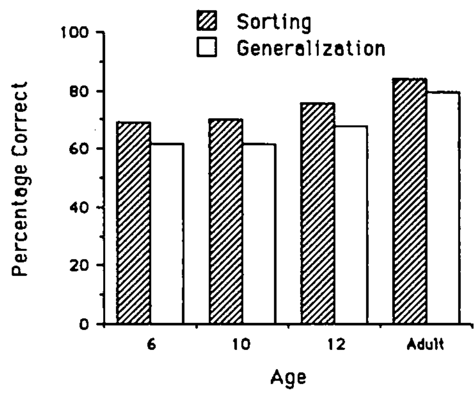

Figure 3. Mean percentage correct classification at each age of exemplars presented for sorting in Experiment 1 and during the generalization phase of Experiment 3. Sorting data are averages of mean performance on 5-bit and 7.7-bit distortions; generalization data are averages of mean performance on 5-bit and new 7.7-bit distortions.

in attempts to find distinctive features cannot be relevant to age changes in classification accuracy. The same developmental function emerges in both tasks, therefore, acquisition of these strategies is effectively ruled out as causative.

In addition, Experiment 3 was designed specifically to evaluate the suggestion of Boswell and Green (1982) that differences between young children and adults in learning strategy have as their outcome differences in the way in which abstract patterns are represented in memory. Boswell and Green found, as we have confirmed, that adults are more successful at generalizing learned categories to new exemplars. They also found that, following learning, children could discriminate training exemplars from new members of the category whereas adults could not. These investigators attributed both of these results to adults' deliberate attempts to form a summary representation of the training exemplars, in contrast to children's attempts to encode each specific pattern. We have argued that this characterization of adults and children suggests that the two age groups should perform the classification task more similarly following training in the array procedure (where common and distinguishing features are easier to find) than following training in the copy procedure, in which exemplars are presented singly. The absence of an interaction of age with procedure in the generalization phase of Experiment 3 therefore suggests that the Bosell and Green hypothesis is not correct.

In addition to this indication that the superiority of adults in classifying category members does not rest on a difference in encoding strategy, our data provide further evidence that children and adults are alike with respect to the automaticity with which they extract prototypical information from these stimuli. Overall classification accuracy was significantly greater on the second generalization trial of Experiment 3 than on the first. During the first generalization trial, subjects were presented both a broader range of exemplars than they had been shown during training (by addition of the prototype and 5-bit distortions) and additional exemplars at the same level of distortion as those they had already seen (new 7.7-bit distortions). Better performance on the second trial implies that refinement of categorical information occurs automatically with exposure to additional exemplars, independent of the subject's own responses (i.e., some of the first trial responses are errors), and in the absence of feedback. An advantage on the second generalization trial was also reported by Homa and Vosburgh (1976) for adult subjects, in a procedure in which, as in ours, exactly the same set of items was presented on each trial. These findings are consistent with other studies in the adult literature previously alluded to, indicating that the encoding of common configural properties of stimuli occurs automatically with exposure.

Improvement on the second generalization trial did not interact with age; the total number of errors fell 17% in the two younger groups and 14% in the two older groups. This shows that young children, no less than older children and adults, profited from mere exposure to an expanded set of exemplars to form a more adequate representation of the prototypical information.

There was no evidence in these data of a three-way interaction of generalization trial, age, and item type. On the second trial the two younger groups reduced errors on olds by 24% and reduced errors on the prototype and other new items by 15%. The two older groups reduced errors on olds by 15% and reduced errors on new items by 14%. Thus, the improvement on olds on the second trial was at least as great as that on new items, at both ages. This implies that in classifying olds, young children, as well as other subjects, utilized prototypical information. Our results suggest that children make no less *use* of prototypical information than do adults although their representation of this information is less *accurate*. This conclusion is opposed to Boswell and Green's inference that young children's representations of the categories are more dependent on encoding of individual exemplars than are the representations formed by adults.

Our rejection of a developmental difference in how children and adults represent prototypical information requires us to provide some other explanation of the ability of Boswell and Green's young subjects to differentiate training exemplars from prototypes in a situation in which adults were unable to do so. We hypothesize that children's ability to identify the training stimuli derives directly from their less adequate representation of the configural properties of the patterns, as reflected in their slower learning and poorer generalization. This limitation makes it plausible that in order to reach the learning criterion children encoded more specific information about individual exemplars than did adults. This information was then available to support identification of those patterns. We differ from Boswell and Green in that we attribute this effect to developmental differences in perceptual ability, rather than to differences in encoding strategy or to differences in representational format.

The developmental function found in Experiment 1 and in the generalization phase of Experiment 3 has been ascribed to an advance in the ability to perceive spatial configurations. The level of this ability must also influence the rate at which subjects learn to categorize exemplars presented during training. However, the developmental function for the learning phase of Experiment 3 did not parallel that for either the generalization phase of that experiment, or the matching task in Experiment 1. In particular, 10-year-olds learned faster than 6-year-olds, whereas their ability to match exemplars with prototypes and their ability to classify exemplars into learned categories was no better than that of the younger children. How is this discrepancy to be explained? We suggest the fewer errors during learning among 10-year-olds is likely to reflect their better command of metamemorial skills relevant to forming arbitrary paired associates. These skills are known to improve greatly in the period from age 6 to age 10. Within this age range older children are more likely to monitor which of a set of paired associates are already learned, and more likely to allocate increased attention to the unlearned pairs. They are also more likely to provide and rehearse verbal associates for abstract patterns (Kail, 1984). Thus, 10-year-olds, equipped with the same spatial skills as 6-year-olds, might have been more efficient learners because they were better at attaching the correct color name to each exemplar. The strategic advantage of 10-year-olds in this regard would not help them generalize the categories to new exemplars.

In addition, it is possible that the greater learning efficiency of 10-year-olds than 6-year-olds reveals a metaperceptual advance. Our data are consistent with a tendency for 10-year-olds to profit from the array procedure more than any other group, in terms of number of errors during learning. One possible interpretation of this trend is that under favorable conditions 10-year-olds deliberately search for distinguishing features. The supposition would be that younger children would not yet have access to this strategy, whereas 12-year-olds and adults would not require special conditions for its execution. We have also raised the possibility that 10-year-olds might have acquired a strategy to look at more of the pattern than 6-year-olds attend to. Our data do not provide strong evidence that either of these strategic possibilities contributes greatly to the enhanced learning efficiency of 10-year-olds, but this does not preclude an effect of other metaperceptual advances. Clearly, however, these possible metaperceptual or metamemorial gains have little or no effect on how categorical information is represented in memory. Ten-year-olds and 6-year-olds do not appear to differ in ability to represent these materials, shown by performance of the generalization task.

It is rare to find a developmental function that is flat between ages 6 and 10, as the present studies suggest for abilities to represent spatial relations among pattern elements. It is unlikely that either ceiling or floor effects are masking developmental change in these experiments. The flat function was found both in the very simple sorting task of Experiment 1 and in the generalization phase of the much more demanding procedure of Experiment 3. Moreover, it was found at several different levels of difficulty within each of these tasks: 5-bit and 7.7-bit distortions in Experiment 1, and all the new items of varying difficulty presented for classification in Experiment 3. Performance was well above chance in all cases and far from ceiling as well. The data presented here are consistent with those of others who have found little or no improvement during these years in tasks requiring encoding of random elements. For example, Mandler and Robinson (1978) found no change between ages 6 and 10 in memory for assemblages of objects arranged randomly. On the other hand, performance levels within the two younger age groups in our samples varied widely, suggesting the need to confirm the apparent lack of change between ages 6 and 10 in future work.

Regardless of the degree of change between ages 6 and 10, there is evidence here of substantial development of spatial ability by age 12 and continuing improvement to adulthood. We have argued against development at a metaperceptual level as accounting for this change, suggesting instead development at a perceptual level. Within this interpretation there are two possibilities, differing in generality. Our description has focused upon developmental changes in ability to represent the spatial arrangement of the dots, implying an increase in the number of spatial relations encoded for each pattern or in the number of dots interrelated by a single spatial descriptor. Such changes would be expected to influence performance of any task in which encoding of spatial relations plays a part, although tasks requiring representation of more complex relationships would be expected to be more developmentally sensitive. Alternatively, however, advances in the ability to represent spatial relations might be just one result of developmental changes in perceptual analysis routines that increase ability to encode all types of distinctive features. Such an increase in general perceptual ability would be expected to influence all encoding tasks, including, of course, the tasks used here and the perceptual learning task used by Gibson and Gibson (1955). However, in the Gibsons' data the period of maximum development was between ages 6 and 10, in contrast to the results obtained here (in the sorting procedure of Experiment 1 and in the generalization procedure of Experiment 3), implying little or no change in perceptual ability during just those years. This discrepancy suggests that global changes in capacity to carry out all types of visual analysis do not account for either the developmental function for encoding dot configurations or for the Gibsons' results. We tentatively conclude that enhanced perceptual ability specifically with regard to the representation of complex spatial relationships is the major source of developmental change in our two procedures. In contrast, improvement on the Gibsons' task probably reflects acquisition of content-specific knowledge of the kinds of features that individuate members of alphanumeric sets, as well, perhaps, as development of strategies for isolating distinguishing features of these stimuli. The first of these factors does not apply to our materials, and the second appears to have only a limited role, if any.

The present experiments have left open several issues. The first is the contribution of the developmental advance in encoding spatial relationships demonstrated here to the encoding of pattern features such as redundancy (as studied by Chipman and her colleagues), and to the encoding of natural objects such as faces. Second, although developmental changes in strategy of the sort probed here appear not to contribute to an appreciable extent to the improved ability to encode configurations, other metaperceptual advances might contribute to the development of this skill. In addition, the possibility that the acquisition of metaperceptual knowledge might contribute to developmental changes in other encoding tasks remains open. Finally, a precise formulation of how the encoding of spatial relations changes with development remains to be given.

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