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Explorations of creative visual synthesis in mental imagery

RONALD A. FINKE and KAREN SLAYTON
State University of New York at Stony Brook, Stony Brook, New York

The mental synthesis of visual patterns has been previously studied by instructing subjects to imagine assembling the component parts in specific ways. We report two experiments that show that subjects can often discover recognizable patterns in imagery when the component parts are randomly chosen and are provided without instructions for how they might be assembled. On each trial, the subjects were given a set of three parts, consisting of geometric forms, lines, or alphanumeric characters, and were instructed to close their eyes and imagine combining the parts to make some type of recognizable pattern. They were successful in doing so on about 40% of the trials. Many of these mentally synthesized patterns were strikingly creative, and few of them could be predicted, either by the experimenter or by the subjects themselves, simply by knowing what the parts were. On the contrary, most of the subjects reported that they had performed the task by imagining various combinations of the parts until a recognizable pattern "emerged." These findings show that visual discoveries in imagery can be reliably induced under appropriate laboratory conditions.

It is well known that people can imagine combining parts of objects to make a whole figure. For example, Thompson and Klatzky (1978) showed that subjects could mentally assemble the separately presented parts of geometric forms to make a whole, synthesized form. Similarly, Glushko and Cooper (1978) showed that subjects could mentally synthesize geometric forms in an image when the parts were merely described. These and related findings (e.g., see Intons-Peterson, 1981; Nielsen & Smith, 1973; Tversky, 1975) suggest that people can use imagery to mentally assemble the parts of a pattern in order to verify that the completed pattern matches one that is actually presented.

A separate issue is whether it is also possible to recognize unexpected patterns, entirely within imagery, after mentally assembling the parts. That is, can people ever make genuine visual "discoveries" in imagery, as opposed to simply verifying that certain parts can be combined to make a particular object or shape?

Some research indicates that people cannot reinterpret the parts of a pattern when the pattern is imagined, but can easily do so when it is actually shown. Reed (1974), for example, found that subjects were seldom able to verify that a structurally "poor" part was contained within a pattern they had previously seen but now only imagined. The same part was, however, easily verified as belonging to the pattern when the subjects made their decision while looking at the pattern (Reed & Johnsen, 1975; see also Palmer, 1977). More recently, Chambers and Reisberg (1985) found that classical ambiguous figures (such as the Necker cube) could not be perceptually reversed in imagery.

These failures may be restricted, however, to the particular types of stimuli that these investigators used. When such simple visual forms as letters of the alphabet or elementary geometric shapes were mentally synthesized, subjects were able to recognize familiar patterns emerging from the synthesis (Finke, Pinker, & Farah, in press). For example, in one experiment subjects were instructed to imagine superimposing the capital letter X directly over the capital letter H. With their eyes closed, they were able to discover various emergent forms in the synthesized figure, such as a bow tie and a rotated letter Z. These and other similar demonstrations extend earlier reports of emergent pattern recognitions in imagery (e.g., Pinker & Finke, 1980; Slee, 1980) and provide evidence that people are capable of making unexpected discoveries in imagery when mentally assembling or transforming a set of basic parts.

There is a major limitation, however, of the Finke et al. (in press) study, as well as of the previous studies that have explored mental synthesis. In every case, the subjects were told explicitly how to imagine combining the parts. Thus, they might never have made any of these visual discoveries without explicit, guiding instructions for how to imagine combining the parts. Hence, these studies do not reveal the extent to which people may be capable of using mental synthesis to make visual discoveries on their own.

In addition, the artificial constraints that such instructions impose may severely restrict the subjects' abilities to make *creative* discoveries in the imagined synthesis. Informal, anecdotal accounts of creative discoveries (e.g.,

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Kekule's famous report of having discovered the molecular structure of benzene while imagining a group of snakes coiled into the distinctive configuration, and other creative inventions described by Shepard, 1978) suggest that it may be possible to induce creative discoveries in imagery, under laboratory conditions, by removing constraints on the imagined synthesis. This challenge motivated the two experiments reported in this article.

EXPERIMENT 1

To explore creative visual synthesis in mental imagery, we provided subjects with a set of basic, randomly chosen parts, consisting of geometric shapes, lines, and alphanumeric characters, and then encouraged them to mentally assemble the parts to make some type of recognizable pattern. In contrast to previous studies, there were no instructions for how the parts were to be combined, and no right or wrong answers. Indeed, because the parts were randomly selected, there was never a specific target pattern that constituted a correct response. The subjects simply reported the name of the pattern, if they were able to discover one, and then drew it. Judges then rated the correspondence between the verbal reports and the drawings in scoring the responses.

Experiment 1 was designed to answer two questions: How often could naive, untrained subjects produce a recognizable pattern using the designated parts? Second, how often could the reported discoveries be guessed, simply from knowing what the parts were?

Method

Subjects. Thirty-nine undergraduate students at the State University of New York at Stony Brook served as volunteer subjects; their participation satisfied a research requirement in an introductory psychology course.

Stimuli. The parts to be used in the mental syntheses were selected from the set of 15 forms shown in Figure 1. Three of these forms were randomly chosen, with replacement, for presentation on each trial, resulting in 1,135 possible combinations. The only restriction was that the first 10 forms, which consisted of simple geometric shapes (circle, square, rectangle, and triangle), horizontal and vertical lines, and the capital letters D, C, L, and T, were three times as likely to be selected as the last 5 forms, which consisted of the alphanumeric characters J, 8, X, V, and P. This was done so that these more complex forms would seldom comprise the entire stimulus set.

Procedure. The subjects were tested in groups of 4-6 in single sessions lasting about 1 h. They were told that the experiment would investigate how people combine visual parts in a mental image. They were shown the 15 forms from which the parts would be selected, and the experimenter indicated the name that would be used to designate each of the parts. They were then told that at the beginning of each trial, three of these parts would be named in any order, sometimes more than once. As soon as the parts were named, the subjects were to close their eyes and try to mentally assemble the parts to make a recognizable figure. It was emphasized that all three of the parts must be used to mentally construct the figure, and that the figure could be anything—for example, letters, numbers, objects, familiar shapes or symbols—as long as it was something a

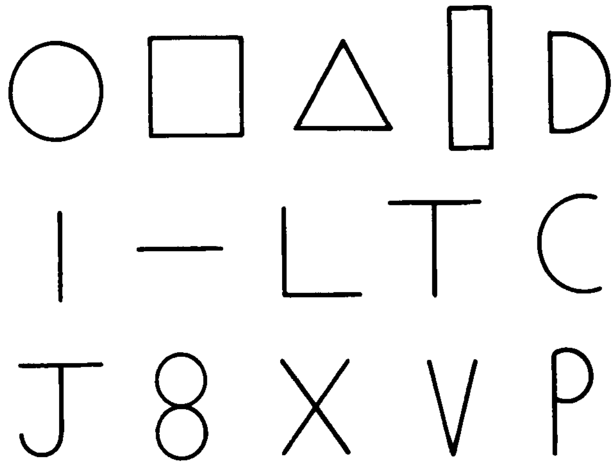

Figure 1. Parts used for the mental syntheses in Experiments 1 and 2.

person could recognize. Also, if a part was named more than once, it had to be used the designated number of times. The subjects were told that they could vary the size, position, or orientation of any part, but they could not bend or otherwise alter the shapes of the individual parts.

The experimenter then showed two examples of possible mental constructions. For one set (the letter L, a circle, and a square), the example patterns were a TV set, a jack-in-the-box, and a flag on a flagpole. For the other set (a horizontal line, the letter L, and the letter T), the example patterns were a pine tree, the letter E, and an antenna. These examples were chosen to illustrate the range of recognizable patterns that could be made out of a given set of parts.

Additional instructions stressed that the figure must be something that could be easily named, without requiring a lengthy description, and that it must be something that another person could easily recognize. Also, if the subjects came up with more than one recognizable figure, they were to select the best one. They were never told to try to be creative in doing the task, but merely to try to discover any type of recognizable pattern.

There were eight experimental trials per group of subjects. At the start of each trial, the experimenter called out the trial number and named the three parts. The subjects closed their eyes, and the names of the parts were then repeated, to make sure they heard the names correctly. They were then given 2 min to come up with a recognizable figure. Additional instructions stressed that they were to leave their eyes closed until instructed to open them, even if they finished early. At the end of the 2 min, the subjects were to write down the name of the figure, if they were able to come up with one, beside the appropriate trial number on a response sheet. They were then instructed to draw the figure in the appropriate space on a second response sheet. If they were unable to come up with a figure, they were to leave these spaces blank. Once they started to draw the figure, they could not go back and change anything they wrote when naming it. This ensured that the subjects were not simply discovering the patterns in their drawings. This same procedure was repeated on every trial.

Because the experimenter was in close contact with the subjects during these procedures, we were careful to use a naive experimenter, as recommended by Intons-Peterson (1983). The experimenter was skilled in performing the task, but was unaware of the major purpose of the experiment. As a further safeguard, the experimenter was given the stimulus set for each trial in advance, and was asked to generate three guesses as to which figures the subjects were most likely to make out of those parts. This served two purposes. First, it provided a conservative control for the possible effects of experimenter bias during the actual task. Second, it provided a means of assessing to what extent the reported patterns were those that might be obviously suggested by the three parts.

At the end of the experiment, the subjects filled out a simple questionnaire asking them to report the most common strategy they used for combining the parts and discovering the recognizable patterns. The alternatives were as follows: (1) "I tried combining the parts by trial and error in my image until I happened to recognize a familiar shape"; (2) "I first thought of a possible shape, and then tried to combine the parts in my image to see whether that particular shape could be made out of those parts"; (3) "I didn't form an image at all, but just thought about how the parts might be combined in a more abstract way"; (4) "I used some other strategy." This questionnaire was included to provide information about how the subjects actually performed the task, since they were never told what particular strategy to use.

Scoring conventions. Three judges independently rated the correspondence between the names of the patterns and the drawings on a 5-point scale, which ranged from *very poor correspondence* (1) to *very good correspondence* (5). They assigned a rating of 4 or 5 only if the drawing could be easily identified from its name. If the reported pattern was notably creative, and the goodness of correspondence was rated at least a 4, the judges were also to score the drawing as a *creative pattern.*[1] If a recognizable pattern (rated 4 or 5) was labeled as notably creative by at least two of the judges, it was classified as a creative pattern; otherwise, it was classified as a *noncreative pattern*. Patterns with an average rating below 4 were classified as *poor correspondence*. If wrong or distorted parts were used, or if only some of the right parts were used, the pattern was classified as *wrong parts*, regardless of the correspondence between the name and the drawing. The final category, *no pattern*, refers to trials on which a subject did not report a pattern.

Results and Discussion

Overall, recognizable patterns were reported on 119 of the 312 trials (38.1%); of these, 19 of the patterns were scored as highly creative. Poor-correspondence patterns were reported on 32.7% of the trials, wrong-parts patterns on 6.7% of the trials, and no patterns on the remaining 22.4% of the trials. These patterns were rarely predicted by the naive experimenter, who correctly generated only 14.3% of the recognizable patterns (and only 1 of the 19 creative patterns), showing that these discoveries are not due merely to experimenter effects or obvious guesses suggested by the parts themselves. Sample sets of parts and examples of noncreative and creative pattern recognitions are presented in Figures 2 and 3, respectively.

In all, 56 different types of patterns were recognized during the imagined syntheses. Thirty-seven of the 39 subjects reported at least one recognizable pattern; 30 reported two or more. Twelve of the subjects made at least one creative recognition. The postexperimental questionnaires revealed that 74.4%, or nearly three-quarters, of the subjects used a trial-and-error imagined synthesis of the parts as their most common strategy for doing the task; these subjects reported 18 of the 19 creative recognitions. This last finding agrees with our own subjective impressions in attempting the task, and suggests that this particular strategy is the most efficient (and sometimes the only) way of discovering the recognizable forms.

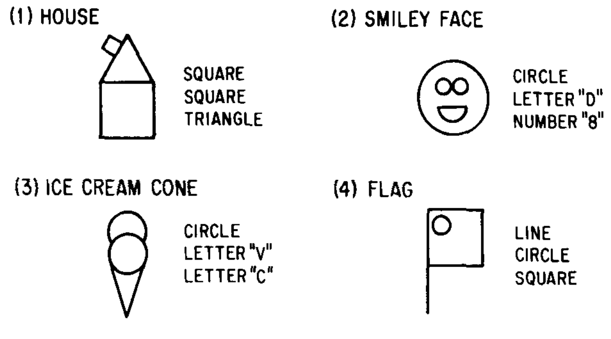

Figure 2. Examples of sets of parts and noncreative pattern recognitions reported by subjects in Experiment 1.

EXPERIMENT 2

Having a single experimenter generate the predicted patterns is limited in two respects. First, the experimenter may not be very skilled at making the predictions. Although the experimenter we used was skilled at doing the task and had run a number of pilot subjects (and thus knew the kinds of patterns that subjects might report), there is no assurance that the experimenter's predictions were particularly insightful or representative. Second, a single experimenter cannot be expected to know the idiosyncratic biases of individual subjects, biases that may produce unpredictable, idiosyncratic patterns. For these reasons, in Experiment 2 the subjects themselves generated predictions about the patterns before actually doing the task.

Method

Subjects. Seventy additional undergraduate students at the State University of New York at Stony Brook were selected as in the previous experiment.

Procedure. The general procedure used in Experiment 1 was repeated, with the following changes: After being shown the 15 parts, the subjects first participated in a guessing condition. They were told that when the experimenter named 3 of the parts, they

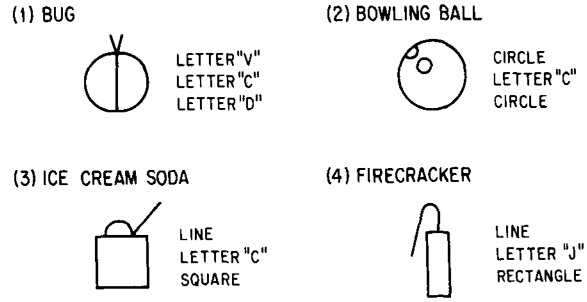

Figure 3. Examples of sets of parts and creative pattern recognitions reported by subjects in Experiment 1.

were to try to guess what types of recognizable figures a person could make by assembling those parts in a mental image. They were explicitly told not to actually do the task, but simply to guess what patterns an experimental subject might come up with, given those 3 parts. As in the previous experiment, the subjects were told that the figures could be anything at all, as long as a person could recognize them; that all 3 parts had to be used, even if the same part was named twice or even 3 times; and that they could vary the size, position, or orientation of the parts, but could not alter the shape of the individual parts. They were then shown the same six examples of mentally synthesized patterns that had been shown to the subjects in Experiment 1.

There were 10 guessing trials for each subject, with the first 2 serving as practice. On each trial, after the parts were named and the names repeated, the subjects were to write down on a response sheet their three best guesses for what patterns could be made out of those parts. They were given 30 sec to do so, and were told that if they could not come up with all three guesses during this time period, to try to come up with as many guesses as they could. We used this time-limited procedure to discourage the subjects from actually doing the imagery task; rather, we wanted their guesses to be based on their initial associations to the parts.

In the second part of the experiment, the subjects participated in the actual imagery task. There were eight experimental trials; on four of these, sets of parts that had been used in the guessing condition were repeated. Selection of the repeated trials, as well as the ordering of all trials, was randomized. The subjects were told to try to come up with a recognizable pattern by mentally combining the parts, and they were told that some of the sets of parts would be the same as in the first part of the experiment. In those cases, they were to try to come up with a pattern that corresponded to one of their previous guesses, if possible. The subjects were therefore encouraged to seek out patterns conforming to their earlier predictions. The rest of the procedure, including the scoring of the subject's responses, was the same as in Experiment 1.

Results and Discussion

For the 280 trials that were repeated from the guessing condition, a total of 124 recognizable patterns were reported (44.3%). Of the recognizable patterns, 19, or 15.3%, were judged as highly creative. Poor-correspondence patterns were reported on 37.9% of the trials, wrong-parts patterns on 8.2%, and no patterns on the remaining 9.6% of the trials.

Table 1
Frequency of Pattern Reports in Experiment 2

Number of Predictions	Recognizable Patterns: Creative	Recognizable Patterns: Noncreative	Poor Correspondence	Wrong Parts
Predicted by Subjects				
1	1	4	4	1
2	3	13	11	1
3	0	2	5	1
Not Predicted by Subjects				
0	1	7	9	2
1	2	24	22	4
2	8	41	43	12
3	4	14	12	2
Nonguessing Trials				
	15	95	125	31

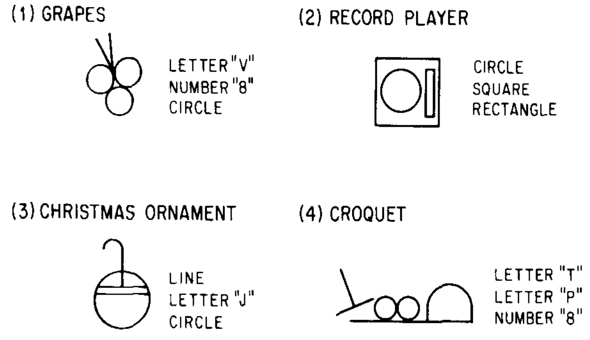

Figure 4. Examples of sets of parts and creative pattern recognitions reported by subjects in Experiment 2.

Distributions of the different types of pattern reports, according to whether or not the subjects predicted the patterns, are presented in Table 1. Although the subjects predicted a greater proportion of poor-correspondence patterns (18.9%) and wrong-parts patterns (13.0%) than the experimenter had done in the previous experiment [$\chi^2(1) = 4.27$, $p < .05$], they did not predict a significantly greater proportion of recognizable patterns [18.5%; $\chi^2(1) < 1$]. Thus, the subjects were no better at predicting their own discoveries of recognizable patterns than the experimenter had been. In addition, as Table 1 also shows, they were least successful when they had made all three guesses, in which case they were able to predict only 10.0% of the recognizable patterns.

For the other 280 trials, on which the subjects had not previously attempted to guess the patterns, they reported a total of 110 recognizable patterns (39.3%), of which 15 were judged as highly creative. Poor-correspondence patterns were reported on 44.6% of those trials, wrong-parts patterns on 11.1%, and no patterns on 5.0% of the trials. These percentages did not differ significantly from those for trials in which the subjects had attempted to guess the patterns [$\chi^2(3) = 5.05$, $p > .10$]. In particular, the subjects were no more likely to discover a recognizable pattern when they had previously seen the parts and attempted to guess the pattern than when they had not done so [$\chi^2(1) = 1.44$, $p > .10$].

In Figure 4, we again present examples of creative patterns that the subjects reported. In all, 67 of the 70 subjects reported at least one recognizable pattern, 61 reported two or more, and 26 reported at least one creative pattern.

GENERAL DISCUSSION

These experiments revealed that people can make creative visual discoveries by imagining novel combinations of simple parts. Of the 353 recognizable patterns that the subjects reported, 53 were judged as being highly creative. Our subjects, moreover, were neither selected for imagery or creative ability nor extensively trained in how to do the task. And, in contrast to previous studies on mental synthesis, they were never told how to go about combining the parts.

The present findings, therefore, show that creative discoveries in imagery can be reliably induced under laboratory conditions where the imagined synthesis is unconstrained. They also show that when these discoveries do occur, they are neither trivially predictable nor simple confirmations of the subjects' own initial expectations. In this respect, they resemble Metcalfe's (1986) recent findings on problem solving, which show that subjects are not good at predicting their own eventual successes on problems that require insightful solutions. Our subjects, too, often reported being genuinely surprised by what they were able to discover after mentally transforming and rearranging the parts.

Nor can our findings be explained in terms of experimenter bias or demand characteristics, given the conservative procedures we used, and the fact that our experimenter was generally unsuccessful at predicting what recognizable patterns would be reported. Indeed, because the parts were randomly selected, there was never a particular, intended "target" pattern on any of the trials. The large number of uncommon objects that were reported further rules out the possibility that the task biases the subjects to restrict their considerations to only a few common, obvious forms.

We believe that these findings have several implications for current theories of image formation. First, they make a distinction between the use of imagery as a convenient representational medium for recalling visual features that one already has stored in long-term memory (e.g., Kosslyn, 1980) and as a functionally useful medium for discovering novel configurations of visual features. Theories of image formation, therefore, need to consider how features are actually combined in an image, and not simply how those features are retrieved (e.g., see Kosslyn, Reiser, Farah, & Fliegel, 1983).

Our findings also suggest that it is not necessary to specify what the imagined pattern will turn out to be at the time one begins to form the image. Our subjects usually reported that they did the task by engaging in a mental, trial-and-error assembling of the parts, to "see" if anything familiar emerged. Moreover, they had difficulty guessing what types of patterns could be made using the specified parts, even when, as in Experiment 2, they were explicitly instructed to do so.

There were also individual differences in performing the task. Although certain subjects seemed particularly talented at coming up with creative, recognizable patterns, and others much less so, we did not attempt to ascertain the reasons for these differences. Successful completion of the mental syntheses may depend on rather specific imagery skills, such as the ability to move parts around in an image or to arrange the parts in an efficient, accurate manner (e.g., Kosslyn, Brunn, Cave, & Wallach, 1984).

Another consideration is the relative efficiency of using different types of parts in a mental synthesis. We decided to use geometric forms, lines, and alphanumeric characters as parts because they are familiar and easy to name, but other types of parts (such as generalized cones; see Biederman, 1985; Marr & Nishihara, 1978) may be equally or more effective.

Finally, in future studies it may be useful to try to distinguish between creative *combinations* of parts and creative *interpretations* of those combinations. In Figure 3, for example, what is most striking about the bowling ball and firecracker patterns is that they represent clever arrangements of the individual parts, whereas in the bug and ice cream soda patterns, it is the way the arrangements are interpreted that makes them distinctively creative.

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NOTE

1. The judges were not to base their ratings on the quality of the drawings per se, but rather on whether the arrangements of parts depicted in the drawings would be recognized as the named objects or shapes if the patterns had been skillfully drawn. These instructions were included so that the subjects would not be penalized for lacking drawing skills.

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