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The Abstraction and Generalization of Dot Patterns

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The Ss were trained on patterns representing different levels of distortion and transferred to test trials containing the old training patterns, the prototype patterns, and new distortions. Training on low levels of distortion consistently produced superior performance on all test patterns except the most distorted ones. The results also showed that the prototypes and low distortion-level test patterns of meaningful concepts were identified more often than prototypes and low distortion-level test patterns of meaningless concepts but the reverse was true for highly distorted test patterns. Training with patterns whose average dot positions corresponded to the original positions of the dots in the prototypes and to two different levels of distortion of training patterns did not facilitate transfer of any abstractions formed.

A two-stage paradigm for the experimental study of abstraction was suggested in Posner and Keele's (1968) article. They derived patterns from four different 9-dot prototypes. During the first stage, their Ss learned to assign the patterns from one prototype to a single response category. The second or transfer stage showed novel distortions of the same prototypes and S was instructed to sort these patterns into the same categories used during the first stage. The frequency of sorting the test patterns based on one prototype into response categories assigned to another prototype (errors) was used to make inferences about the abstraction process.

The present experiments used a similar paradigm. The major difference was that the test trials contained more types of patterns. These trials showed the original training patterns, and the prototype patterns, as well as novel test patterns representing varying degrees of distortions from the prototypes. The Ss were told to assign the test patterns to the same response categories they had learned during the first stage. Abstraction was inferred when both the novel test distortions and the parent prototype were sorted into the same category or when novel test-distortion and training patterns derived from the same prototype were sorted into the same response category with approximately equal fre-

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quency. The notion behind the two definitions of abstraction was that the salient characteristics learned about the patterns could be based on either the original training stimuli or the prototype, depending upon whether S adopted a paired-associate or problem-solving strategy during the original training trials. The term "concept" refers simply to a prototype and all the patterns derived from it, regardless of S's classification of these patterns.

Posner and Keele, (1968, Expts I and II) distorted dot patterns by varying the probability that a dot would move and the distance that the dot might move. The lower the probabilities of movement and the smaller the distances moved, the lower the level of distortion (uncertainty) from the prototype pattern. They constructed three sets of patterns. The two training sets contained patterns of minimal distortion (1 bit/dot) or patterns of an intermediate level of distortion (5 bits/dot) and the test set contained highly distorted test patterns (7.7 bits/dot). One group of Ss was trained on the 1 bit/dot distortions (Group 1 bit/dot) and another group, on the 5 bits/dot distortions (Group 5 bits/dot). Both groups were transferred to the highly distorted 7.7 bits/dot test patterns. The group trained on the 5 bits/dot patterns classified fewer highly distorted test patterns to categories assigned to other prototypes (made fewer errors) than did the group trained on the 1 bit/dot patterns. These data suggested that Ss trained on the more distorted patterns identified the extreme distortions as exemplars more often than Ss trained on less distorted patterns. However, these results provided no information about the formation of abstractions as defined herein. To obtain this information the test trials must include the old training patterns and the prototypes.

It is possible that the formation or acquisition of an abstraction is facilitated by training on minimally distorted instances but that the reduced distortion would have the effect of limiting abstraction. Training on higher levels of distortion might retard the rate of acquisition of the abstraction but extend generalization of the abstraction so that more highly distorted test patterns would be recognized as exemplars. Alternatively, the groups trained with more distorted patterns may learn abstractions or discrimination cues that differ from those learned by the groups trained with less distorted patterns. These possibilities could not be assessed with their design.

Posner and Keele did include various levels of distortion in the transfer test of their third experiment but only one level of abstraction was used in training, 7.7 bits/dot, so the effects of different levels of distortion among the training patterns could not be evaluated. One of the purposes of the first experiment reported in this paper was to study the classification of test patterns of varying levels of distortion after training at each of the three levels of distortion (1, 5, and 7.7 bits/dot).

Another purpose was to study the effects of the meaningfulness of the prototypes. In their first two experiments, Posner and Keele used three meaningful or familiar prototypes (a triangle, the letters F and M) and one random prototype from which to generate the distortions. On the transfer test, Ss trained on minimally distorted patterns (Group 1 bit/dot) tended to assign highly distorted test patterns to the response associated with patterns generated from the random prototype more often than did Ss trained on intermediate levels of distortion (Group 5 bits/dot). The Group 1 bit/dot Ss apparently adopted standards for the admission of patterns into the meaningful category that were different from those of Group 5 bits/dot. The false alarm rate may have been higher for the meaningless patterns or the generalization of the meaningful abstractions may have been more restricted for Group 1 bit/dot than for Group 5 bits/dot. If this were the case, training on low-distortion meaningful patterns would increase test errors on highly distorted transfer patterns more than training on low-distortion meaningless patterns. Training on highly distorted meaningful and meaningless patterns would not differentially affect test performance. Such an interaction could explain the superior performance of Posner and Keele's Group 5 bits/dot on the highly distorted test patterns (Expts I and II). Thus, the first experiment studied test performance following training on three levels of distortion of meaningful and random prototypes.

EXPERIMENT I

Method

Materials. The materials were prepared by distorting four prototype patterns (a triangle, the letter F, and two random patterns) according to statistical rules of a random walk procedure similar to that used by Posner, Goldsmith, and Welton (1967). Each original 9-dot prototype was plotted in a 30 × 30 matrix on standard 20 squares-to-the-inch graph paper. The results of the procedure given below yielded an actual maximum matrix size of 21 × 21 and the cells were renumbered accordingly.

The original positions of the dots were then distorted by applying a statistical rule that specified the probability that each dot would move and the area to which it would move. These probabilities and areas were indicated by the level of distortion, as shown in Table 1. The areas or concentric rings about the original position of a dot were defined as follows: the center cell, Area 1, was numbered zero; the next ring of cells, Area 2, was numbered 1–8; the next ring, Area 3, 9–24; the next Area 4, 25–48; and Area 5, 49–80. The probabilities given for Area 1 are the probabilities that a dot would remain in the same position. Table 1 shows that when a 1-bit/dot distortion was being constructed, the probability was .88 that a dot would remain in the same position. For 7.7-bits/dot patterns, the probability of remaining in the same position was .00, so that for these patterns all dots moved from their home positions. Table 1 contains the probabilities that a dot would move into Area 2 (the eight squares surrounding the prototype position) or into the other three areas. If a dot were displaced to an area other than Area 1, the probability of its assignment to a particular position (cell) was equally likely for each of the cells within the area. For example, if a dot moved into Area 2, the probability of its assignment to each of the eight cells of Area 2 was 1/8.

For each of the four prototypes six different patterns were constructed at the 1-, 5-, and 7.7-bit levels of distortion, and three different patterns at the 3-bit level. No restrictions were placed on the direction of movement of the dots.

The average distances actually moved by the dots are given in Table 1. The distances moved represented information of slightly less than 5 and 7.7 bits per dot but these labels were maintained because they were consistent with the mathematical parameters governing the distortion procedures. Table 1 also shows the actual distances reported by Posner, Goldsmith, and Welton (1967) for comparable distortions. The average distances moved in the two experiments were quite similar, although the 1-bit patterns in Expt I showed slightly greater movement than the 1-bit patterns constructed by Posner *et al.* and the dots of the 5- and 7.7-bit patterns of Expt I moved somewhat less than the dots of Posner's 5- and 7.7-bit patterns.

Three patterns of 1-bit distortions were selected randomly and designated as the training patterns for Group 1. The three 1-bit patterns from each of the four prototypes were randomized to form a block of 12 pat-

TABLE 1
Probabilities of Movement, Experiment I

Level of distortion	Probabilities of moving into each area Areas and numbers of squares within each area					Average distance moved per dot	
(Bits/dot)	1(0)	2(1–8)	3(9–24)	4(25–48)	5(49–80)	Expt I	Posner *et al.* (1967)
1	.880	.100	.015	.004	.001	.33	.23
3	.590	.200	.160	.030	.020	.68	.66
5	.200	.300	.400	.050	.050	2.07	1.91
7.7	.000	.240	.160	.300	.300	3.96	4.56

terns. The 12 patterns were then duplicated to provide two additional blocks to be used in training and each block was randomized. Transparencies of the patterns were placed on 2 × 2-in. slides and the 36 slides were placed in the training magazine for Group 1. The training magazines for Groups 5 and 7 were prepared in the same way from 5- or 7.7-bit patterns, and used the same order of presentation. Three test magazines were prepared, one for each training group. Each test magazine contained, for each of the basic prototypes, the three new 1-bit patterns, three 3-bit patterns, three new 5-bit patterns, three new 7.7-bit patterns, the training patterns, three repetitions of the prototypes and three new random patterns, for a total of 75 slides. This procedure held constant the "new" patterns at each level of distortion that were shown in the test series. The order of presentation of the slides was randomized and the same order was used for each of the test magazines.

Subjects and design. The Ss were 48 introductory psychology students at Indiana University who participated to fulfill a course requirement. The Ss were assigned to 16 replications of the block of three training groups.

Each of the four concepts learned by an S was assigned to one of four telegraph keys. Four arrangements of the concept-telegraph key assignments were made so that each concept was associated equally often with each telegraph key. Four Ss in each group used each arrangement.

An additional three Ss assigned to the 5-bit group and five Ss assigned to the 7-bit group failed to reach the criterion of learning and were replaced by the next S. Thus, the data reported for Group 7 in particular, represented a conservative estimate of performance under this condition.

Procedure. Each of the training slides was presented by a projector (Kodak Carousel) to Ss in Groups 1, 5, and 7 until S pressed a telegraph key to indicate his choice. A reinforcement lamp then signaled the correct key. The procedure continued in this manner until S correctly identified 24 consecutive patterns. The test slides were presented in the same way except that no feedback was provided. The Ss were informed before the test slides were shown that the reinforcement lights would not come on and that they were to use the same system of assignment they had learned during the training trials. The test slides were shown twice for a total of 150 trials and response latencies were recorded. After the test trials all Ss drew the patterns they thought were associated with each of the four keys.

Results

Training-trial responses. The mean errors made by Groups 1, 5, and 7 during the training trials were 3.83, 15.84, and 29.48, respectively,

$F(2,45) = 29.90$, $p < .01$. The mean numbers of errors did not differ appreciably for the distortions of the four basic prototypes, $F(3,135) = 1.36$, and their interaction with the groups were not reliable, $F(6,135) = 1.23$.

Test-trial errors. An analysis of variance was computed on test-trial errors with the three groups as a between-*S* variable, the two test trial blocks, the four concepts, and the six different types of test patterns (old training, prototype, 1, 3, 5, 7-bits) as within-*S* variables. The following main effects and interactions were statistically significant: Groups, Test Patterns, Groups × Test Patterns, Groups × Test Patterns × Concepts.

Group 1 made the fewest errors on the test patterns, and Group 7, the most, $F(2,45) = 26.52$, $p < .01$, indicating that test performance was facilitated by training with the low levels of distortion. The mean errors increased as the level of distortion increased, $F(5,225) = 10.15$, $p < .01$. All groups made the fewest errors on the training patterns and the most errors on the new 7-bit distortions. The groups interacted with the test patterns, $F(10,225) = 9.71$, $p < .01$.

Table 2 shows that Group 1 made about the same number of errors on the prototypes, the old training patterns, and the novel 1- and 3-bit distortions but Group 1 showed a reliable increase in errors over their performance on the old training patterns when tested on the novel 5- and 7-bit distortions. Thus, it is reasonable to assume that whatever Group 1 learned on the training trials permitted them to classify prototype and

TABLE 2
Mean Errors on Transfer Test and Drawings of Prototypes, Experiment I

Training condition	Transfer patterns: Old training patterns	Prototype	1	3	5	7.7	Number of reasonable facsimiles
Group 1							
Meaningful	.04	.08	.09	.31	.98	2.40	15-1/2
Random	.38	.48	.34	.47	.86	1.58	10-1/2
Mean	.21	.28	.22	.39	.92	1.99	13
Group 5							
Meaningful	.84	.80	.96	1.18	1.88	1.76	7
Random	.78	1.04	1.44	1.36	1.33	1.89	6
Mean	.82	.92	1.20	1.27	1.60	1.83	6-1/2
Group 7							
Meaningful	1.04	1.75	1.67	1.76	1.61	1.86	3-1/2
Random	1.08	1.72	1.61	1.73	2.05	2.28	1/2
Mean	1.06	1.73	1.64	1.75	1.83	2.07	2

new test patterns up to the level of 3-bit distortions as accurately as they classified the training patterns. Group 5 showed a similar profile of responding but they made more errors than Group 1. Group 7, on the other hand, yielded no evidence of positive transfer. They made reliably more errors, at the .05 level or beyond, on all novel test patterns than they made on the original training patterns.

The next analysis considered the meaningfulness of the prototypes. The main effect of Concepts was not reliable, $F(3,135) = 1.90$, $p > .05$, but the triple interaction with Groups and Distortions was, $F(30,675) = 3.41$, $p < .01$. Scheffé's test showed that Group 1 made fewer errors on the low level distortions derived from meaningful prototypes than on the low level distortions derived from meaningless prototypes, but the reverse was true for the 7-bit transfer patterns. In this case, Group 1 made more errors on the 7-bit patterns derived from meaningful prototypes than either of the two other groups. Group 1's increase in errors from the prototypes to the 7-bit transfer patterns was reliable for the two meaningful patterns but not for the two random patterns. The meaningfulness variable did not have a systematic effect upon the transfer performance of Groups 5 and 7.

Test-trial latencies. The latencies were scored on both "correct" and "incorrect" classifications of the test patterns for the three groups (Table 3). In general, the latencies were longer for incorrect classifications and for high levels of distortion than for correct classifications and for low levels of distortion, but these differences were not evaluated statistically because of the severe item and S-selection problems. Instead, the latencies were averaged over both correct and incorrect responses and two analyses of variance were applied to the non-transformed data. The data were not transformed because visual inspection suggested that the latencies were not radically skewed. Analyses of variance and subsequent Scheffé comparisons indicated that all groups responded to the prototypes as fast or faster than they responded to the old training patterns, suggesting that Ss had stored something about the prototypes themselves.

TABLE 3
Latencies, Experiment I

Training conditions	Means for correct, only	Means for wrong, only	Means summed over correct and wrong: Training	Prototypes	1	3	5	7.7
Group 1	1.12	1.83	1.04	1.04	1.04	1.26	1.45	1.82
Group 5	1.21	1.51	1.32	1.11	1.28	1.37	1.42	1.55
Group 7	1.31	1.50	1.41	1.19	1.31	1.38	1.56	1.65

Response latencies increased as the levels of the distortion of both the training patterns and the test distortions increased.

Prototype sketches. The numbers of Ss drawing reasonable facsimiles of the prototypes after the transfer trials had been completed are given in Table 2. Two *E*s judged the drawings as resembling or not resembling the prototypes. The judgments were identical for most cases and the others were resolved through discussion. In general, the meaningful prototypes were drawn by more Ss than the meaningless ones, $F(3,18) = 12.11$, $p < .01$, and the groups differed, $F(2,18) = 12.96$, $p < .01$. Both meaningful and meaningless prototypes were reproduced with high accuracy after training on 1-bit patterns, and with fairly low accuracy after training on 5- or 7-bit patterns. When asked to draw "what went with Key 1," some Ss in Group 7 attempted to draw all of the patterns that had been associated with the first category. These Ss may have assigned the training patterns to categories in a paired-associate manner.

Discussion

Experiment I indicated that the formation of abstractions resembling the prototypes was facilitated by training on low levels of distortion. With the higher levels of training distortions Ss frequently failed to reproduce accurately the meaningless prototypes, and many Ss stated that they had attended to some, but not all, of the dots. Thus, any abstractions formed under these conditions would not have corresponded to the prototypes. Group 7, which showed no transfer to the new test patterns, did not form abstractions, as herein defined. Group 7's failure to show transfer may have been due to poorer learning of the training patterns or to more rapid forgetting of the training patterns. The error rate for classifying old training patterns during the test trials increased with increases in the level of distortion of the training patterns, despite the fact that all regular training groups achieved the same criterion of learning.[2] The Group 7 Ss in the present experiment may not have been carried to a high enough criterion of learning to manifest abstraction. One reason that extensive training on highly distorted patterns may be necessary for

[2] Bregman, A. S. and Charness, N. reported at the meetings of the Eastern Psychological Association in 1970 that training on prototype patterns was superior to training on distorted patterns when a set number of trials was given but that this difference disappeared when training was taken to a criterion. The relevance of this work to the present studies was difficult to assess because the distortions were not scaled, actual prototypes were used in training, all test patterns were distorted, and Ss in another experiment with the same distortions reported using paired-associate strategies.

the demonstration of abstraction is that Ss tend to learn the initial classifications in a paired-associate manner, as suggested by some of the Group 7 sketches.

Not only was the accuracy of identifying the prototypes greater when the groups were trained on patterns with low levels of distortion but these groups correctly classified more distorted test patterns. The results appeared to contradict the findings of Posner and Keele (1968) who reported that performance on 7-bit transfer patterns was superior following training on 5-bit patterns. The discrepancy may have been produced by a difference in the average distances moved by the training patterns in Expt I and the Posner–Keele experiments or by the difference in the number of meaningful concepts used. The latter seems more plausible. In Expt I, more errors were made to 7-bit distortions of meaningful concepts following training on 1-bit patterns than following training on 5- or 7-bit patterns, but Group 1 made fewer errors on the 7-bit test distortions of meaningless concepts than Groups 5 or 7. Apparently, Group 1 Ss were less likely to consider highly distorted patterns as belonging to a concept. Posner and Keele used three meaningful concepts and one meaningless (random) concept so a further increase in errors on 7-bit transfer patterns would be expected by their Group 1 Ss, compared to their Group 5 Ss.

The results of Expt I indicated that the level of distortion of the training patterns interacted with the level of distortion of the test patterns. These results might have been artifactually produced by including distortions of both meaningful and meaningless prototypes in the same list or they might have reflected variations in the average physical distances between the locations of dots in the training and test patterns that represented deviations from the same "home" locations of the dots in the parent prototype. These distances would increase directly with increases in the level of distortion. Experiment II addressed this problem.

EXPERIMENT II

Experiment II was designed to investigate abstraction when the average physical distance between the dots of the training and test distortions derived from the same prototype was varied and when it was held relatively constant. The average physical distance separating training from test patterns was called the within-concept distance. New training patterns of 1- and 5-bit distortions were generated that minimized the within-concept distance with the test patterns. No 7-bit training distortions were used in Expt II because of the great difficulty in holding the within-concept distances almost constant when the level of distortion of the test patterns ranged from 1-bit to 7-bits/dot.

Experiment II used the two random concepts. The meaningful concepts were not used in Expts II–IV because it seemed likely that Ss trained with low levels of distortion would be recognizing old concepts rather than abstracting and learning new ones.

Method

Materials and design. Three 1-bit/dot distortions and three 5-bits/dot distortions were prepared for each prototype with the restriction that the average within-concept distance separating the test distortion from the training patterns be approximately the same as the distance separating the training patterns from their prototypes. Three slides were prepared for each training pattern. The new "constant" training patterns were generated using a computer program which calculated dot movements according to the values given in Table 1 and then compared the average distance of these patterns from the prototype patterns and from the test distortions. The computer program accepted the first three patterns for each level of training distortion whose range between the distance of the pattern from the prototype and the distance of the prototype from the test patterns did not exceed .20. Table 4 shows that the distances moved more for the "constant" 5-bit patterns than for the "constant" 1-bit patterns.

The 1-bit/dot training slides for the constant within-concept distance group (Group 1 Con) were put into one training magazine, and the slides for the 5-bit/dot training patterns for the constant within-concept distance group (Group 5 Con) were placed in a second training magazine. Two other training magazines were prepared for 1- and 5-bits/dot training patterns whose average within-concept distance increased as the distortion level of the test patterns increased (Groups 1 Var and 5 Var). These slides were taken from the materials of Expt I. All four

TABLE 4
Average Within-Concept Distances, Experiment II

Training conditions	Within-concept distances[a]				
	Prototype	1	3	5	7.7
1 Con	.33	.33	.32	.35	.34
1 Var	.15	.33	.68	1.26	2.52
5 Con	1.31	1.38	1.49	1.44	1.45
5 Var	1.22	1.41	1.61	2.07	3.01

[a] Mean distances from training patterns to transfer patterns of various levels of distortion.

training groups were transferred to the same test magazine. It contained, for each concept, three new patterns of 1, 3, 5, and 7.7 bits/dot distortions, three slides of the prototype, and the training patterns. The test slides were taken from Expt I, with the exception of the training patterns prepared for the first two training magazines of Expt II.

Subjects. The Ss were 64 introductory psychology students who had not participated in Expt I. The Ss were assigned randomly to eight replications of the block of eight experimental conditions: the four groups (1 Con, 1 Var, 5 Con, 5 Var) and the labeling of the first random concept (1 or 2).

Procedure. The procedure was similar to that used in Expt I, except that Ss were instructed to use the first two telegraph keys to indicate their choices during training. Training was continued to the criterion of 24 consecutive correct identifications of the patterns. Before the test slides were shown, Ss were told that if they could not identify a pattern as belonging to Key 1 or Key 2, they could assign it to Key 3. No feedback was given during the test trials. Each S went through the test magazine twice. No latency measures were taken in Expt II.

Results

Training trials. The mean numbers of errors for Groups 1 Con, 1 Var, 5 Con, and 5 Var were 3.06, 2.56, 14.31, and 25.06, respectively, $F(3,60) = 13.92$, $p < .01$. There were no reliable differences between Groups 1 Con and 1 Var or between 5 Con and 5 Var.

Test trials. Errors were scored for the test patterns (Table 5), excluding the inappropriate training slides. The mean errors made by groups trained with 1-bit distortions (.45) was reliably lower than the mean errors for the groups trained with 5-bit distortions (.72), $F(1,60) = 10.67$, $p < .01$. The mean for the groups with constant within-concept distances (.53) was somewhat lower than the mean for the groups with varied within-concept distances (.64), but neither this difference $F(1,60) = 2.60$, nor the interaction between the two variables was significant, $F < 1$.

The mean numbers of errors increased as the level of distortion of the test patterns increased, $F(5,300) = 101.04$, $p < .01$, and the errors on prototype patterns did not differ reliably from the errors on the old training patterns for any of the groups. Reliably fewer errors were made on the prototype patterns by Groups 1 Con and 1 Var, than by the two other groups. No other individual comparisons were statistically significant.

The errors were subdivided into confusion errors or false alarms (Concept "1" was called "2" and vice versa) and misses (calling pattern

TABLE 5
Summary of Performance on Test Trials, Experiment II

Training condition	Transfer patterns: Old training patterns	Prototype	1	3	5	7.7	Overall proportion	Number of reasonable facsimiles
1 Con								13
Correct	2.89	2.89	2.95	2.71	2.54	1.73	.90	
Total errors	.11	.11	.05	.29	.46	1.27	.10	
False alarms	.09	.06	.00	.15	.32	.82	.06	
Misses	.02	.05	.05	.14	.14	.45	.04	
1 Var								12
Correct	2.93	2.79	2.84	2.71	2.11	1.32	.86	
Total errors	.07	.21	.16	.29	.89	1.68	.14	
False alarms	.05	.19	.14	.22	.53	1.02	.09	
Misses	.02	.02	.02	.07	.34	.66	.05	
5 Con								5-1/2
Correct	2.61	2.70	2.73	2.50	1.93	1.46	.83	
Total errors	.39	.30	.27	.50	1.07	1.54	.17	
False alarms	.34	.21	.15	.38	.87	.80	.13	
Misses	.05	.09	.12	.12	.20	.74	.04	
5 Var								5
Correct	2.66	2.64	2.62	2.39	1.88	1.25	.81	
Total errors	.34	.36	.38	.61	1.12	1.75	.19	
False alarms	.18	.25	.33	.38	.67	1.00	.12	
Misses	.16	.11	.05	.23	.45	.75	.07	

a "3"—an instance of neither experimental concept). As shown in Table 5, the proportions of false alarms were lower for the groups trained with 1-bit distortions than for groups trained with 5-bit distortions. The proportions of correct responses showed the opposite trend, indicating that the group trained with 1-bit distortions showed superior discrimination, under both levels of the within-concept distance. The frequencies of misses did not differ to any great extent for the four training groups, possibly because the instructions indicated that most, if not all of the test patterns could be assigned to Keys 1 or 2.

The total errors made by Groups 1 Var and 5 Var were compared with errors made by the 1- and 5-bits/dot regular training groups of Expt I averaged over the two random concepts. The Expt II groups, who learned only two classifications, made reliably fewer errors on the old training patterns, the prototypes or distortions of 1, and 3 bits/dot.

Prototype sketches. The last column of Table 5 gives the number of Ss (of 16) drawing reasonable facsimiles of the prototypes, as judged by two *Es*. The number of reasonable drawings increased with the number of correct responses on the test trials.

Discussion

Essentially the same pattern of responding on the test trials was obtained when control test patterns having the same distance relationships to the training patterns as the protoypes were included and when the distance between the test patterns, the training patterns, and the prototypes was allowed to vary with the level of distortion of the patterns. As with Expt I, test-trial performance was better when Ss had been trained on low-distortion patterns, even though only the two random prototypes were used in Expt II. Thus, it seemed likely that the superiority of Posner and Keele's Group 5 on the highly distorted test trials arose from the inclusion of meaningful concepts in their design rather than from restricted within-concept distances.

It is interesting to question whether *S* abstracted prototypes only, abstracted prototypes and memorized patterns, or memorized some kind of cue that facilitated test-trial performance. Answers to these questions are closely related to the particular kind of training provided. If only a prototype were abstracted, the prototype should be sketched accurately and the latencies of assignment of the prototype should be lower than the latencies of assigning the other test patterns. If *S* abstracted prototypes and memorized patterns, prototype reproduction should be quite accurate and latencies of responding to the old training patterns and to the prototype patterns should be approximately equal. If *S*'s test-trial performance was based on the memorization of a particular cue or cues, prototype reproduction might consist of a few dots and the latencies of responding should be most rapid for the training patterns.

The results of Group 1 were most compatible with the notion that *S* both abstracted prototypes and memorized patterns. Their prototype reproductions were quite accurate and their mean latencies of responding to old training patterns and to the prototypes were identical. In addition, they responded to new 1-bit patterns as quickly as to the training and prototype patterns, a result which differs from the predictions stated above. Groups 5 and 7 responded more rapidly to the prototypes than to any other test pattern but their prototype reproducion was so poor that they may have responded to a subset of dots on the test patterns.

An underlying assumption of the method employed to generate the distorted patterns is that the single best estimate of the aggregate of distorted patterns would be the prototype pattern if a sufficient number of patterns were generated or if the distortions were restricted to ensure that their average was the prototype position.

Suppose S does attempt to abstract a prototype from the distortion patterns. He might add the locations of the distortions of a particular dot. If, in the first distortion of a prototype, a dot moved one space to the left and the "same" dot moved down one space in the second distortion of the prototype, both of these locations would be represented in the abstraction being formed. The addition of these varying locations would generate regions or areas corresponding, in relative terms, to the physical distances between the dots that were distortions of the same prototype. The size of the region representing each dot would increase with increases in the level of distortion of the training patterns. Training on highly distorted patterns should establish regions that would be more likely to encompass the novel test patterns than training on minimally distorted patterns. Hence, performance on the test trials should be better for groups trained with highly distorted patterns than for groups trained with less distorted patterns, in contradiction to the data of Expts I and II.

Instead of adding the locations of a particular dot, S may average these locations. The composite of these averages would be "abstraction" he has contructed. This abstraction would differ from the prototype whenever the means of the distortions did not yield the prototype or home position and when S misassigned the dot to the wrong home position. Misassignments would tend to increase as the level of distortion of the training patterns increased. Thus, the differences between the constructed abstraction and the prototypes also would reflect the level of distortion of the training patterns. The more divergent the constructed abstraction from the prototype, the less likely S would be to accept the prototypes or the novel test patterns as exemplars of his abstraction. The averaging notion expects that training on minimally distorted patterns would provide greater evidence of abstractions that corresponded to the prototypes and greater generalization than training on highly distorted patterns. Note that the averaging formulation does not claim that a novel pattern must be identical to the constructed abstraction to be labeled an exemplar. On the test trials, each pattern may be compared in some way with whatever characteristics have been learned about the training patterns and/or the abstraction. The details of how this comparison is effected are not included in either of the forementioned models.

The results of Expt I and II are consistent with the predictions made by an averaging model but cannot be interpreted as support for that model because subsequent analyses indicated that the average locations of the dots of the training patterns did not always yield their home locations in the prototype. The deviations of these averages from the home location tended to increase as the level of distortion increased. Hence, the average locations of the dots shown to Groups 5 and 7, in particular, did not always correspond to the prototype. This situation presumably occurred in the Posner–Keele experiments, as well. Consequently, the 1- and 5-bit training patterns of Expt III were constructed so that the means of the locations of the dots corresponded to their prototype locations, thus providing the opportunity for S to obtain an average of the locations of distortions that corresponded to the prototype regardless of the level of distortion of the training patterns.

EXPERIMENT III

Three training groups were employed in Expt III: 1-bit, 5-bit, and a combination of 1- and 5-bit training patterns. The last group (1&5) was introduced to see if explicit training on both low and high distortion patterns might yield greater generalization than training on a single level of distortion.

Method

Materials and design. The three 1-bit training patterns and three 5-bit training patterns for the two random concepts were taken from Expt I. Nine additional 1-bit distortions and nine 5-bit distortions were prepared for each of the two random prototypes with the restriction that the arithmetic average of the dots representing distortions of one position equal that original position when taken over the various directions of deviation separately. Thus, if a dot moved straight up two spaces in one pattern the comparable dot would be positioned two spaces straight down from the original location in another pattern. The test slides were the same as those used in Expt II. The three training slides for each concept that were included in the test magazine were the slides that had been used in Expt I. Training magazines were prepared for each of the Groups 1, 5, and 1&5. Two training magazines were made up for the 1&5 group, one with half of the 1-bit distortion and half of the 5-bit distortion, and the other magazine contained the remainder of the training slides. The training and test slides appeared in a randomized order.

Subjects. Forty-eight new Ss from introductory psychology courses were assigned to eight replications of the block of three groups and two assignments of the first random concept (1 or 2). The Ss assigned to Group 1&5 were then reassigned to either the first or the second magazine for Group 1&5. Half of the Ss assigned to the first magazine for Group 1&5 labeled the first random concept as "1," and the other half labeled it as "2." The labels were balanced for Ss assigned to the second magazine for Group 1&5. Sixteen Ss assigned to Group 5 and one assigned to Group 1&5 failed to learn in 45 min; two Ss in Group 1, two Ss in Group 1&5, and one S in Group 5 were excused because of apparatus failure; one S in Group 1&5 and one in Group 5 were excused because of *E* error. Each S excused was replaced by the next S to appear.

Procedure. The procedure was identical to that employed in Expt II. The Ss were permitted to press Key 3 on the test trials if they felt the pattern could not be assigned to either Key 1 or Key 2.

Results

Training trials. Group 1 made the fewest errors ($\bar{X} = 5.19$); Group 5 the most ($\bar{X} = 33.94$); and Group 1&5, an intermediate number ($\bar{X} = 22.69$), $F(2,45) = 16.82$, $p < .01$.

Test trials. The only statistically significant main effect for test-trial errors was Test Patterns, $F(5,225) = 74.59$, $p < .01$. The mean errors for the three groups did not differ reliably, $F(2,45) = 1.52$, $p > .05$, but the interaction with test patterns was significant, $F(10,225) = 3.52$, $p < .01$. The three groups were consistently ordered on all test patterns, with Group 1 making the fewest errors, and Group 5, the most. Group 1 performed significantly better than Group 5 on the old training patterns, the prototypes, and the new 1-bit and 7-bit distortions but the performance of the two groups did not differ reliably for new 3-, or 5-bit distortions.

If presentation of both levels of distortion during training facilitated test performance, Group 1&5 should have made fewer errors than the other groups, particularly on the more distorted patterns. In fact, Group 1&5 made reliably *more* errors on the new 5- and 7-bit distortions than Group 1 and their performance did not differ from that of Group 5. Clearly, the presentation of additional training patterns aided neither the formation of abstractions nor the generalization to highly distorted test patterns.

Table 6 also lists the proportions of correct and false alarm responses. Group 1 showed the best discrimination with the highest proportion of correct responses and the lowest proportion of false alarms. The false alarm rate increased significantly as the level of training distortion increased, $F(2,45) = 9.76$, $p < .01$, indicating that groups trained on the higher levels of distortion were more likely to include noninstances in their concepts. The false alarm rates were slightly higher for Expt III than for Expt II.

Prototype sketches. Group 1 Ss drew the most drawings that resembled

TABLE 6
Summary of Performance on Test Trials, Experiment III

Training condition	Transfer patterns: Old training patterns	Prototype	1	3	5	7.7	Overall proportion	Number of reasonable facsimiles
Group 1								10
Correct	2.78	2.98	2.88	2.38	2.17	1.44	.79	
Total errors	.22	.02	.12	.62	.83	1.56	.21	
False alarms	.13	.00	.06	.42	.36	.89	.10	
Misses	.09	.02	.06	.20	.47	1.67	.11	
Group 5								4-1/2
Correct	2.36	2.56	2.54	2.12	1.92	1.10	.72	
Total errors	.64	.44	.46	.88	1.08	1.90	.28	
False alarms	.42	.28	.30	.63	.60	.81	.17	
Misses	.22	.16	.16	.25	.48	1.09	.11	
Group 1&5								5
Correct	2.62	2.74	2.66	2.28	1.70	1.12	.73	
Total errors	.38	.26	.34	.72	1.30	1.88	.27	
False alarms	.18	.12	.22	.47	.60	.71	.13	
Misses	.20	.14	.12	.25	.70	1.17	.14	

the prototypes; Groups 5 and 1&5 drew fewer reasonable facsimiles (last column, Table 6). Again two *E*'s judged the drawings.

Discussion

The inclusion of additional training patterns did not facilitate test performance nor did exposure to training patterns representing both 1- and 5-bit distortions produce greater generalization.

If the averaging model is correct, the poorer test performance by Group 5 may indicate that the dots of the more highly distorted training patterns occasionally are assigned inappropriately. As a further test of this possibility, Expt IV presented patterns of two different levels of distortion during training. The averaging model, including the provision for misassignment, would predict that training on 1- and 5-bit patterns would yield the best test-trial performance; training on 1- and 7-bit patterns, the next; and training on 5- and 7-bit patterns, the poorest test performance.

An additive model, although largely ruled out by the results of the first three experiments, would predict superior test-trial performance by the group trained on 1- and 7-bit patterns because the range of the dots representing a particular position would be the greatest under a 1- and 7-bit training regimen.

EXPERIMENT IV

The Ss were trained on 1- and 5-bit distortions, on 1- and 7-bit distortions, or on 5- and 7-bit distortions of the random patterns and then transferred to the test patterns of Expt III.

Method

Materials and design. The slides prepared for patterns representing the two random prototypes in Expt I were used in Expt IV. The training magazine for Group 1&5 contained three blocks of 12 slides. The 12 slides showed three different 1-bit distortions and three different 5-bit distortions of each of the two concepts. The order of the slides was randomized within each block. The training magazine for Group 1&7 was prepared the same way, using duplications of the three 1-bit distortions and three different 7-bit distortions of each of the concepts. The training magazine for Group 5&7 contained copies of the 5- and 7-bit distortions used for the two other groups. The test magazine from Expts II and III was modified by adding the 7-bit training distortions. Thus, the test magazine contained a randomized ordering of the three training distortions of 1, 5, and 7-bit/dot, three new distortions of 1, 3, 5, and 7-bit/dot, and three slides of each prototype, for each concept. This magazine was used for all three training groups.

Subjects. The Ss were 48 new students from the same source as Expts I, II, and III. They were assigned randomly to six replications of the block of three training groups and assignment of the first random concept as Key 1 or Key 2.

Procedure. The procedure was similar to that used in the other experiments. Training was continued to a criterion of 24 consecutive correctly identified patterns. The same test magazine was shown twice to every S. Thus, each S saw a total of 96 test slides.

Results

Training trials. Group 1&5 made the fewest errors ($\bar{X} = 22.25$); Group 5&7 ($\bar{X} = 75.00$); and Group 1&7, the most ($= 86.44$), $F(2,45) = 7.92$, $p < .01$.

Test trials. The errors were scored on test trials, counting both false alarms and misses. Performance was scored for appropriate training distortions, only.

Group 1&5 made the fewest mean errors (.50); Group 5&7, the most (1.12); with Group 1&7, in between (.78), $F(2,45) = 12.21$, $p < .01$, as predicted by the averaging model. The errors rose as the level of distortion of the test patterns increased from the prototypes (.44) to the new

7-bit pattern (2.04), $F(6.270) = 69.34$, $p < .01$. The interaction between the groups and the levels of distortion of the test patterns was significant at the .05 level, $F(12,270) = 2.28$.

The interaction was evaluated using Scheffé's test. All groups showed a significant increase in errors from the prototype to the new 7-bit test patterns. The mean errors on the prototype patterns did not differ reliably from the errors on either set of training patterns for Group 1&5 nor from the errors on the 1-bit training patterns for Group 1&7. The errors on the prototype patterns were reliably below the mean errors on the 7-bit training patterns, suggesting that Ss had not learned these training patterns particularly well. Group 5&7 made reliably more errors on the prototype patterns than on either set of training patterns. Thus, any abstractions they formed did not correspond to the prototypes.

The proportions of correct and false alarm responses are given in Table 7. The false alarm rates increased from Group 1&5 to Group 5&7, $F(2,45) = 10.36$, $p < .01$, suggesting again that training on highly distorted patterns fostered the inclusion of extraneous patterns in any abstracted concepts.

Prototype sketches. The last column of Table 7 shows the number of

TABLE 7
Summary of Performance on Test Trials, Experiment IV

Training condition	Old training		Transfer patterns						Number of reasonable facsimiles
	LoD[a]	HiD[b]	Prototype	1	3	5	7.7	Overall proportion	
Group 1&5									10
Correct	2.80	2.75	2.89	2.89	2.69	2.27	1.19	.83	
Total errors	.20	.25	.11	.11	.31	.73	1.81	.17	
False alarms	.01	.02	.02	.01	.03	.07	.14	.01	
Misses	.19	.23	.09	.10	.28	.66	1.67	.16	
Group 1&7									8
Correct	2.86	2.06	2.78	2.67	2.59	1.69	.89	.74	
Total errors	.14	.94	.22	.33	.41	1.31	2.11	.26	
False alarms	.04	.25	.07	.08	.08	.23	.26	.05	
Misses	.10	.69	.15	.25	.33	1.08	1.85	.21	
Group 5&7									6
Correct	2.35	2.28	2.00	2.11	2.12	1.48	.78	.62	
Total errors	.65	.72	1.00	.89	.88	1.52	2.22	.38	
False alarms	.15	.20	.21	.18	.18	.32	.33	.07	
Misses	.40	.52	.79	.71	.70	1.20	1.89	.31	

[a] LoD = the lower distortion-level training patterns.
[b] HiD = the higher distortion-level training patterns.

Ss (of 16) who drew reasonable facsimiles of the prototypes, as judged by two *E*'s. Group 1&5 drew the most.

DISCUSSION

The four experiments showed that training with minimally distorted patterns facilitated the correct classification of the prototype patterns and produced greater transfer than training with more distorted patterns. The groups trained with highly distorted patterns showed no positive transfer to the test patterns and the other training procedures yielded an intermediate amount of transfer. Furthermore, groups trained on more distorted patterns made more false alarms than groups trained on minimally distorted patterns. Apparently, any abstractions fostered by training with highly distorted patterns were broad enough to include noninstances.

The level of distortion of the training and test patterns might have affected the formation of abstractions in at least two ways. In one case, S may add information about characteristic positions of the input patterns. Increases in the level of distortion would increase the size of the region representing each dot, thus permitting more accurate identification of the prototype as well as the highly distorted test patterns. These predictions were not supported by the data. Performance was adversely affected by training with highly distorted patterns.

The second process assumed that S averaged the locations of the distortions of a particular dot and that the likelihood of an abstraction resembling the prototype would increase as the level of distortion of the training patterns decreased. The data were consistent with these predictions.

Neither the additive nor the averaging model necessarily assumed that S attended to all dots in a pattern nor did the models have anything to say about serial versus parallel processing of the information. The models were relevant to the template-distinctive features controversy (e.g., Caldwell & Hall, 1970; Pick, 1965) to the extent that a template theory would be essentially the same as the additive model, unless it is assumed that the computed averages become the template. The averaging model is more consonant with a distinctive-features explanation, although the distinctive-features formulation and the averaging model are quite different. It was possible that Ss averaged over certain distinctive characteristics during training and that a limited set of averages governed their test-trial choices or that they averaged over all dot positions during training but used a distinctive-feature analysis to determine their test-trial response, or that some other combination of the two approaches was used. In Expt I, Group 1's latencies of responding on the test trials suggested that some form of distinctive-feature analysis might have been used. Group 1 classified new and old 1-bit patterns as rapidly as they classified the prototypes. The rapid classification of the old training patterns could be explained by postulating that Ss acquire abstractions *and* memorize the training patterns but this provision does not cover the rapid classification of the new 1-bit distortions. The simplest possibility seems to be that S bases his test-trial classification on the match of some subset of the dots. The dots of 1-bit patterns are almost as likely to duplicate the dot positions of an abstraction as are the dots of the prototypes; hence both prototypes and 1-bit patterns are classified quickly.

Training on highly distorted exemplars may hinder the formation of abstractions regardless of whether S added or averaged incoming information. The S might misassign dots, thus creating abstractions that differed from the prototypes. Or S might treat some dots as irrelevant and exclude them from any abstraction being evolved. Another way that highly distorted training patterns might hinder test performance is that S may have resorted to a paired-associate strategy as the easiest technique for learning to classify the complex training stimuli and failed to form any abstractions. Explicit instructions about the construction of the patterns and a grouping of the patterns derived from the same prototype might enable S to form prototype-resembling abstractions from highly distorted patterns.

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