THE RELATIVE DIFFICULTY OF MECHANICALLY EQUIVALENT TASKS

A Study in Human and Animal Learning

Donald Snygg

A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy in the University of Toronto.

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DONALD SNYGG

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IN THE SENATE CHAMBER

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THESIS

(Summary)

The Relative Difficulty of Mechanically Equivalent Tasks: A study in human and animal learning.

Theories of learning in general fall into one of two quite dissimilar groups; objective theories, which ignore any relationship between the learner's achievement and the way he is experiencing the task, and phenomenological theories, which tend to attribute all changes in response to changes in the experiential nature of the task. The failure of the objective theories to take account of what is introspectively the most important feature of learning may be due to inadequacies of the usual repetitive method of studying learning. There is need for experimental work directed towards this feature, if possible, in a manner that may be applicable with animals as well as human subjects.

The present study describes an attempt to study the effect upon performance of experiential differences between tasks which require identical or equivalent motor responses. With motor responses equivalent in kind it is possible to attribute differences in amount of performance or in learning time to phenomenological differences between the tasks, and thus to examine objectively the experience-activity relationship.

In a series of five preliminary experiments on human subjects it was found that the time required for performance of a task was dependent upon the subject's conception of the nature of the task: The more parsimonious the principle and the more obvious the perceptual differentiation essential for solving the task, the more complete the performance in terms of the objective criteria used.

This hypothesis proved adequate for the accurate prediction of the difficulty to white rats of eight different patterns of ten section Warden U mazes. Those of the mazes tested which were constructed on simple visual or spatial principles as "correct path always white" or "true pathway always to the left", which were thus open to performance by a single procedure, were learned by the animals in from 6 to 10 trials; in contrast to the 34 and 45 trials required by two groups to learn the "standard" maze of the same length and number of turns. Another maze, supposedly insoluble by rats, was learned in 41 trials when a visual cue was placed in the proper section; and was learned by another group in 6 trials when the perceptual prominence of the cue was increased. As in the tests with human subjects, tasks requiring two procedures for performance were intermediate in difficulty to single and multiple procedure tasks.

In general, the relative speed of learning two mechanically equivalent tasks is determined by the experienced simplicity of the procedures required for performance and the perceptual practicability of these procedures. The results of the study suggest that the mode of attack used by a learner is determined by his initial perception of the nature of the problem; this being a gross response to a relatively undifferentiated situation. Should this procedure prove inadequate the task is differentiated perceptually into segments, each of which may be solved by a simple procedure. The greater the number of sub-problems into which the task must be differentiated the longer will be the time required for mastery.

GRADUATE STUDIES

Major Subject:

Comparative Psychology—Doctor K. S. Bernhardt.

Minor Subjects:

Systematic Psychology and Principles of Learning —Professors E. A. Bott and W. Line.

Anthropology—Professor T. F. McIlwraith.

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Introduction

The investigation here reported was concerned with the question: 'Why is one task more difficult than another?' with special emphasis on the psychological problem of difficulty in learning. Such a question bulks large in the educational setting since the whole justification for training teachers as distinguished from examiners lies in the assumption that a skilled teacher may so alter a task that the progress of a student toward any arbitrary standard of performance is accelerated. This ability to change the difficulty of the task is necessarily contingent upon some knowledge of the factors which govern the comparative difficulty of such tasks. It was with the hope that it may eventually be possible to formulate general laws descriptive of these factors that the present investigation was begun.

If we accept the time required to perform a task as the criterion of its difficulty, it is obvious that one task may be more difficult than another because of the mechanical factors involved. It requires more time to run one hundred yards than to run ninety, more time to move a piano than a chair. The human body is a machine of limited energy output and the limits of its motor performance are quite fixed, so that if the gross mechanical factors were the only determinants of speed, any two tasks involving movement of equal mass over equal distances by the same effector mechanisms would be performed in the same time. If, however, we discover that such mechanically equivalent tasks do differ consistently in the time required for performance we must conclude that the mechanical factors are not the sole determinants of difficulty.

Fortunately for teachers, it is not at all difficult to demonstrate

that wide and consistent differences do exist between the performance times of tasks which are mechanically equivalent or even identical. As an extreme instance, the speed of writing 20 has little to do with the speed with which a child adds 4, 4, 4, 4, and 4. Without in any way changing the manner in which the child writes the answer, a marked improvement is possible if the teacher leads the child to recognize the task as 4 x 5. If this example appears too obvious let us take a case in which the motor activity is more prominent. It is easier to cancel the letters, d r i n k, from a paragraph of pied letters than to cancel the letters, r d n k i, from the same paragraph. Mechanically the two tasks are identical but unless they are recognized as identical they are performed at very different rates. It thus appears that the factors determining the difficulty of tasks are both mechanical and 'something other'; and it is plain that if the 'something other' is to be investigated it must be studied under conditions where the mechanical factors are constant or controlled. From this point of view our investigation involves the systematic comparison of the difficulty of tasks which are mechanically equivalent in the sense that they are performed by the same gross effector mechanisms and involve the movement of equal mass over equal distances.

Having accepted performance time as the criterion of difficulty, the difficulty of learning a task can be recognized objectively by the length of time or the number of trials required to bring that task to the required standard of performance. In other words, if the 'task' is the performance of an operation we know how to do, the measure of its difficulty is the performance time; if the 'task' is the learning

of an operation the criterion of difficulty is the time or number of repetitions required to reach an acceptable standard of performance. In either case the criterion of the difficulty is the time required to complete the task.

From the standpoint of psychological method the situation is this: we are interested primarily in the difficulty of learning and so must study the learning process. Traditionally the study of learning involves the observation of successive performances of the same task by an outside observer or by the learner himself. Under these circumstances the description of the process is altogether dependent upon the point of view. Objectively, that is as experienced by the outside observer, the problem remains unchanged while the activities of the learner change. Subjectively, that is as experienced by the learner, it is the task that changes. The observational method as described is inadequate for the investigation of our problem because, while the temporal criterion of difficulty and its mechanical factors can be observed, any other determinants cannot be observed but must be inferred; and the likelihood is that they will be referred to physiological changes in the learner. The participation method is likewise unsuitable because our purpose would ultimately require that features of the task experienced only by the learner be compared with features of the task experienced only by an outside observer, an obvious impossibility.

The problem, then, is that in order to investigate the 'non-mechanical' conditions of difficulty these conditions must be made open to observation and modification by the experimenter, that they may be as observable by him as is the criterion of difficulty with which they are to be compared.

As we have already suggested, it is entirely feasible to make at

least some of those 'other' conditions observable and objective by studying the performances by the same individuals, or by comparable groups, of tasks which are mechanically equivalent. Under such circumstances any differences in the performance times may be compared with the other objective differences between the tasks, since there are no gross mechanical differences. It is upon this general method, the comparison of performance times of mechanically equivalent tasks, that the experiments in this investigation were based. Since the method was not fully developed prior to the experimentation, but grew out of the exigencies of the search, the earlier experiments fell short of the ideal form. In the final experiment on human subjects it was possible, by selecting suitable tasks and using each subject as his own control, to equate the tasks for motivation, maturation, and previous experience as well as for motor responses.

In short, the first section of the present study is the description of an effort to make so called 'subjective' conditions of difficulty observable and objective to the experimenter. These conditions might then be systematically varied, and the results of such variation used as data for the formulation of principles adequate for prediction. The second section is an account of a series of experiments in which the principles derived from the work on human subjects were applied in predicting the comparative number of trials required by white rats for the mastery of various maze problems.

SECTION I

Experiment 1

In the introduction we have classified the determinants of performance time as: (1) 'mechanical', the gross physical features of the activity in terms of mass and distance, and (2) 'something other', the unknown factor which we intend to investigate. Since the 'mechanical' features include most of the objective data discernible by an outside observer, it is impossible for that observer to proceed further alone without abandoning observation and drawing inferences of 'practice', 'repetition', or 'synaptic conductivity' as explanations of difference in performance times. There is, however, another observer in the situation, namely the subject; and while it is impossible to compare change in his experience of the tasks with changes in their performance times with any degree of precision, it is possible to determine if any general relationship exists between them. If such a relationship does exist, mechanically equivalent tasks experienced as different will approach a common performance time as they come to be experienced as equivalent.

Subjects were asked to give as rapidly as possible the opposite of each of ten words which they read from a typewritten list. Three lists were used: A, consisting of words with a high probability of evoking opposites in a free association test; B, of words not so readily associated with their opposites; and C, of words which can be considered to have opposites only in one sense or relationship.

A	B	C
up	work	call
hot	start	dive
slow	hill	refrigerator
young	silence	twelve
good	tame	red
high	music	hold
new	hungry	ride
hard	command	anger

Table 1

Table 1
Opposites Tests
Mean Performance Times in Seconds
Test

Trial	A	B	C	C'
1.	9.8	31.7	39.7	11.2
2.	11.2	19.7	36.8	9.5
3.	12.6	13.9	32.6	9.6
4.	9.5	12.5	23.4	8.9
5.	9.9	12.3	17.8	8.0
6.	9.7	10.7	11.3	9.0
7.	9.9	12.0	13.1	8.7
8.	9.3	11.0	12.8	8.5
9.	8.0	11.5	8.8	8.4
10.	8.6	8.6	9.2	9.2
11.	8.2	10.8	9.4	9.1
12.	9.0	9.1	9.6	8.8

The lists were presented in A,B,C,A,B,C order with the order of words changed at each presentation. The response words and spontaneous comments were recorded by the experimenter.

The average times of five graduate students in their first twelve trials at one sitting are presented in Table I.

Table I.

Two subjects were allowed to read list C before testing. Their results are listed in column C' of the table.

Results

The mean performance times for all lists became approximately equal by the tenth trial, when the average times were 8.6, 8.6, 9.2, and 9.2 seconds. In both list A, where the 'opposite' response was fluent from the beginning, and in list C' there was little improvement during the practice period. While inspection of the gross time scores shown in Table I shows improvement with practice, the detailed responses of the subjects do not indicate improvement by practice. In the case of the two subjects who were allowed to find satisfactory opposites for list C before being tested on it there was little improvement with further practice. In all cases the time curves levelled off as soon as the subject had found the opposites that completely satisfied him. The longer performance times in the earlier presentations of B and C were thus largely due to conscious seeking for a satisfying responses. Although several words evidently considered inadequate were given, they were always given after a delay during which a 'better' opposite had been sought. In spite of the insistence on speed in the instructions and the presence of a whirring stop-watch on the table, there were no cases where a subject deliberately chose a short word to save time. The final selections for the opposite of 'refrigerator' were 'oven', 'furnace', 'stove', 'incubator' and

'warming oven'. Both of the users of the last two reported that they specifically rejected 'stove' because it did not give the exact shade of meaning they required. 'Incubator' was used in the sense of a laboratory incubator of bacterial cultures as opposed to the refrigerator, which inhibits the growth of micro-organisms. The exponent of 'warming oven' shortened his response to 'oven' after he had made it clear that 'warming oven' was meant. Another subject who had alternated between 'write' and 'hear' for 'call' expressed great satisfaction when she hit upon 'beckon'.

The longer performance times in the first presentations of B and C may be largely attributed to this conscious seeking for a satisfying response. When a completely satisfactory opposite was found it was thereafter evoked fluently. Relatively unsatisfactory responses were often repeated but only after an effort to find a more pertinent word. The effort would be renewed momentarily on subsequent presentations until the satisfying response was found.

The only evidence of any other type of improvement was the report of a subject whose time on list A suddenly dropped from 8.3 to 6.8: "I didn't have to think 'up-down' that time. It was just 'down'".

Summary

Subjects were asked to name the opposites of words of various degrees of ambiguity. As soon as appropriate opposites were found for all words the completion times of the various lists tended to become equal. In spite of frequent use, a response inappropriate to the subject's concept of the stimulus word was always slow because he first sought a better. The satisfactory response was always fluent.

Conclusion

In this experiment mechanically equivalent tasks initially experienced as different were performed in the same time as they became equivalent in experience.

Experiment 2

Although the results of the first experiment indicate a relationship between the way the task is experienced by its performer and the time required for completion, the method used was quite inadequate for any precise investigation of the relationship. Since this lack of precision is due to the inability of the experimenter to share the experience of the performer except at second hand, it would be more satisfactory to present the subject with a task which can be experienced in either of two quite different ways, both of which are known to the experimenter. In the following experiment the task was the reproduction of a series of letter triads which could be viewed as nonsense syllables or as a familiar poem. In order to make group testing possible, the speed of performance was rated by the number of triads reproduced in unit time, instead of total performance time.

Forty-one pupils in a senior third (sixth grade) class were allowed to study a 20 line list of nonsense syllables and consonant triads for two minutes. They were then asked to write in one minute the triads they remembered. Three different lists were used; the first ten lines of each running:

I	II	III
ere	und	for
und	ere	men
ead	spr	may
spr	ead	com
cho	ing	can
ing	cho	dmo
utt	stn	nnn
stn	utt	ygo
the	ree	but
ree	the	igo

Table II

Table II

Average Number Trials Reported Per Trial

Trial	Group A Discovered Principle	B Tutored in Principle	C No report	D Individual Devices
1.	7.25	6.43	6.43	6.67
2.	10.38	9.86	9.23	8.00
3.	11.50	11.43	11.00	8.67
4.	10.87	12.14	11.05	8.67
5.	12.50	13.43	11.67	10.67
6.	12.25	9.00	9.50	10.00
7.	14.25	11.13	11.77	10.00
8.	16.25	12.43	13.18	10.00
Recall	18.50	12.13	8.23	5.00

List I was given three times in succession. In the fourth and fifth trials list II was used. This, while consisting of the same triads as list I needed only regrouping to spell out the opening lines of Longfellow's Village Blacksmith, with which the children were familiar. The sixth exposure was of list III, and the seventh and eighth of list II. The children were told that they were being tested to see who could learn the fastest and no comment was made on the results. One week later, at the same period, the experimenter re-entered the room and asked the children to write out as much of the material as they could remember. Writing time was limited to five minutes. At the end of that time they were asked to report in writing any device they had used to assist in remembering the lines.

Results

Fifteen pupils reported that they had remembered the triads as the opening lines of the Village Blacksmith; three used individual mnemonic devices; twenty-three made no report. The previous reports of the fifteen who reported recognition of the poem were examined and indications of recognition during the test were found in the reproductions of eight. The other seven had failed to reproduce the syllabic order and had apparently learned the principle from classmates after the original test. Averages of the four groups are given in Table II.

Table II

The features at once evident are:

1. The close similarity of the results of the three main groups in the first three trials where the principle was securely hidden.

2. The superiority of the group which later reported discovering the poem (group A) in the results for trial 6 when the "for men may com..." verse was given its only presentation. The individuals discovering the principle previously now applied it to the new poem.

3. The continued superiority of group A when list II was again presented in trials 7 and 8. Individuals deriving the principle for the first time in trial 6 now applied it to the earlier list.

4. The marked superiority of group A in delayed recall. In this test, in which five minutes was allowed for report instead of two minutes as allowed in the practice series, group A reported more triads than on any previous trial. No individual in the three other groups scored as high as the group A average.

5. The similarity of groups B and C, neither of which had discovered the 'poem principle' during the practice series.

6. The superiority in delayed recall of group B (which learned the principle from classmates after the practice series) over group C.

7. The inferiority of individual mnemonic methods, as used by group D.

It should be noted that not all of the eight members of group A had derived the principle until the 8th trial. Using correct order as a criterion, two individuals had recognized the principle at the 4th, four at the 6th, five at the 7th, and eight at the 8th. On the 8th trial only four individuals in the other groups (12%) made a score equal to the average of group A. In the delayed recall test none of the other thirty-three members of the class scored as high as the group A average.

The scores on these two trials correlated .30 and .28 respectively with National Intelligence scores and -.01 and -.01 with class standing.

Summary

Forty-one senior third grade children were asked to learn lists of nonsense syllables constructed on a hidden principle. The final average score of the children finding the principle was 182% that of the children not finding it.

In a surprise test one week later the children who had discovered the principle reported on an average 225% as many syllables as the other children and 14% more than in their own last practice trial.

The delayed recall score of the children who had learned the principle from playmates between practice series and recall was 98% of their final practice series score.

The delayed recall score of children not reporting the principle was 62% of the final practice score.

Conclusions

Children discovering the hidden principle were somewhat superior on immediate recall and markedly superior in delayed recall to children using other methods. The way in which the task was experienced considerably affected the amount of work accomplished.

All the children who found one hidden poem were able to apply the same general principle in finding another.

Experiment 3

In the last experiment the children showed an ability to discover and use general principles. Having found that one list of nonsense syllables could be recognized as a familiar poem, they sought to find hidden poems in other lists. The following experiment was devised to investigate the question: Do people tend to use such general principles or procedures in solving groups of similar problems; and if so, do these modes of attack affect the performance time of the several tasks?

Five graduate students were individually asked to find the next three numbers in each of the following series:

I.	1	2	3	4	5	6	7	8	9
II.	15	14	13	12	11	10	9	8	7
III.	1	5	2	5	3	5	4	5	5
IV.	9	4	8	4	7	4	6	4	5
V.	9	1	8	2	7	3	6	4	5
VI.	1	15	2	14	3	13	4	12	5
VII.	2	17	12	3	16	12	4	15	12
VIII.	26	14	5	25	14	6	24	14	7
IX.	5	12	1	6	11	2	7	10	3
X.	9	1	19	8	2	18	7	3	17
XI.	19	1	9	10	18	2	8	11	17
XII.	2	4	6	8	10	12	14	16	18
XIII.	1	2	4	8	16	32	64	128	256
XIV.	1	2	4	7	11	16	22	29	37
XV.	1	3	6	4	7	21	18	22	88

Table III

Table III
Number Series Problems
Solution Times in Seconds

	Group I			Group II	
Problem	A	B	C	D	E
I.	4.3	4.4	2.7	2.8	2.2
II.	4.0	4.5	2.9	3.4	2.9
III.	7.8	8.7	7.9	21.8	30.5
IV.	5.7	4.3	4.2	47.4	23.6
V.	11.5	6.3	17.9	27.8	45.3
VI.	6.0	6.4	8.7	44.6	16.3
VII.	17.2	21.0	15.9	138.4	495.2
VIII.	14.1	20.4	9.9	106.0	31.0*
IX.	16.6	9.2	13.2	134.8	18.1
X.	8.3	11.4	15.1	31.8	18.1
XI.	14.3	22.5	11.7	81.3	31.4
XII.	10.6	15.0	2.9	3.7	6.2
XIII.	17.5	29.8	15.9	23.6	9.8
XIV.	19.3	31.1	16.6	10.1	11.1
XV.	Failed (960)	613.0	771.3	241.5	423.0

* Used either method from this point.

Results

The method of procedure was inferred from the written calculations which the subjects used in their solutions.

The performance times of the subjects were found to divide themselves into two groups in accordance with the mode of attack adopted. The performance times of the individual subjects A,B,C D, and E, on each problem are given in Table III.

Table III

Although all subjects were given the same instructions, there was a sharp difference in completion times beginning with the third problem. A, B, and C, recognized that series as 1, 2, 3, 4.... with an intervening constant, 5. D and E, however, found a secondary relationship in the differences of the successive digits; 4, -3, 3, -2, 2, -1, 1, -0, 0 and completed the series by adding 1, -1, and 2 to secure the correct answers. They solved the problem in 21.85 and 30.55 as compared with 7.85, 8.75, and 7.95 for A. B, and C. Beginning each solution by finding the differences between the successive numbers, D and E were markedly slower in performance time up to and including problem VII, which they solved in 138.4 and 495.2 seconds respectively as against an average of 14.5 seconds for A, B, and C. E thereafter adopted the method used by group I, seeking the component series directly in the presented material, and her time scores fell to the general level of group I.

Up to this point group I had been uniformly superior. Its simpler and less cumbersome procedure, however, proved quite inadequate for the solution of problem XV. The fastest solution by a member of group I was 10 min. 13 sec. while A failed to find the solution in 16 minutes.

D and E, on the other hand, solved the problem with little difficulty, in 4 and 7 minutes respectively.

Summary

Comparison of two small groups solving the same problems by different principles shows:

1. Marked time superiority for the group using the more direct principle where that principle was adequate for solution. In one case the problem was solved by this group in 6% of the time required by the other group.

2. Equally great superiority in other problems of the group using the other principle.

3. There was little change in methods of procedure during the test. The performance time of the various subjects on problem XV was largely determined by the principle of solution they used in the third problem.

Conclusions

1. In this situation the chief determinant of the performance time was the general principle employed in the solution of the problems.

2. There was a strong tendency to preserve unchanged any principle which leads to solution.

3. Changes of principle did occur in cases where the old principle had proved inadequate. The written work indicates that J altered his mode of attack after the first method had proved cumbersome in the seventh problem. All subjects solving problem XV eventually solved it by using the group II principle of finding the intermediate relationships.

4. The results conform to those of Husband (1) in his investigation of methods used by human subjects in maze running. He concluded that

> "much of the high variability which has always characterized maze results was found to be due to the many different methods used in learning... Each method, as employed by different learners has its own mean, with cases clustered about it." (Ibid, p.274-275).

He also found that the methods were carried over by the subjects into new tasks.

Figure 1

Number Maze I
Key-12

	1	4	8	8	4	5	3	1	2
	6	3	2	4	5	6	7	8	7
	1	6	3	8	8	6	4	5	9
	9	5	6	5	9	8	7	1	3
Start	4	4	4	4	4	4	4	4	4 Finish
	8	7	2	3	7	1	6	9	1
	2	3	1	4	9	6	7	4	3
	5	2	9	7	5	2	7	7	1
	4	2	3	4	5	9	4	1	5

Number Maze VI
Key-18

	1	6	6	2	5	7	6	6	7
	6	2	1	6	7	6	5	1	6
	1	6	5	2	6	7	1	6	5
	2	1	6	5	2	4	6	8	4
Start	6	8	4	6	8	6	9	3	6 Finish
	3	6	9	6	3	6	3	6	9
	9	6	3	6	9	6	1	6	7
	6	2	6	6	2	6	5	6	5
	5	6	6	1	7	6	6	1	2

Experiment 4

In the previous experiment in number series completion, there were strong indications that individuals who have used one plan of attack in the solution of a problem will continue to use the same general method on similar problems.

The following experiment was conducted to determine under what conditions such principles are abandoned or modified.

Six graduate students were asked to find two out of three possible paths through each of six number mazes. The problem was to find a path from start to goal on which each set of three successive digits added up to a given number. In the example shown in figure 1 the number is 12. There were no blind alleys in the mazes. Moves were

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Figure 1

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vertical, horizontal, or diagonal. The subjects were warned that they were being timed.

The plan of attack was inferred from the type of path chosen and the consistency of the order of preference among the possible paths.

Results

Both in the first test and in a repetition a week later the paths chosen by each subject indicate consistent plans of attack, the following principles being used by the various subjects:

a. Begin on the horizontal line from the start (directly toward the goal).
b. Begin the search for suitable digits with a clockwise sweep with the starting point as a pivot.
c. As above, with a counterclockwise sweep.
d. Search for a path whose digits were each 1/3 the required sum.

All subjects tended to continue the use of a principle until they were forced to find a new one because:

1. The old principle was inapplicable or led to difficulties. 4 changes by 4 subjects.

2. The older principle had proved inefficient in the last previous maze. Of the twelve trials made up of the two slowest performances of each subject, five were followed by a change of procedure.

Principles of procedure were usually not discarded until another had been 'accidentally' found. When the use of principle B or C, for instance, led to the use of a path which also involved A or B, the new principle might be used in the next problem. Of the fifteen changes of principle, seven appear to have followed such discoveries.

The horizontal line leading directly toward the goal was the first choice 18 times in the first trial and 30 times in the second, out of a possible 36.

The greatest difficulty in the maze solutions was the discovery of any section of a path leading directly away from the goal.

Principle B, which involved the least calculation but in the later mazes was associated with the longest of the three paths, tended to be used most by those subjects who did not discover that each path was made up of successive identical triads.

Summary

When six subjects were asked to find two of three possible paths through each of six similar digit mazes:

1. Three-fourths of the problems were solved by the same method of search as was the immediately preceding maze.

2. Changes in method of search appear to be largely due to marked inadequacy of the older principles or to the accidental discovery of new ones.

3. Changes in perception of the nature of the problem alter the

relative difficulty or effectiveness of the principles. Regardless of distance, a 4 4 4 4 4 4 path tended to be preferred to a 5 3 4 5 3 path until the latter was recognized as being necessarily a series of identical 534 534 534 triads. Once this was discovered the preference between principles was in terms of the probable distances of the paths.

Conclusions

1. Individuals tend to use the same types of procedure on similar tasks.

2. They do not seek new principles as long as those used are even moderately successful.

3. The comparative difficulty of carrying out alternative principles of solution may depend upon the way in which the task is perceived.

Figure 2

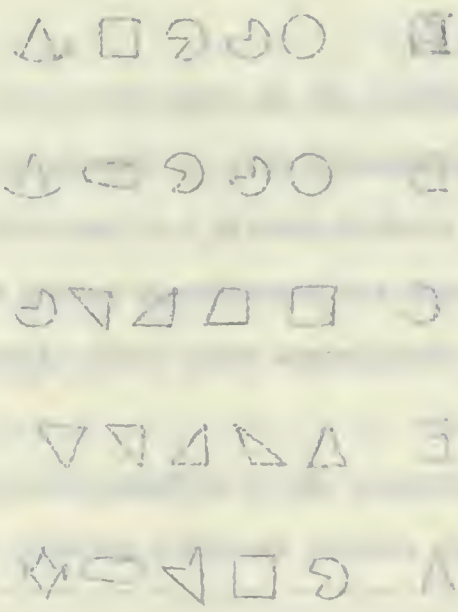
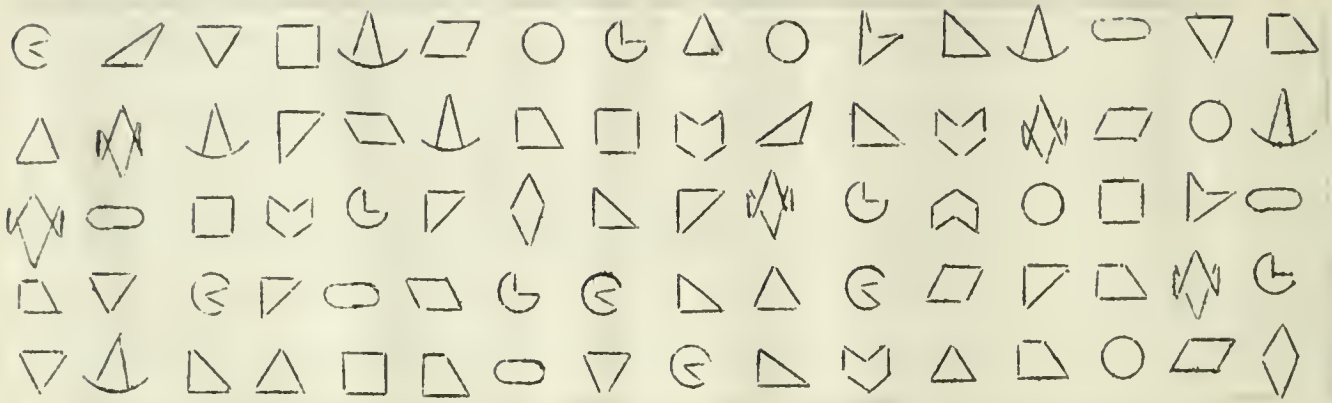
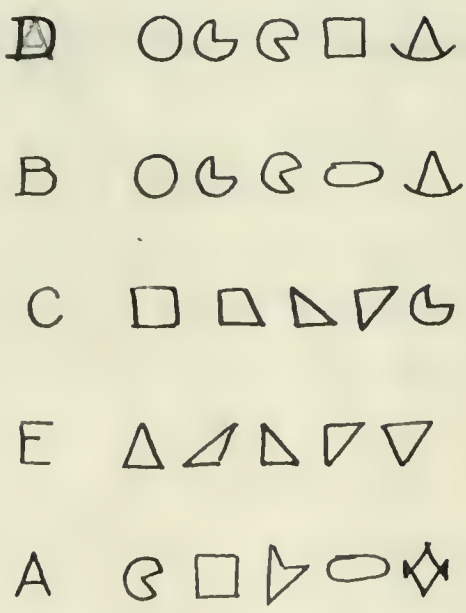


Figure 2

Cancellation Test Material





xperiment 5

In the experiments conducted up to this point we have compared the difficulty of two tasks mechanically equal, but experientially different, and found that they became of equal difficulty, measured in performance time, as they became experientially equivalent. We have compared the performance times of the same task by different individuals and have found that the performance time is largely determined by the subject's mode of attack. We have seen that this mode of attack is not peculiar to the individual problem but is in conformity with general principles which govern the individual's procedure in like situations and that the relative efficacy of these principles may vary with phenomenological changes in the task.

These indications, that differences in the difficulty of two mechanically equivalent tasks are concomitant with phenomenological differences, appeared to require verification in a situation where comparison could be made not only between two groups experiencing the same task in different ways but between mechanically equal tasks experienced in different ways by the same individual.

Such a comparison is made possible in the cancellation of the material shown in Fig. 2. of the eighteen different symbols that appear in each

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Figure 2.

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block, five contain curved lines; five contain one or more right angles; five are triangles; and seven are miscellaneous figures. The total number of symbols containing curved lines is 26; of lines containing right angles, the same; of triangles, 22. The cancellation of the symbols containing curved lines is mechanically equivalent to the cancellation of the figures

containing right angles in the sense that both involve the same number of pencil strokes distributed fairly evenly over the same area.

Part 1

Subjects

Eighty-eight students in a second year undergraduate laboratory course acted as subjects in the first part of this experiment, which was conducted as a group test.

Procedure

The subjects were issued mimeographed sheets of the material to be cancelled and were shown one of the three lists of symbols to be cancelled as shown in Fig. 2. List A consists of five miscellaneous figures; list B of all the figures containing curved lines; and list C of all the figures containing right angles. After cancelling the required figures in the first block as rapidly as possible the subjects were asked to make a note of anything which had helped them to remember the symbols to be cancelled and were instructed to do the same for the other two lists, cancelling each list in turn until each had been cancelled in six blocks. Each subject timed himself.

Results

Forty (45%) of the subjects reported that they discovered the principle "cancel all figures with curved lines" in performing task B. Twenty-one others reported that they had used the concept "three circles, an oval, and a 'do-funny' in this task. The remaining twenty-seven reported no principle.

The average performance time of the last trial shows a clear relation between the concept derived and the performance times:

Tabl IV

Table IV

Median Performance Times
of Subjects Reporting the Principle
"Cancel all curved lines."

F	Trial Reported	1	2	3	4	5	6
13	1	32	30	28	22	23	20
5	2	70	35	29	27	24	24
3	3	53	48	33	36	27	20
6	4	62	45	43	33	32	32
7	5	60	53	54	43	30	25
6	6	52	50	35	35	42	24

Explanation: 13 subjects reported that they had used the principle on the first trial. The 5 subjects who reported using it for the first time on the second trial averaged 70 seconds for the first trial, 35 for the second, and 29 for the third.

Average Performance Times, Task B, Last Trial

Principle	F	Seconds	Slower than Av. of Group 1.	Faster than Av. of Group 3.
1. (No concept)	27	41.6 ± 12.4	28%	4%
2. (Three circles)	21	32.0 ± 5.8	5%	10%
3. (All curves	40	24.1 ± 6.5	0	50%

Of the forty subjects who recognized the task as the cancellation of all symbols containing a curved line, every one made faster time on the sixth trial than the average of the individuals who did not report any concept of the symbols. Conversely, only one member of this 'no concept' group was able to perform the task as quickly as the average member of the group deriving the principle. The subjects using the concept 'three circles, the oval, and the pie' were intermediate to the other two groups in performance time, only one of the twenty-one being as slow as the average member of the no concept group and only two as fast as the average of the 'curve' concept group.

The average superiority of 17.5 seconds which the 'curves' group had over the 'no concept' group is exactly equal to the average improvement made by all subjects on the first trial on which the concept was reported. The abrupt improvement occurring at this point may be easily traced in Table IV. Two features of the performances of task B are at

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Table IV

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once apparent in this table: the uniformity of the performance time at which the principle is first reported, and the comparatively small degree of improvement thereafter. Among the subjects reporting the concept later than the first trial, the average improvement on the trial immediately

Figure 3

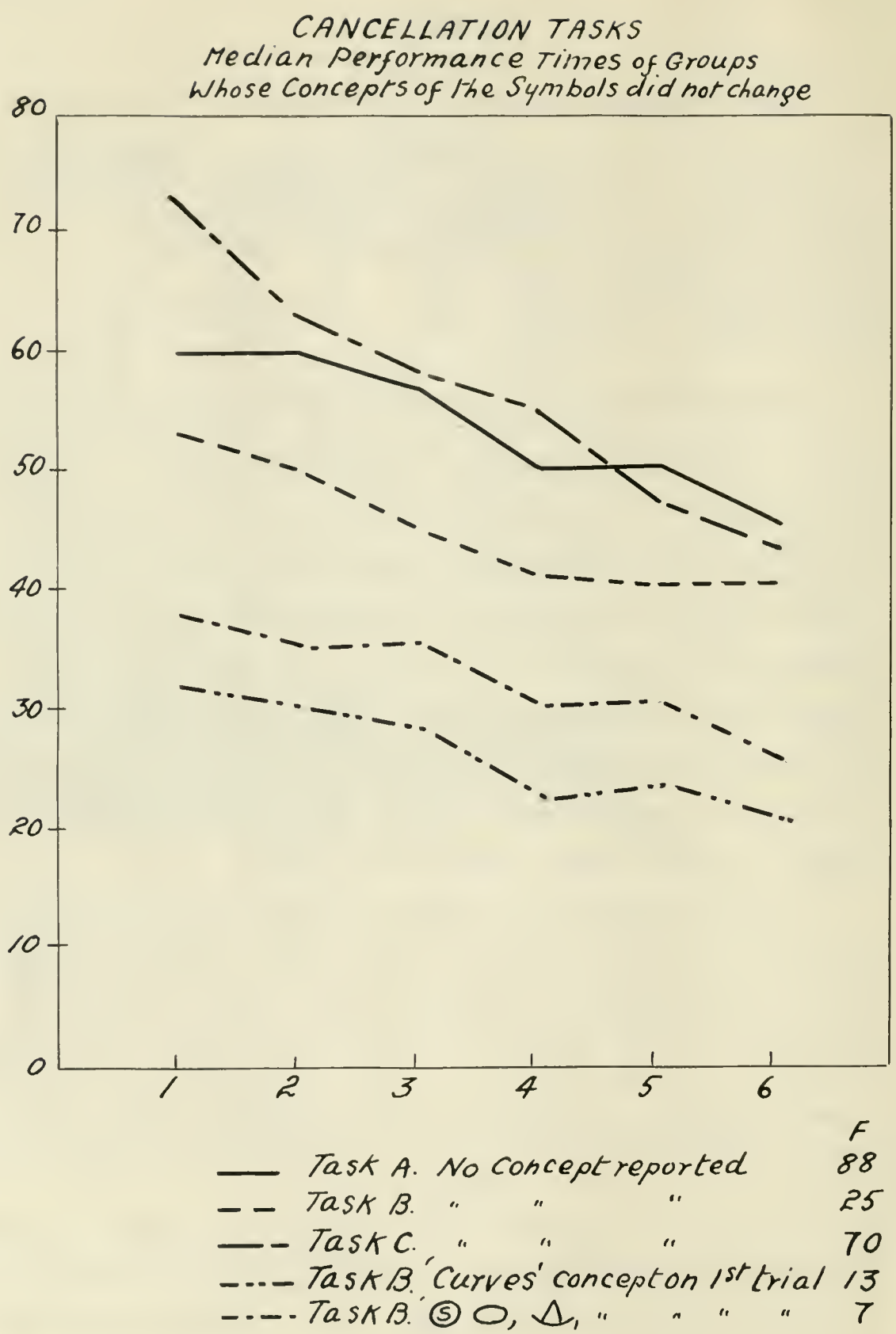
CANCELLATION TASKS
Median Performance Times of Groups
Whose Concepts of the Symbols did not change
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
F
Task A. No Concept reported 88
Task B. " " " 25
Task C. " " " 70
Task B. 'Curves' concept on 1st trial 13
Task B. ⑤ ○, △, " " " " 7

FIGURE 3.

preceding the report was 17.5 seconds; the average improvement on other trials was 3.4 seconds.

Only eighteen subjects reported the discovery of the principle "cancel all symbols containing right angles" in task C. Those who did were superior in this task to the seventy other subjects, who reported less inclusive concepts, or none at all:

Average performance times, task C, last trial

	F	Seconds	Slower than 4	Faster than 5.
4. (No concept)	70	43.7 ± 14.1	45%	15%
5. ('Right angles')	18	35.8 ± 9.2	28%	55%

No subject reported any inclusive concept for the symbols to be cancelled in task A. The mean final time for the 88 subjects was 45.7 ± 15.1. Thus where no principle was reported there was no reliable difference in the performance times of the three tasks, the final averages being 45.7 ± 15.1, 41.6 ± 12.4, and 43.7 ± 14.1 for A, B, and C. The graph in Fig. 3 shows how similar was the

Figure 3.

course of improvement among these tasks. It is interesting to note in this figure the nature of the curve which describes the performance times of the 13 individuals who reported the 'curved line' concept at the end of their first trial in task B. It follows a course similar to that of the 'no concept' curves but is faster throughout. The performance times of groups who derived the 'curved line' principle at a latter stage shows a sudden drop from the higher to the lower level as the concept is reported, as shown in Figure 4.

Figure 4.

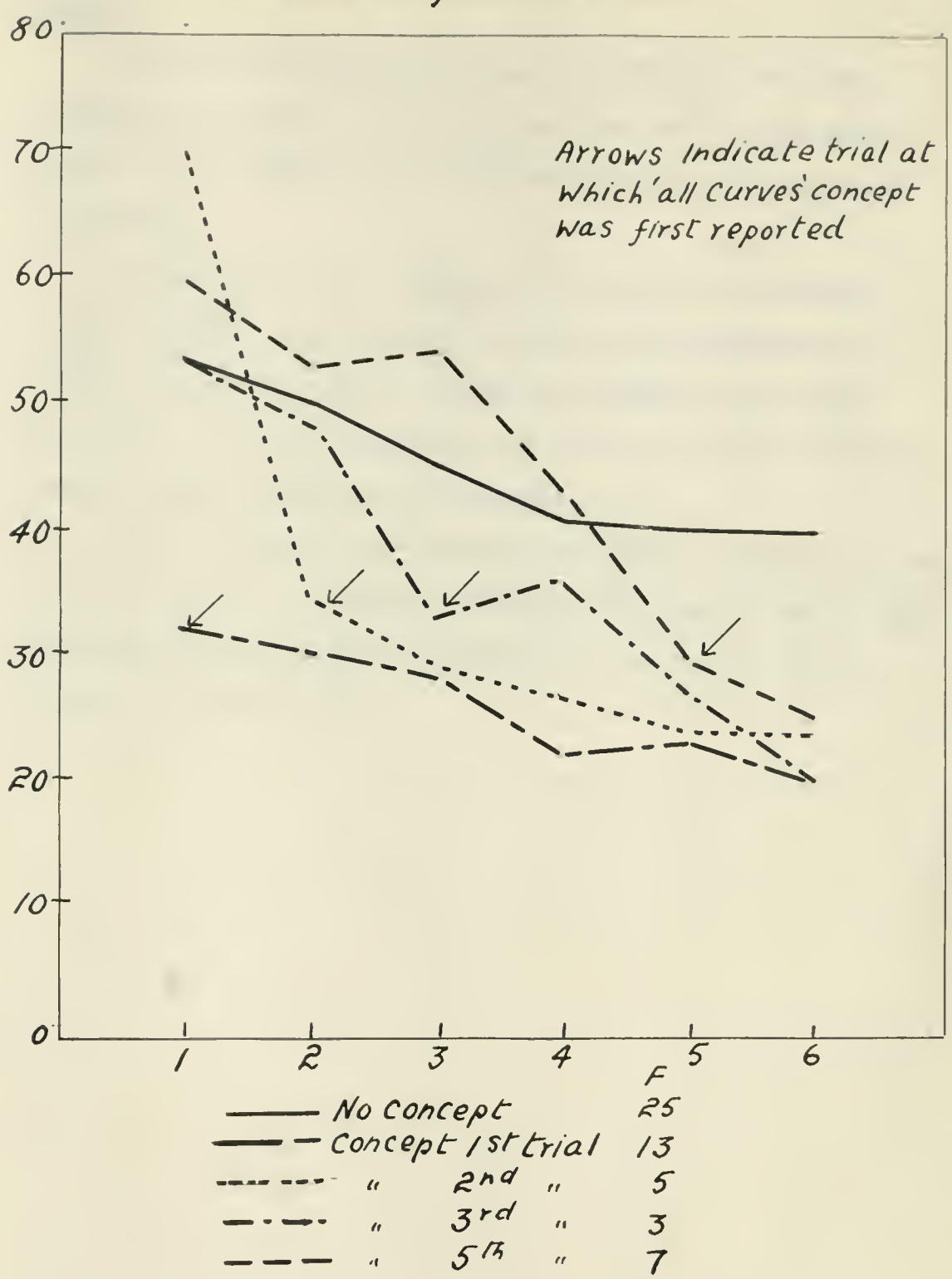
CANCELLATION TASK B.
Median Performance Times
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
Arrows indicate trial at which 'all curves' concept was first reported
No Concept 25
Concept 1st trial 13
" 2nd " 5
" 3rd " 3
" 5th " 7

FIGURE 4.

Summary

When three mechanically equivalent cancellation tasks were performed by 88 subjects the performance times of the sixth trial proved to be a function of the subjects' concept of the symbols to be cancelled.

In the same task the concepts were effective in the order of their parsimony. "Cancel all curved lines" was performed in an average time of 24.1 seconds; "cancel all circles, the oval, and the piece of pie" in 32.0 seconds; and the average time of subjects using all other methods was 41.6 seconds.

When two principles were equally parsimonious ("cancel all curved lines" and "cancel all figures containing right angles") the principle involving the least perceptual difficulty in its use was the more effective by 24.1 to 35.3.

Table V

Table V

Symbol Cancellation
Median Times of Five Subjects

Trial	Task A	B	C	D	A'*
1	46.6	41.4	56.0	56.6	25.3
10	35.7	17.1	23.8	26.4	14.3
20	20.5	15.0	20.0	21.3	13.8
30	16.9	14.6	20.3	18.5	9.6
40	16.5	11.6	18.5	16.5	8.7
50	15.3	11.2	16.4	13.8	6.6
70	13.3	10.0	14.2	14.8	4.6
90	12.0	9.0	12.8	11.4	3.6
Test	25.7	13.9	19.2	16.4	26.5

* One subject only. See text.

Experiment 5

Part II

The symbol cancellation was continued by five graduate students with one or more trials daily for a period of three months. In addition to the tasks used in the group experiment these subjects also performed task D, which was the same as B except that the square was substituted for the oval, making the principle 'cancel all curves' inapplicable. Task E, which could be performed by cancelling all triangles, was performed by all subjects until the concept had developed and thereafter continued by only one subject.

At the end of 90 trials the subjects were tested by being asked to cancel the required symbols from material in which the order of the symbols had been changed.

Results

The results in general conform closely to those of the first section. Task B was, even after 90 trials, the easiest for all the subjects who performed the tasks in rotation. In the case of the one

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Table V

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subject who performed both B and E, the two tasks amenable to solution by the most parsimonious principles ('cancel all curves' and 'cancel all triangles') the performance times were almost equal, with B slightly superior. The 'curves' could be judged on the basis of the bottom line, while more complete perception of the 'triangles' was necessary since there were several other angular figures in the material.

D, differing from B in only one symbol, required about 25% more time for performance throughout. While all subjects used the principle

'cancel all curves' in task A, the concept in D was 'the circles, the square, and the pie'. The performance times of the subjects in part I who had used a similar concept 'the circles, the oval, and the pie' for task B had closely approximated the times of the group using the more parsimonious but perceptually more difficult concept 'cancel all right angles' in task C. All the subjects in this section used this 'right angle' principle in solving C; and the close correspondence of performance times with those of I may be seen in table IV.

In those tasks, B, C, D, and E, where general concepts of the group of symbols to be cancelled were derived the individual performance times showed marked drops when the concept was reported. B, C, and E offer the most inclusive and consequently parsimonious concepts; 'all curves', 'all right angles', and 'all triangles'; and the performance times were in order of the perceptual difficulty of applying the concepts: E, B, and D.

It will be noticed that the performance times for task A, while showing a more gradual rate of drop, came by the twentieth trial into the approximate level of tasks C and D. Although the use of explicit principles and concepts had greatly accelerated learning at first it may be possible that in some cases the adoption of a static principle may 'freeze' the performance and prohibit further progress. Something of the sort may have occurred in Vincent's (2) experiment where the rats given visual cues made much greater initial progress but were eventually excelled in performance time by the animals who did not use visual cues and did not have to slow down to watch for them.

The results of the previous experiments in this series had led the experimenter to anticipate this result. To check this possibility one

subject was not asked to learn task A until he had completed the others. He was then told that it was not possible to derive a compact, inclusive concept of the task A symbols, but that he could use any method he wished in learning the task. He determined to learn the location of each symbol to be cancelled and in two weeks, as shown in column A', table IV, he had, by the aid of a rhythm he discovered in the material, reduced the time of cancelling the 22 symbols to 3.6 seconds. His best time for task B had been 6.4. When tested, however, on the same material in changed order his time for A rose to 26.5 seconds, while B was performed in 8.1. In A he had learned to mark certain locations; in B he had learned to cancel curved lines. The learning in A was applicable to only one block of symbols; that in B to any situation where there are figures with curved lines.

All subjects, as shown by the persistent omission of certain symbols, learned to depend partially on the spatial position of the symbols to be cancelled. Judging by the comparative increases in time when tested on cancellation of new material, the dependence on location was much greater in A, where no parsimonious principle of performance was possible.

Summary

Four mechanically equivalent cancellation tasks were performed 90 times each by five subjects.

A list of symbols which could be cancelled by use of the principle 'cancel all curved lines' was cancelled at least 25% faster than the same list in which a square had been substituted for an oval to make performance by the single principle impossible.

The task which could be performed by cancelling all curves was performed faster in all cases than the task which could be performed by cancelling all right angles.

The relative difficulty of the tasks, measured either by initial rate of improvement or by speed in cancelling from new material, was determined by the degree of parsimony of the principles of procedure and by the perceptual difficulties involved in their use.

Summary of Section 1

The results of the five experiments on human subjects which have just been described appear to warrant the following conclusions:

1. Difference in difficulty between two mechanically equivalent tasks corresponds to a difference in the way the two tasks are experienced. Exp. 1,2,5.

2. Individuals solving problems use general principles and methods of procedure (Exp. 2,3,4) which are modified according to the exigencies of the situation. Exp. 3. 4.

3. The relative speed of learning among mechanically equivalent tasks is determined by the degree of parsimony of the principles required for performance, and by the perceptual difficulties involved in the application of these principles. Exp. 2,3,5.

4. There are some indications that the greater speed of learning of tasks amenable to performance by parsimonious principles is also associated with greater efficiency in delayed recall (Exp.2) and, what may be the same thing, with greater transfer (Exp.5).

Accepting for the moment the validity of these conclusions, their implications for pedagogy are unmistakeable. There, as in most

educational situations, the prime consideration is the acquisition of an adequate performance in the shortest possible time, the comparative times necessary to bring two alternative tasks to the required standard of performance are of prime importance. If it is possible to predict which of two equivalent tasks will be learned the faster it is possible to predict how any task may be altered to accelerate mastery.

In the next section the validity of the third conclusion will be tested by applying it to prediction of the maze running performances of white rats.

Section II

The Effect of Practice
on
The Comparative Difficulty of Mazes
for
The White Rat

Introduction

In the preliminary investigations reported in section 1 of this thesis the relative difficulty of mechanically equivalent tasks appeared to be determined by the degree of parsimony of the principles required for their performance and by the perceptual difficulties involved in the application of these principles.

As a general thesis applicable to the whole field of behavior of learning, the conclusion suffers from the narrow field in which it was derived. The tests in general were of an abstract type requiring a minimum of motor activity. Will the hypothesis prove valid in the learning of motor activity by animals? In the following section it is purposed to test the validity of the hypothesis in maze learning by white rats.

Material

The mazes used in the following experiments were ten-section modified Warden U mazes (3), the individual sections having built-in floors and being fitted with a tongue at the exits and groove at the entrance for easy shifting. All sections were identical except that the interiors of the sections used in the visual mazes were painted white on one side and black on the other, the dividing line running down the wall and floor directly in the middle of the entrance. The other maze sections were painted black. Since ten sections were used in all cases all paths were of equal length and number of turns. Doors to prevent retracing were used only at the starting box exit and the food box entrance.

Procedure

The animals used were purchased from a local dealer and were five to seven weeks old when the experiments were begun. As a preliminary training the animals were fed in the food box of the maze for five days. During the experiments two runs were made each day at an interval of nine hours. The animals were allowed to feed two minutes in the food box and were then removed to the feeding cage. No food except lettuce was supplied in the home cage.

The criterion of learning was three errorless runs in four consecutive trials. The placing of both front feet into a blind alley was scored as an error.

Experiment 1

What is the comparative difficulty of a maze constructed on a visual principle (correct path black, blind alleys white) with a conventional maze of identical pattern and dimensions?

Mazes

Maze B: a Warden U maze of the standard LRRRLLRLLR pattern (5) (4).

Maze B-W: An identical maze with the blind alley half of each section painted white.

Subjects

Two groups of white rats, 13 in each group. The groups were equated for weight and there were 6 males and 7 females in each group.

Procedure

Group 1 was run in maze B and Group 2 in maze B-W for 45 trials each. The groups were then interchanged, Group 2 being run in maze B for 45 trials and Group 1 in maze B-W for 30.

Results

	Median Trial Learned	Range	Number Learning	Percent Learning	Fastest Time
Maze B					
Group 1	34	14-?	7	54%	7.4 (45)
Group 2	45	3-?	7	54%	7.4 (26)
Maze B-					
Group 2	7	5-17	13	100%	7.0 (26)
Group 1	6	3-17	11*	100%	7.2 (10)

1. The maze constructed on the visual principle was learned the more rapidly by 7 and 6 trials as compared to 45 and 34.

2. All animals learned the B- maze within 17 trials while only 54% learned the B maze in 45 trials.

3. The percent of perfect runs in maze B after fulfilling the criterion of learning was 55.5% for group 1 and 61.8% for group 2. The corresponding percentages in B- were 91.8% and 93.4%.

4. In maze B- all animals had made 9 perfect runs out of 10 consecutive trials by the 24th trial. In maze B only 20% of the animals were able to reach this standard by the 45th trial.

5. Performance time of the rats in the B- maze, although approached by the rats in the B maze, remained superior to the end of the experiment.

6. In spite of the fact that the two mazes were spatially identical, only one animal from each group was able to run the second maze on the first trial after 45 runs in the first maze. In both cases the performance time of these animals increased about four times.

7. Of 5 surviving animals in Group 1 who had learned maze B, only one was able to run it without error two weeks after completion of the runs in maze B-. The others made 3, 4, 5, and 7 errors respectively.

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*Two animals died near the end of the runs in B.

8. Of the 13 animals in Group 2, 7 made errorless runs in B-W two weeks after completion of the runs in B.

Discussion

The objective results of the experiment agree very closely with those of Vincent (1) except that the rats in the B-W maze remained throughout superior in performance time and made fewer errors than the animals in B. It is likely that this difference in results is due to the different position of the visual cues in the two experiments. In the present experiment both the black and white were visible to the rat while he was still at some distance from them and he was consequently able to make his choice without slowing his pace as appears to have been necessary in the Vincent maze. This greater prominence of the visual cues in the present maze may also account for the greater accuracy of the animals in maze B-W. 3 of the 14 rats who 'learned' maze B subsequently 'forgot' it while the percentage of correct choices for either group in B-W never fell below 99.6% after the 20th trial.

Summary

When two comparable groups of rats were run in two spatially identical mazes, one of which was constructed on a visual principle, the group in the maze amenable to solution by derivation of a principle was superior in speed of learning, performance time, and retention.

When the same group was run in both mazes, the performance in the maze constructed on the visual principle was superior.

Experiment 2

In the preceding experiment the maze constructed on the simple visual principle proved markedly easier to learn than the standard maze of the same pattern. Two questions at once arise:

(a) To what extent may the learning of the B- maze have been affected by a natural preference of the animals for dark passageways?

(b) The animals in the B-V pens had, through the spatial identity of the two mazes, the same possibilities for learning as the animals in the B maze, with the additional aid of the visual distinction between correct path and blind alleys. Would the learning take place faster than in the standard maze if animals in the visual maze were forced to rely upon the visual principle alone?

To find an answer for these questions 26 rats were run for one trial in a standard LRRRLLRLLR pattern maze in which the correct pathways were painted white, the blind alleys black. On the basis of their performance in this trial they were divided into two equivalent groups. One group was trained in the test maze, which was designated as the V-B constant pattern maze or V-BC. The other group was trained in a maze constructed of the same sections, on the same V-B principle, but with the pattern varied according to the flip of a coin for each trial. This was the V-BV (V-B variable pattern) maze. Both mazes were made up of the same sections and in every case contained the same number of right and left turns.

Although the usual procedure was as described above, for purposes of comparison the variable group was run in maze V-BC every tenth trial. On the 11th and 31st trials both groups were run in a mirror image of the V-BC maze.

Results

	Median Trial Learned	Range	Percent Learning	Fastest Time
Maze [illegible]-BC	7	5-11	100%	6.4 (17)
Maze [illegible]-BV	10	6-21	100%	7.1 (19)

1. In the first trial in the [illegible]-B mazes the animals were correct on only 38% of the choices the first time the choices were made. In B-[illegible], 62% of the choices had been correct and in B, 40%. This would appear to indicate an initial preference for the darker pathway.

2. Maze [illegible]-BC was, in spite of this initial preference, learned as quickly as B-[illegible] had been. [illegible]-BC was learned in 7 trials with a range of 5-11; B-[illegible] in 7 with a range of 5-17.

3. Maze [illegible]-BC was learned earlier than [illegible]-BV but both were learned much faster than B had been.

4. Comparison of the constant and variable groups in the same maze:

		Median Time		Perfect Runs		Median Errors	
		C	V	C	V	C	V
Maze [illegible]-BC							
Trial	1.	340.0	319.0	0	0	20	19
	10.	8.2	8.0	11	7	0	0
	20.	6.4	8.0	13	10	0	0
	30.	7.3	7.1	12	11	0	0
[illegible]-BC reversed							
	11.	16.0	10.4	1	8	2	0
	31.	18.8	8.2	2	10	2	0

The group trained in the variable maze was only slightly inferior in accuracy and approximately equal in performance time to the constant pattern group when tested in the constant maze. It was markedly superior in other mazes involving the common principle.

Summary

Two comparable groups of rats were trained in two mazes constructed of the same sections and on the same [illegible]-B visual principle. When the groups

were compared in the constant pattern maze the animals trained in that maze were somewhat superior in accuracy. When compared in mazes of other patterns the group trained in the variable pattern maze was markedly superior.

The group trained in the constant pattern maze fulfilled the 3-4 criterion of learning at the 7th trial, the variable maze group at the 10th.

Conclusions

1. In spite of a considerable difference in incidence of wrong choices on the first trial, there appears to be no significant difference in the difficulty of mazes constructed on light and dark path principles.

2. A pure visual discrimination maze with a variable pattern is only slightly more difficult to run accurately than a constant pattern maze constructed of the same units; and the individual runs are made in approximately the same time.

3. Animals in the V-BC maze depended partly on visual discrimination and partly on pattern. This was true to a lesser degree in the V-BV maze*

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* For a more complete account of this experiment see the appendix.

Experiment 3

In the previous experiments mazes constructed on simple visual principles were learned in from one-third to one-sixth the number of trials necessary to learn standard mazes of the same pattern.

Will the same ease of learning be found in mazes constructed on parsimonious spatial principles?

Procedure

9 animals were trained in a ten section maze of LLLLLLLLL pattern; that is, the correct path is always to the left.

Results

1. The criterion of learning (3-4) was satisfied at the 6th trial. The range of the group was from 4 to 6, with no animal making an error after the third trial.

2. Even on the first trial no errors were made beyond the 7th section.

Discussion

The median trials required for learning are quite closely in line with those required for learning mazes of the same length and number of turns constructed on simple visual principles. (Exp. 1, 2) The extreme shortness of the range, however, is interesting in view of the findings of Krechevsky (5) that rats show somewhat greater readiness to adopt spatial than visual hypotheses.

Experiment 4

The distinction between 'principle' and 'perceptual difficulty' as determinants of the degree of difficulty of mechanically equivalent tasks does not mean that they are to be thought of as independent of or unrelated to one another. We have already seen in Experiment 4, Section 1, that the mode of attack upon a problem is largely dependent upon the phenomenological character of the task. Subjects using one principle of solution while experiencing a problem as an exercise in addition and subtraction, suddenly shifted to other principles when they perceived the task as the finding of series of identical digit triads. In such a case the chances of any one 'principle' being used at all depend upon the perceptual difficulties of applying it.

To illustrate the point let us consider the mazes RLLLLLLLLL (R1-L9) and LLLLLLLLR (L9-R1). Both are the same length and contain the same number of right and left turns. To a human subject the simplest adequate directions are "around the corner and keep to the left", and "nine sections left and then right". The difference is not in the parsimony of the statements but in the perceptual difficulties of carrying them into effect. The first involves the perceptual differentiation of the maze into two parts; the second demands its differentiation into ten sections, the first nine individually distinguished from one another by the verbal designations 'one', 'two' .... 'nine'.

Since the differentiation necessary for the derivation and use of the principle adequate for performance of R1-L9 should be possible in less time than the more complete differentiation necessary for the solution of L9-R1, (6) it should be expected that human subjects will learn the former maze more quickly than the latter.

With rats the difference in difficulty between the two mazes would be accentuated since the principle of solution of maze L9-R1 involves a mechanism of verbalization which they cannot command. If the results of Spragg (7) are applicable to this situation, the L9-R1 maze should be practically insoluble by rats. Spragg ran 4 rats for 100 trials in a Dalton U maze of RRRRRRRL pattern and found that none of them were able to master the problem.

Suppose, however, that a visual sign or cue is placed in the entrance to the tenth section of the L9-R1 maze. There is now the possibility of solution by derivation of the principle 'left to the sign, then right'; and, if our postulates are correct, the chances for such a solution will increase with the size or impressiveness of the visual cue.

We now have two mazes, R1-L9 and L9-R1, amenable to solution by what we may designate as principles of the second degree of parsimony (to distinguish them from the unitary principle adequate for maze L10 in the last experiment). Although these two mazes do not differ in parsimony of principle they do differ considerably in the manner in which the principles are applied. In view of the reported tendency of rats to use spatial cues, which will be adequate in R1-L9 and inadequate in L9-R1 (8) we should predict that R1-L9 would be slightly more difficult to master than the more parsimonious L10 and that the difficulty of L9-R1 would vary above this limit with the character of visual cue used.

The experiment was carried out simultaneously with Experiment 3 to allow comparison with the results of L10.

Mazes

L9-1, no apparent differential visual cues except a piece of white crayon laid in the entrance to the blind alley in section 10.

R1-L9, no apparent differential visual cues.

Subjects

9 white rats chosen by lot simultaneously with the animals used in the previous experiment were run in each maze. Unfortunately one of the animals in L9-R1 died early in the experiment so the results of this group are of 8 animals.

Procedure

The amount of crayon placed in maze L9-R1 was varied beginning with the 31st trial.

Results

	Trial Learned	Range	Percent Learning	Best Time	Trials Run
L10	6	4-6	100	6.8 (6)	10
R1-L9	6	5-18	100	6.3 (8)	20
L9-R1	41	24-69	100	7.3 (54)	80

1. Since R1-L9 was learned in a median of 6 trials with a range of 5 to 18 and L10 in 6 with a range of 4 to 6, the difficulty of R1-L9 was, as had been expected, only slightly greater than that of L10. Both approximated in difficulty the unitary visual principle mazes investigated in the earlier experiments.

2. L9-R1 was learned more slowly and was never run with any degree of reliability by any animal. Although all animals passed the criterion of 3 perfect runs out of 4 consecutive trials, none passed a 9 out of 10 criterion.

3. During the first 30 trials in 19-1 the percent of perfect runs for each five trials was 12, 2, 5, 18, 25, and 12. The number of pieces of crayon in the cue position was then increased to 10 and the percentage of errorless runs rose to 28, 38, 43, 53, and 60. In the succeeding runs one piece of crayon was removed at the end of each run. During this period the perfect runs stood at 50 and 55%. The precentage did not fall at once upon the exhaustion of the crayon, for the percentage on the next five trials was 57%. It then dropped to 28 and 25%, at which point the experiment was discontinued.

Experiment 5a

In the previous experiment, in which two mazes amenable to solution by equally parsimonious principles were tested by comparable groups of white rats, one maze proved decidedly more difficult to master than the other. On the basis of our hypothesis such a difference must be accounted for by the perceptual difficulties of discovering or applying the postulated parsimonious principle. If this is true there are two ways in which it should be possible to teach the difficult L9-R1 so that it might be learned in as short a time as the 'easy' maze R1-L9.

The possible methods of decreasing the difficulty of the perceptual task are: (a) Increase the size or vividness of the feature of the situation whose perception is necessary to solution. And (b) train the learners in other situations where the perception and recognition of similar signs are necessary.

Due largely to the accident that the only animals immediately available in the laboratory were four young rats who had been used in a motion picture demonstration of the B- maze described in Experiment 1, both methods were used in the present experiment. These animals had run from one to five trials in the B- maze whose principle was 'avoid the white'. The maze now used was the L9-R1 pattern, as used in Experiment 4, except that the last blind alley was painted white as in the visual mazes reported in Experiments 1 and 2.

Results

This maze was learned in 6 trials with a range of 4 to 6.

Conclusions

The greater difficulty of maze L9-R1 in the previous experiment when it was learned only after 41 trials, as against 6 in the present experiment, was due to lack of perceptual prominence of the essential cues.

Experiment 5b

Was the performance of the animals who learned the L9-1 maze so readily based upon the pattern or the principle of the maze? Although the rapidity of learning is almost enough to dispose of the first possibility without comment the question was answered by running the animals in an L10-1 maze on the 7th trial and in an L8-1 maze on the 8th. In both cases the last section had a white blind alley. All 4 subjects ran the maze without error in each case.

Changes in the spatial character of the maze did not interfere with performance so long as the principle on which the maze was constructed remained unchanged.

Experiment 5c

It does not necessarily follow, however, that the principle used by the teacher in planning a problem is the one used by the pupil in solving it. This lesson, learned in Experiment 3, Section 1, was again impressed upon the experimenter by the behaviour of the animals in the maze L8-R2 in which they were placed at the next trial. This maze, in which the ninth section had the white blind alley, was constructed by the experimenter on the principle, 'correct path to the left, then right at the white section'. If the animals had derived this principle they should have run the L8-R2 maze without error. Only one of the animals was able to do this; the other three turned left again at the tenth section. Two of these pushed and clawed at the door at the end of this blind alley for several seconds in a manner eloquent of confidence in the correctness of their choice. Their behaviour conformed to the

principle 'left but stay off the white', which would have been quite adequate for all the mazes they had run up to that point.

After further training in the 18-22 maze, in which the criteria of learning were satisfied in 5, 13, and 14 trials by the three animals who had erred on the first run, three of the four animals ran the maze 14-23, also constructed on the 'left to white, then right' principle, on the first trial. The animal who had run the 18-22 pattern without error from the first trial was the one who made the only mistake.

At this point the group had made 20 runs in five maze patterns all based on the principle 'left to the white, then right.' This principle also governed the construction of the maze with the crayon cue, used in the experiment 4 maze. When the rats used in the present experiment were placed in the experiment 4 maze (14-1) all made errorless runs on the first trial, their 24th in mazes constructed on this 'left-sign-right' principle. In the same evening only 3 of the 8 animals in the Experiment 4 group, then in their 43rd trial in this maze, made errorless runs.

In spite of this successful run on the first trial the 4 animals were not able to repeat it on the next. The difference in the character of cue used at the crucial section thus had its effect, not on the first but on the following trials. The performance of these animals fell to the approximate level of the Experiment 4 group, already reported, and it was not until 20 trials later that the initial record of 100% perfect runs was equalled.

Summary

Four rats were run in mazes, all constructed as follows: the correct choice was always to the left until a white surface was encountered.

from there the correct choices were to the right.

After mastering an L9-R1 pattern all the animals were able to run L10-R1 and L8-R1 mazes without error on the first trial.

One of the four was able to run an L8-R2 maze without error on the first trial.

After mastering the L8-R2 maze, three of the four ran an L8-R3 maze without error on the first trial. All were then able to run without error an L9-R1 maze in which the cue for a change in direction was a pile of white crayon instead of the white surface. This performance, made on the first trial, was markedly superior to that of animals who had been trained in the test maze, and to their own performance in subsequent trials in the same maze.

Section II

Summary

Eight comparable groups of white rats were trained in one or more ten-section Warden U mazes. With three errorless runs in four consecutive trials as the criterion of learning, mazes constructed on simple visual or spatial principles were learned in only 17% to 29% as many trials as the standard maze of the same number of sections.

1. Mazes in which the correct pathway was lighter or darker than the blind alleys were learned in 7 trials as against the 34 trials required for the standard maze of the same pattern. Ex. 1, 2.

2. A variable pattern maze constructed on the simple 'light pathway' principle was learned in 10 trials. Ex. 2.

3. The maze constructed on a parsimonious 'all left' principle was learned in 6 trials with a range of 4 to 6, while the RLLLLLLLL 'right, left' principle maze was learned in 6 trials with a range of 5 to 18. Ex. 3, 4.

4. A putatively insoluble maze (LLLLLLLLR) was learned in 41 trials when crayon was placed in the entrance to the last blind alley; and in 6 trials when the last blind alley was painted white. Ex. 4, 5.

5. When a group of animals were trained in five mazes constructed on the principle 'left to the white blind alley, then right' the behaviour in each new maze was in accordance with principles which would have been adequate for the solution of all the mazes run up to that time. Ex. 5b.

6. Animals trained in a number of mazes constructed on the same principle were much more successful in running other mazes constructed on that principle than were animals whose training had been confined to one maze. Ex. 6.

Conclusions

The hypothesis that the relative difficulty of two comparable tasks is determined by the degree of parsimony of the principles used in their performance and by the perceptual difficulties involved in the application of the principles is adequate for the prediction of the relative difficulty of the eight mazes investigated. As applied to mazes of equal length and number of choices it may be stated: the relative difficulty of two maze patterns composed of spatially equivalent units is determined by the number of changes in procedure necessary for errorless performance and by the perceptual prominence of the cues which indicate where the procedure must be changed.

This principle is not only adequate to explain differences in the number of trials required to run our own mazes but is very well illustrated by the results of Montpellier (9). His mazes in which the correct choice was always to the right, falling under our classification of the most parsimonious principle, were learned in 7.5, 5.6, and 8.0 trials respectively. His maze 1, involving a shift in procedure from simple to double alternation, required more than 15 trials with the most frequent errors occurring in the section where the change in procedure was necessary.

A decreasing incidence of error as the goal was approached in the simple principle mazes is cited by Montpellier as evidence for the goal gradient hypothesis. We would rather regard it as due to the selection by some of the animals of an adequate procedure before the latter sections are reached even for the first time. In our [illegible] maze the errors made at the successive sections on the first trial were:

Section	1	2	3	4	5	6	7	8	9	10
Errors	5	2	2	5	2	4	2	0	0	0

there is not only a decrease in the incidence of error choices as the goal was approached for the first time, but in the last three sections the correct choice was made on the first attempt by every one of the 9 rats in the group. The animals, in exploring the earlier section of the maze, selected procedures which enabled them to make the correct choices in the last three sections the first time these sections were entered. Since these animals had never reached the food-box the phenomenon is not backward elimination or food-box conditioning. It is rather analogous to the forward determination found by Rees (10) in the reproduction of narrative material by school children, in which the function of each successive item of the original was limited and defined by the tenor of the preceding items. Just as the possibilities of the narrative were increasingly limited and defined by each new item, the possibilities of the maze were narrowed by each successive section until every animal had selected an adequate procedure.

In general, those mazes where the adequate procedure might be based on the general character or principle of the maze were learned much faster than those where the performance must be pertinent to individuated features of the maze.

General Conclusions

1. The diversity of difficulty among mechanically equivalent tasks is concomitant with phenomenological differences among the tasks. Tasks experienced as equivalent are performed with equal facility; tasks experienced as different are performed in different times.

2. The degrees of difficulty of two mechanically equivalent tasks are in the same relation as their experienced complexity. The relative speed of learning is determined by the experienced simplicity of the procedures required for performance and by their perceptual practicability.

3. When an individual, rat or human, is confronted with a task, he shows an activity which might be described as the selection of a procedure for its performance.

4. The general procedure he adopts is determined by his initial perception of the nature of the problem; it is a gross response to a relatively undifferentiated situation. Problems experienced as similar are attacked by similar procedures. In the present investigation, the tasks constructed upon simple parsimonious principles, and thus amenable to performance by these immediate responses to the grosser aspects of the problem, were mastered in a fraction of the time required for the learning of tasks whose performance necessitated behaviour specific to various segments of the situation.

5. Should the first procedure, the response to the gross situation, prove inadequate, the task is differentiated perceptually into segments each of which may be solved by simple procedures. The greater the number of sub-problems into which the task must be differentiated and the greater the difficulties of this differentiation, the longer will be the time required for mastery.

General Summary

This study describes an investigation of some of the factors underlying differences in difficulty between tasks involving the same or equivalent motor behaviour. The method involves the comparison of such mechanically equivalent tasks in terms of the time required for performance or the number of repetitions required for learning.

In the first of a series of preliminary experiments with human subjects it was found that differences in performance time between such tasks were associated with the ways the tasks were experienced by the performer. When they were experienced as similar tasks they tended to be performed in equal times. School children who recognized rote material as verse were able to reproduce more than twice as much in delayed recall as did children to whom it was nonsense material. The time required by graduate students for solution of number series completion problems likewise proved to be determined by the individual's concept of the nature of the task.

In a search for more definite knowledge of this relationship between the subject's experience of the task and the time he requires for its performance, eighty-eight university students were asked to perform each of three different cancellation tasks, all of which required the cancellation of the same number of symbols from the same paragraph of material. Under these circumstances the task which could be performed by following the simple principle 'cancel all curved lines' was performed by the subjects who discovered the principle in only half the time they required for performing the other tasks, which were mechanically equivalent but experientially more complex. Even after ninety trials over an interval of two months, this 'curves' task was performed on the average 25% faster than another

task in which only one symbol was different. In a general comparison of similar cancellation tasks it appeared that their relative difficulty was determined by the parsimony of the principles necessary for performance and the perceptual practicability of those principles.

This hypothesis proved adequate for the accurate prediction of the relative difficulty to white rats of various patterns of ten section Warden 3 mazes. Those of the eight mazes tested which were constructed on simple visual or spatial principles as 'correct path always white' or 'true pathway always to the left', which were thus open to performance by a single procedure, were 'learned' by the animals in from 6 to 10 trials, in contrast to the 34 and 45 trials required by two groups to 'learn' the standard LRRRLLRLLR maze of the same length and number of turns. Another maze, supposedly insoluble by rats, was learned in 41 trials when a visual cue was placed in the proper section; and was learned by another group in 6 trials when the perceptual prominence of the cue was increased. As in the cancellation tests by human subjects, tasks requiring two procedures for performance were intermediate in difficulty to single and multiple procedure tasks.

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A P P E N D I X

1. The Perceptual Character of Maze Learning

In the main body of this thesis it was suggested that maze learning is dependent upon the perceptual differentiation of the maze into such segments as are individually amenable to solution by simple, parsimonious methods of procedure. While the evidence given at the time is adequate justification for the conclusion, it appears desirable to report the corroborative data, which is so extensive that its inclusion in the original report was inadvisable.

As previously reported, two comparable groups of white rats were trained, Group I in a standard Lashley-Warden U maze (Maze B) and Group II in a spatially identical maze in which the blind alleys were painted white (Maze B-W). After 45 trials the two groups were shifted to the other maze, Group I to B-W, Group II to B.

In view of the time honored (1), although often challenged (2) (3) (4) theory, that rats "turn to kinaesthetic cues and habits once the maze has been mastered" (4), the performance of Group II in their first trial in the B maze was watched with unusual interest. These animals had run 45 times in the spatially identical B-W maze, an average of 38 trials of over-learning. During their last 25 trials they had been correct in 99.6% of their choices. If there is any tendency for relegation to kinaesthetic cues to take place it should be manifest in such a group. In any case where the animal had turned completely to such cues in the B-W maze it does not seem illogical to expect a perfect performance in the first attempt at maze B.

Of the 13 animals, one (M22) did make such an errorless run although even he showed a marked rise in performance time. The other animals

made from 4 to 26 errors each. It must be considered that the performance of M22, in a room where the extra-maze stimuli were unfamiliar, can indicate nothing but dependence upon the common feature of both mazes, their spatial pattern. There still remained the possibility that the other animals may have been prevented from using the same method by distracting features of the new situation. If so, they should have made a rapid improvement to errorless performance as soon as they became accustomed to the new conditions. This did not occur. The median trial at which they learned the B maze was the 45th; while the untrained group 1 had met the same criterion at the 34th trial. This would indicate that 12 out of 13 rats could not run correctly an identical maze pattern under different sensory conditions, even after considerable overlearning.

However, animal M22 had obviously responded to pattern or he would not have been able to run maze B without error on his first trial. It is not necessary to assume, however, that such response to maze pattern implies kinaesthetic control or that it is the final stage in learning. At the 40th trial in maze B the first and second sections of the maze were interchanged. At that point M22 had made 73 consecutive errorless runs, 34 in B-A and 39 in maze B. If the performance were controlled by kinaesthesis the shift of the two sections would have had no effect. If the performance were controlled in the same way as it had been on his first trip through the maze the shift would have had no effect. In following the correct path in this LRRRLLRLLR maze the first turn is to the left and the second to the right. When the starting box door was lifted the animal, after having turned left at this point for 73 consecutive trials, now turned right, making the response

appropriate to section 2 in its former position. The turn was made without hesitation and carried the animal well around to the end of the alley. He then turned, went to the entrance to the next section and there made the response appropriate to its former position, a left turn. The rest of the run was made without error. Of the 13 animals in the group 6 made errors in the shifted sections on this run although none had erred in this part of the maze during the preceding 8 trials. In addition one other animal who previously made errorless runs made three errors farther on in the maze. One animal made a perfect run in spite of the change. The other 5 animals unaffected by the shift had failed to learn the maze.

The implications of these results are plain. An animal formerly able to run the maze without differential sectional cues other than possible proprioceptive ones had come to rely upon localized cues in his performance. The animals able to run the shifted sections without error were, with one exception, animals who had failed to learn the maze. In this case maze learning appears to be closely associated with the increasing differentiation of the various sections. Complete differentiation to the point where the individual sections are clearly distinguished is not necessary in this maze but the tendency is for the differentiation process to continue to this point.

This view of maze learning as perceptual differentiation is in full agreement with the findings of Perrin, (5) in his excellent investigation of maze learning by human subjects. He reports "Two chronological stages were in evidence in the conscious part of the learning. The subject was guided in the first few trials by a general scheme of direction, gained when the exit was reached for the first time. He then found that in order to perfect his route a number of separate segments, presenting special problems, must be studied." (ibid p. 95)

here the gross differentiation of general direction ferrin gives as the first stage is adequate for perfect performance, as in the LLLLLLLLL maze reported in the thesis proper (p. 45), errorless performances were made almost at once. Of the 9 rats trained in this maze, 2 made no errors after the first trial and no animal entered a blind alley after the third trial. The mazes in which the correct path was differentiated by shade from the blind alleys so that the maze could be run by the perception of the general white or black path without specific recognition of any section or turn were also run perfectly by some animals on the second trial, and by the majority on the third or fourth.

In standard mazes, as B, more complete differentiation would be necessary; recognition of each turn or at least of those turns where a change of sequence takes place. Thus in the B maze:

L	R	R	R	L	L	R	L	L	R
1	2	3	4	5	6	7	8	9	10

these critical turns would be at sections 2,5,7,8, and 10. Once the animal has become aware of a goal and its general direction from the starting box the maze must be further differentiated into five segments or sub-problems, each one having for its immediate goal the finding of a critical section. Results published by Spragg (6) indicate that when such a critical turn is successfully made there is an abrupt decrease in errors in the immediately following sections. The animal has by the successful completion of one sub-task gotten a fresh start for the next.

In any maze the differentiation of the goal out of the situation is indicated by the tremendous drop in performance time of the second trial as compared with the first. The early discovery of the general direction

of the food box is evidenced in uni-directional mazes by the rapid drop in retraces, retracing being rarely found after the fifth or sixth trial (7).

A table of the distribution of errors made in the various sections of maze 9 strikingly shows the progressive differentiation into sub-mazes postulated above.

Errors Per Section, Maze 9.

	Trial	L 1	R 2	R 3	R 4	L 5	L 6	R 7	L 8	L 9	R 10	Total
Group I	2	4	9	3	3	5	4	7	6	7	7	55
	12	2	2	2	4	2	2	4	4	4	3	33
	22	1			6	1				2		10
	32	1			6	2	2	2	1	4		18
	45	1			5					2		8
Group II	2	4	3		3	3	1	6	6	7	6	39
	12		1		9		5	5	2	11	4	37
	22	1			3	1	6	3	2	6		22
	32	1	1		5	3		4		7		21
	45	1			5		1	4		4		15

The inadequacy of any view of maze learning as mechanical elimination of errors is at once evident. Some errors are not eliminated. In both groups more errors were made in section 4 on the 45th trial than on the 2nd trial in spite of the fact that errors on the 45th trial were made by only half as many animals.

Combining the error scores of the two groups for the 45th trial we find that all of the 23 errors were entrances into the blind alleys immediately preceding the 'crucial' sections 2,5,7,8, and 10:

Section	1	2	3	4	5	6	7	8	9	10
Turn	L	R	R	R	L	L	R	L	L	R
Errors		2		10		1	4		6	

Husband (7) found that section 4 presents the greatest difficulty to both rat and human subjects and believes, as does Spragg (8), that such

| | | |

errors are due to anticipation of the change in sequence.

The close association of the errors with the postulated crucial sections becomes much more significant when we consider the results obtained by Dennis in his investigation of the proprioceptive ability of white rats. Dennis (9) trained rats to run on a smooth surface from a starting box to a ladder six feet away. The rats were then blinded and, running under supposedly proprioceptive control, made an average error of 20% in distance, tending to stop and circle before reaching their objective. The type of error made in our maze is, then, exactly the type which would be made by rats seeking the crucial turns by means of proprioceptive cues. The tendency is to under-run the objective and the greatest percentage of error is made in the section where this would lead us to expect it, the section ending the longest directional sequence.

The greater tendency to enter the sections just preceding the critical one is the result of a perceptual differentiation of the problem, and is not in evidence in the early runs. In Group 1 only 45% of the errors on the 2nd run were made in such sections; but on the 22nd trial 90% of the errors were in such positions; and on the 45th trial 100%. The corresponding percentages for Group II are 54%, 87%, and 100%.

The same indications that the animals have differentiated the maze into five or more sub-tasks is to be found in the record of errors made by seventeen animals on the last run in which they made errors:

Section	1	2	3	4	5	6	7	8	9	10	Total
Errors	4		1	9		6	3	1	8		29

27 of the 29 errors are made just before the 'critical' sections. This grouping suggests that the differentiation into sub-problems is an

essential part of the process of learning the maze. Once this is done the maze can be run without error by the further differentiation of the crucial sections 2, 5, 7, 8, and 10 to the point where they are recognized by definite cues. That these cues may be proprioceptive is shown by the success of some animals in negotiating the maze when the sections had been shifted. In addition to the performances of the two animals in Group II already mentioned, one animal in Group 1 was able to run the maze when it had been shifted, six weeks after his last practice. The evidence is quite definite, however, that the best performers came to recognize the critical sections by exteroceptive cues. Of the animals undisturbed by the shift of sections 1 and 2, mentioned above, only one animal had learned the maze. Animal F20, the most dependable of Group 1, made 25 consecutive perfect runs in maze B, and then 45 errorless runs in maze B-F. When she was tested two weeks later in the B maze with sections shifted she made 7 errors. Her training was continued for a motion picture demonstration and she made errors at sections 4 and 9 in each of the three trials. Another animal used in the demonstration performed in similar fashion. The perceptual differentiation of the individual sections being no longer effective because of the shift, the animals fell back on the antecedent sub-maze differentiation.

If the chief difficulty of maze learning is, as this leads us to suppose, the perceptual differentiation of the critical turns, any cues placed in them will accelerate the learning. Spragg (8) ran 4 rats in a Dalton U [illegible] pattern and found that none of them learned in 100 trials. In the last five trials 12 of the 15 errors were made just before the crucial last section. To investigate the effect of visual cues we placed white crayon in the tenth section of a Warden U maze LLLLLLLLR. All of the 8 rats used had fulfilled the criterion of learning (3 perfect runs out of 4 trials) by the 69th

trial. When the cue was emphasized by placing a section having a white blind alley in the crucial position all 4 of the rats tested learned within 6 trials.

Summary and Conclusions

Analysis of learning and errors in several maze experiments indicates that maze learning is a process of increasing differentiation from the total situation during which the maze is first perceived as a general path to the food-box and is then differentiated into sub-mazes whose solution is dependent upon the further differentiation from one another of their component sections or turns. This hypothesis is supported by the fact that mazes, so constructed that the final complete differentiation of parts is either aided or is unnecessary, are learned much more easily than standard mazes of the same length and number of turns. We have already shown in the main body of the thesis that when the adequate response may be made, not to the individuated parts of a situation but to a general feature or principle of the task, learning takes place much faster than when the individuated response is required. The implication is that the less complete individuation is prior in learning, as it is in perception (10).

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