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Cognitive Processes and Stimulus-Response Mappings

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SUMMARY

The primary objective of the proposed research was to investigate the effects on learning of various stimulus-response (S-R) mapping schemes. It was hypothesized that S-R connections are not simply arbitrary, that the way stimulus and response classes are mapped together may have a profound effect on learning rate. To study this problem, two paradigms based on discrimination learning procedures were constructed.

The first paradigm made possible <u>qualitative</u> variations in mapping via the study of one-one, many-one, and one-many S-R connections -- while holding constant across conditions the number of required associations. Selected possible outcomes were theoretically related to type of mapping variation and the development of cognitive processes with age. The results obtained were puzzling. One order of difficulty was found for age 12 and another for age 14. The theorizing engaged in was not capable of handling such a result.

The results of the second study are more intelligible. The paradigm used in this study made possible the <u>quantitative</u> variation of S-R mapping on an order-disorder dimension. (In less technical language, this is equivalent to numerically varying the number of exceptions to a classification rule.) The results indicated that one degree of mapping disorder (one exception) produced about the same number of errors as a completely irregular mapping. But the difference between one degree of mapping disorder and zero degrees of mapping disorder (a classification rule with no exceptions) was extremely large: the task was trivial when there were no exceptions and it became quite difficult with only one exception. A theory based on hypothesis sampling and generation was put forth to explain the observed results.

INTRODUCTION

<u>The S-R Mapping Problem</u>

Stimulus-response (S-R) connections, or mappings, bulk large in contemporary psychology, both experimentally and theoretically, but surprisingly little is known about the relation between various mappings and learning efficiency. A few examples will help make clear the nature and depth of the problem.

Fries (1963) and Gibson (1963) have pointed out that one of the difficulties inherent in learning to read the English language resides in the irregular mapping relations that occur between the printed alphabet letters (stimuli) and the phonemes of spoken utterances (responses). The printed words "red", "$read_1$", "$read_2$", and "reed" illustrate this nicely. "Red" is a printed symbol for a color, and "$read_1$" is a printed symbol for what <u>has</u> been done with a book. They are different stimuli but they have the same spoken response. In contrast "$read_2$" is a symbol for what <u>will</u> be done with a book, and therefore "$read_1$" and "$read_2$" are identical stimuli, but they call for different responses. To further complicate matters, "reed" combines with "$read_2$" to give another instance of different stimuli having the same response. In practice of course, experienced readers suffer little from the effects of such mapping irregularity because they are sensitive to the context. But beginning readers are not likely to be so fortunate. It is for this reason that phonemic alphabets, like augmented Roman (Downing, 1965), are of great potential importance: they allow the beginning reader to work with a one-one regular mapping between written and spoken forms before transfering him to the irregular mappings that exist between the written and spoken forms of a natural language like English.

Another example concerns the problem of machine translation of language (say, Russian to English) and the problem of second language learning. Lamb (1965) points out that there exists no simple one-one mapping between words in one language and words in another. If there were such a mapping, the problem of machine translation would be ridiculously easy. All that would be needed is a computor with fairly large memory storage and a concordance between the "source" language (e.g. Russian) and the "target" language (e.g. English). Also in this particular case since the mapping is one-one the procedure is completely reversible. As Lamb claims, there is obviously no one-one mapping between languages at the level of <u>words</u>, or perhaps at any other level. For a machine translation to be adequate, it must take into account language structure as well as individual units, and any talk of structure would have to deal with at least constituent analysis (Gleason, 1961) and transformations (Chomsky, 1957). At these more abstract levels of analysis it is still not too likely that very many one-one mappings can be found between a source language and a target language. In any case one-one mappings are not necessary: many-one mappings will be perfectly adequate. The problems arise when one-many relations are found at some level of analysis; additional machinery is required to sort out which of the "many" is most appropriate.

Now it is possible to consider second language learning, at least in its initial stages, as human translation between one language and another. If this argument is accepted, it is at once clear that one-one, many-one, and one-many mappings and their associated problems apply to second language learning just as surely as they do to machine translation.

A final detailed example of an experimental nature will suffice to show the magnitude of effects attributable to mapping differences. Goldstein and Weber (1965) used the old Lashley (1938) conditional discrimination paradigm as a point of departure. There were four displays: x/ab, x/ba, y/ab, y/ba. Each display had three highly distinctive nonsense forms on it. The two elements 'a' and 'b' were arrayed horizontally on the display and were offered as alternatives for choice. The third element, either 'x' or 'y', appeared at the top of the display and was a symbol or cue determining the correct choice. In other words, the correct response was made conditional on the particular cue item present in the display. For one group whenever cue item 'x' was present 'a' was the correct or reinforced choice, irrespective of the position of 'a', left or right, in the display. Whenever cue item 'y' was present 'b' was the correct choice, again irrespective of the position of 'b'. Hence in this group a particular cue form was made to correspond to a particular response form. But in another group, position of the response rather than its form was the relevant feature. Thus in the presence of cue 'x' the left hand response element (irrespective of whether it was 'a' or 'b') was the correct choice; and in the presence of cue 'y' the right hand element (again irrespective of its form) was correct. Striking differences in learning occurred under these two schemes of cue-response mapping. When the correct response was based on mapping form-to-form the task was trivially easy for Ss (everyone of the high school Ss learned, and mean errors to a 20-errorless-trial criterion was 3.7). But when the correct choice was based on a form-to-position mapping, the task became quite difficult (3 out of 10 Ss failed to learn in 1280 trials; and mean errors to criterion for the 7 learners was 45.1). Now both groups of Ss saw exactly the same displays in exactly the same order; the sole difference in treatment for the two groups resided in the way cue-response mappings were set up. In the easy case the mapping was based on form-form pairing and in the difficult case on a form-position pairing.

For various reasons involving the impossibility of strictly orthogonal comparisons and the impossibility of numerical variation in degree of S-R mapping, the Goldstein and Weber experiment and procedure is not ideal for the systematic study of S-R mapping. (And such was not its intention). Nonetheless it indicates that the way correct responses and their corresponding stimuli "dovetail" or "map" together can have a potent effect on ease of learning.

There are, of course, other relevant references, and they would include the following: Fitts and Seeger (1953), Shaffer (1965), Weber (1965), and Weber and Woodward (1966).

The following two experimental paradigms serve to make more precise the notion of S-R mapping and supply needed detail on the research conducted.

EXPERIMENT I

One-one, Many-one, and One-many S-R Mappings

A study was made of effects on acquisition due to various S-R mappings. A one-one mapping means that for each stimulus or cue item there is one, and only one, corresponding correct response item; conversely, each correct response is conditional on one, and only one, cue item. An example of this is the standard paired associate task in which number of cue items and number of response items are equinumerous. A many-one mapping means that several different cue items correspond to a single correct response. An example of this is afforded by the paired associate work of Bower (1961) in which there was a total of ten different stimulus items corresponding to only two different response items. A one-many mapping means that each stimulus item corresponds to several correct response items. Examples of this mapping in the paired associate literature are difficult to find. About the closest approximation is Osgood's (1949) transfer paradigm in which Ss first learn S_1-R_1 and then S_1-R_2. But this transfer task is probably not directly relevant here because the present task does not involve transfer, and by using discrimination learning techniques Ss need only recognize rather than recall a correct choice. The recognition task means that E can specify on each trial the response options available to S. It is thus possible to have a pure one-many task when discrimination procedures are used. This is in contrast to the paired associate procedure in which 2 or more recall responses correspond to a single cue item: in this case S can thwart our experimental manipulations by using only one of the responses and thereby collapsing the task to a simple one-one mapping. Discrimination procedures also have the advantage of enabling one to hold constant the minimum number of required associations among the various types of S-R mapping. This will be made more clear in the Method section.

Method

Subjects. Two age groups, 12 year olds and 14 year olds, were employed. They were randomly assigned to conditions, 10 per group, for 6 groups giving a total of N=72.

Design and Procedure. Table 1, illustrates the experimental design. Letters of the alphabet serve to represent distinctive visual nonsense forms (Goldstein and Weber, 1965). Each display contains one cue item (w,x,y, or z) at the top of the displays and two response items (a,b, and/or c,d -- depending on the group) at the bottom of the display (Goldstein and Weber, 1965). For group 1-1 there is a one-one mapping between cue items and correct response items (correct choices are represented by underlining in Table 1). In other words each cue item has associated with it one and only one correct choice, and each correct response has associated with it one and only one cue item. For group M-1 there is a many-one mapping between cue items and correct response items; several (two) cue items are associated with each response item. Finally for group 1-M there is a one-many mapping between cue and response items; each cue item is associated with several (two) correct response items. It is important to note that the number (four) of distinct associations between cue and response items is constant across the various mapping conditions; hence number of associations is not confounded with type of mapping. However, there is a partial confounding between mapping type and number of distinct visual forms as denoted by letters of the alphabet. This number is eight for group 1-1 and six each for groups M-1 and 1-M, and it is reflected by the different uncertainty values at the bottom of Table 1.

The eight displays of each mapping condition appeared in successive randomized blocks. The displays were on 4- X 6-in. cards. S responded by pointing to one or the other of the two choice items. E provided reinforcement by saying "Right" or "Wrong". A noncorrection procedure was employed. Data consisted of error scores.

TABLE 1

Display Content and Reinforcement Assignment[a]

Mapping Scheme		1 - 1	M - 1	1 - M
		w/$\underline{a}$ b	w/$\underline{a}$ b	w/$\underline{a}$ b
		w/b $\underline{a}$	w/b $\underline{a}$	w/b $\underline{a}$
		x/a $\underline{b}$	x/a $\underline{b}$	x/a $\underline{b}$
		x/$\underline{b}$ a	x/$\underline{b}$ a	x/$\underline{b}$ a
		y/$\underline{c}$ d	y/$\underline{a}$ b	w/$\underline{c}$ d
		y/d $\underline{c}$	y/b $\underline{a}$	w/d $\underline{c}$
		z/c $\underline{d}$	z/a $\underline{b}$	x/c $\underline{d}$
		z/$\underline{d}$ c	z/$\underline{b}$ a	x/$\underline{d}$ c
Uncertainty in Bits	Cue Items	2	2	1
	Response Items	2	1	2
	Cue and Response Items	3	2.58	2.58

[a]Note: Underlining is employed to schematically indicate correct choices.

RESULTS

The major results are presented in the following Table. Taking the Mean error score per $\underline{S}$ as a point of departure we note that for Age 12 Group Many-one is least difficult (32.0 errors) and Group One-many the most difficult (53.2 errors). This result corresponds to what will be termed the "transfer surface hypothesis" in the Discussion section. The result makes good sense until the findings for Age 14 are considered.

For Age 14 all groups are essentially equivalent in Mean errors, ranging from 34.3 to 39.0. This result corresponds to what will be termed the "equality hypothesis" and also makes sense theoretically. There seems to be an interaction between age and kind of stimulus-response mapping. The type of mapping is an effective variable at age 12 but makes no difference at age 14. This is not difficult to understand; but it is puzzling as to why age 12 should do better on the Many-one condition than age 14, while doing more poorly on the other conditions.

TABLE 2

Descriptive Error Statistics as a Function
of Age and Mapping
(N = 10 per Group)

Mapping	Age	Mean	SD	Mdn
Many-one	12	32.0	21.42	21.0
	14	36.7	17.54	38.5
One-one	12	42.3	17.61	44.5
	14	34.3	16.42	33.0
One-Many	12	53.2	9.83	54.0
	14	39.0	18.04	36.0

Perhaps the most difficult part of making any meaningful interpretations arises from the large variability encountered. This reflects the fact that a number of _Ss_ did not perform at better than a chance level. The standard deviations are correspondingly large.

In terms of statistical effects the large variabilities again complicated matters. An analysis of variance was conducted and neither the main effects (age and type of mapping) nor the interaction produced an _F_ ratio approaching significance at the .05 level.

Discussion

If we use the symbol "x<y" to indicate that group x is less difficult than group y, then at least the following outcomes would possess psychological meaning in the sense that arguments could be adduced for them.

(1) 1-1 < 1-M, M-1. This would be the outcome expected on the basis of the rationale behind the augmented Roman alphabet (Downing, 1965), i.e., learning ought to be better when the S-R mapping is 1-1, as in phoneme-letter matching. We might term this the augmented Roman hypothesis.

(2) 1-M < M-1 < 1-1. An outcome of this form might be expected if _Ss_ were "response bound", that is, _Ss_ are more likely to observe a display item if they are required to respond to it (Lashley, 1938). If this is true, then _Ss_ ought to learn 1-M easier than M-1 because the former has the most uncertainty associated with response items and the latter with cue items. Finally group 1-1 ought to be most difficult

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because its response uncertainty is greater than or equal to that of the other groups, and the uncertainty associated with cue items is also greater than or equal to that of the other groups. What would be particularly interesting here is if there were an interaction with type of mapping and the age variable. Younger Ss might be more "response bound" than older Ss. Weber and Woodward (1966) have, for example, found that college students are quite proficient in observational learning of complex discrimination problems. In short, younger Ss might show the order of difficulty 1-M < M-1 < 1-1, while older Ss would display some other order of difficulty, because they extract information from displays irrespective of whether they respond to a particular item or not. Hypothesis (2) will be termed the "response bound" hypothesis.

(3) M-1 < 1-1 < 1-M. An outcome of this form would be expected if Osgood's (1949) transfer surface were somehow applicable. As pointed out in the introductory section of Experiment I, the applicability of the transfer surface is not at all clear cut. If it were, then we would expect group 1-M to be most difficult because, learning a list $S_1 - R_1$ and then transfering to a list $S_1 - R_2$ often produces negative transfer. Similarly, group M-1 ought to be easiest because $S_1 - R_1$ followed by $S_2 - R_1$ often produces positive transfer, and group 1-1 ought to be intermediate because the learning of $S_1 - R_1$ followed by $S_2 - R_2$ would be the control condition for assessing whether positive or negative transfer occurred in the other groups. This is the transfer surface hypothesis.

(4) 1-1 = M-1 = 1-M. It is entirely possible that all groups would be of equal difficulty. This might be because the mapping variable as proposed here might be too easy and lead to a ceiling effect in which all Ss readily learn. It is for this reason and others, that two different age groups were used. The ceiling effect might very well occur in the older age group but not in the younger: there might be an interaction effect between the two main effects, type of mapping and age of Ss. This is the equality hypothesis.

The results suggest that the transfer surface hypothesis would somehow be applicable for age 12, while the equality hypothesis would be most applicable at age 14. But in the absence of statistically significant effects these conclusions must be very tentative.

EXPERIMENT II

Numerically Varied S-R Mapping Disorder

Only a brief account of this study is given since it proved publishable and reprints are attached.

Mapping disorder (exceptions to a classification rule) was numerically varied. Zero degrees of mapping disorder (a classification rule with no exceptions) proved trivially easy. One degree of mapping disorder produced a dramatic increase in mean errors. Degree of mapping disorder was related a priori to a linear variable (number of different correct choices) and to a quadratic variable (conditional mapping uncertainty $U_s(R)$). Mean errors were significantly related to only the quadratic component. Other results included: a closer relation between $U_s(R)$ and standard deviations than between $U_s(R)$ and means; within groups unique patterns of errors related to mapping structure; and a correspondence between post-experimental subjective awareness and both task structure and difficulty. Finally, several post hoc explanations of mapping effects were considered. An explanation phrased in terms of mapping uncertainty and hypothesis storage, sampling, and generation gave the best account of the obtained results.

CONCLUSIONS AND RECOMMENDATIONS

It seems clear that mappings between stimulus and response classes are extremely important for such practical concerns as reading instruction, second language learning, and language translation. The studies in this contract were designed to get at potentially important mapping variables at a theoretical level.

It is apparent that the results of the first study ("One-one, Many-one, and One-many S-R Mappings") are ambiguous: no significant differences occurred with respect to either task or age level. This is no doubt due to the difficulty of the task because a number of subjects in each condition failed to learn. With stimulus materials that were more meaningful (words, high-meaning nonsense syllables, etc.) more subjects would learn, and the results might fit much better with one of the theoretical outcomes discussed.

Experiment II ("Numerically Varied S-R Mapping Disorder") was an unqualified success. It shows clearly that even one exception to a classification rule is enough to severely disrupt learning. This suggests further experimentation on how exceptional material ought to be programmed. For example, in the case of spelling rules and exceptions: should the rule be mastered before the exceptions are introduced?; What would happen to rule learning if exceptions were introduced along with rule instances at the beginning of learning? In short, are spelling rules learned better in the absence of exceptions, and, if so, how much better.

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