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CHRONOMETRIC ANALYSIS OF CLASSIFICATION[1]

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This series of studies represents an effort to extend the subtractive method of Donders to the analysis of depth of processing in simple classification tasks. The stimuli are always pairs of items (letters, nonsense forms, digits) to which S must respond "same" or "different" as quickly as possible. Levels of instruction are physical identity (e.g., AA), name identity (e.g., Aa), and rule identity (e.g., both vowels). By use of the subtractive method, times for matches at each level are analyzed. The emphasis is not placed upon the times themselves but upon their relevance for understanding the operations and mechanisms involved in perceptual matching, naming, and classifying.

Nearly 100 years ago the Dutch physiologist Donders presented a paper (Donders, 1868) on the time for simple cognitive operations. This well-known paper initiated the use of the subtractive method of latency analysis to measure the time for internal mental processes such as recognition and choice. Although the subtractive method has received a good deal of criticism (Boring, 1950), there is once again active interest in pursuing it. Recent work includes detailed analysis of successive stages in simple reaction time (McGill, 1963), separation of recognition from choice time (Taylor, 1966), effect of task variables such as S-R compatibility upon the component times (Broadbent & Gregory, 1965), and development of dynamic decision models to predict and explain various components of choice time (Fitts, 1966; Stone, 1960).

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The "c" technique of Donders was the first effort to study a simple classification task. Five stimuli were used but only one required an overt response. Donders subtracted the simple reaction time (RT) from the time obtained in the classification task in order to obtain the speed of discrimination. Recently a number of investigators have applied this general technique to the study of cognitive processes involved in simple classification. Neisser (1963) embedded a single target in hundreds of nontargets and found a linear relationship between items searched and latency. He computed the slope of the function in order to obtain the time necessary to classify a stimulus as a nontarget. Egeth (1966) and Sternberg (1966) have extended this slope analysis to multidimensional stimuli and to stimuli stored in recent memory.

Neisser and Beller (1965) proposed a rather different use of the subtractive method. They suggested two depths at which a stimulus could be examined. The first involved the physical properties of the stimulus (looking for a K), the second required examining stored information (looking for a proper name). In both situations the authors were able to calculate slopes relating latency to items searched. The rate of scanning for stimuli involving memory examination was significantly slower than for stimulus examination. This suggested that the a priori distinction between the two levels was also reflected in the performance of their subjects (*S*s).

The present paper represents an attempt to develop a more detailed analysis of the bases upon which *S*s make classifications of simple stimuli. The goal is to find levels of processing which depend primarily upon the physical attributes of the stimulus and levels which depend upon more detailed analyses such as naming or relation to a superordinate. To obtain this goal a single experimental paradigm is developed which provides an opportunity to observe processing at different levels within the same experiment. The stimuli are pairs of letters, digits, or forms and the response is always pressing one of two keys ("same" or "different"). What is varied is the level of instruction upon which *S* is to base his classification. The instructions used to define "same" are physical identity (e.g., AA), name identity (e.g., Aa) and rule identity (e.g., both vowels). This technique allows the same stimulus-response combination (e.g., AB-different) to occur with instructions at quite different levels. The experiments are designed to determine if the different levels of instruction produce orderly differences in the rate at which *S* can make the classification and then to obtain additional information concerning the variables which affect processing of information at each level of instruction.

Since the process of matching or recognition at various levels of complexity is basic to much human cognition (Price, 1953), it is hoped that this analysis will open a variety of covert processes to experimental investigation.

METHOD

Most of the experiments involve the simultaneous visual presentation of pairs of letters. The letter pairs are selected from populations consisting of capital and small letters. The populations are shown for each experiment in Table 1.

In Experiment I the letters were presented by two in-line displays. Each letter was up to 1 inch high and the total display was 3¼ inches wide and was viewed from about 25 inches. The letters remained present until *S* responded by pressing a switch. In most other experiments the letters were printed from a Rapi Design letter guide with a Rapidograph #0 tip pen on 4 × 6 cards. The display subtended about 2½ degrees of visual angle. The cards were exposed in a Polymetric Tachistoscope for one second. In all experiments the intertrial interval was 10 seconds.

Typically, each experiment had from three to five *S*s who practiced for 1 day on digit pairs and 3 to 7 days on the letters. There were approximately 90 trials per day, the exact number depending upon the experimental conditions. The *S*s were all male students at the University of Oregon and were paid $1.50 per hour.

The *S*s were instructed to classify pairs of stimuli either as same by pressing a response key labeled "same" or as different by pressing a key labeled "different." The two response keys were counterbalanced for hand across *S*s. Level 1 instructions were to classify each pair of stimuli "same" if they were physically identical and "different" if they were not. Level 2 instructions were to classify letters "same" if they had the same name and "different" if they did not. Level 3 instructions were to classify letters "same" if they were both vowels or both consonants and "different" if they were mixed. The particular level of instructions given to the *S*s is shown in Table 1 for each experiment.

A standard deck of 88 cards was employed in Experiments II, III, and IV. Of the 88 cards, 24 had physically identical pairs (e.g., AA), 24 had pairs that were physically different but had the same name (e.g., Aa), and 40 were physically different and did not have the same name (e.g., AB).

The *S*s were instructed to classify each pair as rapidly as possible, trying to keep errors to a minimum. After each trial they were provided with feedback concerning time taken and correctness of their response. In Experiments II, III, IV, and V

TABLE 1

OVERALL REVIEW OF RT EXPERIMENTS

Experiment	Letter populations	Days						
		1	2	3	4	5	6	7
I	ABFK abfk	Practice with digits	Level 1 instructions with letters	Level 1 instructions with letters	Level 1 instructions with letters	Level 1 instructions with letters		
II	ABCE abce	Practice with digits	Half of list at Level 1 and half of list at Level 2	Half of list at Level 1 and half of list at Level 2	Level 3 instructions with letters	Level 3 instructions with letters		
III	ABCE abce	Practice with digits	Level 2 instructions with letters	Level 2 instructions with letters	Level 2 instructions with Gibson figures	Level 2 instructions with Gibson figures	Level 2 instructions with Gibson figures	Level 2 instructions with Gibson figures
IV	ABCEIH abceih	Practice with digits	Level 3 instructions with letters	Level 3 instructions with letters	Level 3 instructions with letters	Level 3 instructions with letters		
V	ABCE abce	Practice with digits	Level 2 instructions with letters	Level 2 instructions with letters	Level 2 instructions with letters	Level 2 instructions with letters		
Crossmodality	Digits 0–9	Level 1 instructions with digits	Level 1 instructions with digits	Level 1 instructions with digits	Level 1 instructions with digits	Level 1 instructions with digits		
Crossmodality	Digits 0–9	Level 3 instructions with digits	Level 3 instructions with digits	Level 3 instructions with digits	Level 3 instructions with digits	Level 3 instructions with digits		

Note.—For Experiments I–IV, $N = 4$; for Experiment V, $N = 3$; for Crossmodality, Ns $= 5$.

stimuli to which errors were made were repeated later in the list.

Comparison of Level 1 and Level 2 Instructions

Table 1 summarizes the various experiments conducted in this series. In each case the number of *S*s and the letter populations are listed. The particular condition (level of instruction) is indicated for each day. Experiment I involved four *S*s who received a practice day and 4 experimental days on letter pairs. Level 1 instructions were used so that *S*s were asked to respond "same" *only if the stimuli were physically* identical. The letter population is shown in Table 1. Of the 90 trials given each day, 48 had physically identical stimuli, 26 had letter pairs which were different both in name and appearance, and 16 had stimuli which were physically different but had the same name.

Experiment II was undertaken to make a direct comparison between processing with Level 1 and 2 instructions. On each of 2 days, four *S*s performed 44 trials (one-half the standard deck) with Level 1 instructions and 44 trials with Level 2 instructions. Over the 2 days combined the same standard list of stimuli was used at both levels. The proportion of "same" responses with the two instructions was different at the two levels (.27 at Level 1 and .55 at Level 2) since pairs such as Aa require a "same" response at Level 2 and a "different" response at Level 1. The long interstimulus interval (10 seconds) and the use of only two responses tends, however, to reduce the response-repetition effects (Hyman, 1953). Moreover, a control study was run in which the stimulus decks at the two levels were varied so that the response probabilities were kept at 50%. This study involved four *S*s making 48 responses at each level on 4 successive days. The control experiment confirmed all of the major findings discussed below.

RESULTS

The mean, median, and standard deviation of all *S*s' scores for each day were calculated. Only the mean values are discussed below since in all comparisons the mean and median values led to the same conclusion. The average *SD* for a given *S* on a given day was between 15 and 20% of the mean. For most of the comparisons discussed below the differences between conditions are true of every *S* on every day. Moreover, these differences are many times greater than the standard error of the mean. In those cases where the differences were not completely consistent between *S*s or where they depend upon grouped data, we have provided additional statistical argument.

The major result of Experiment I is summarized in Table 2. This table shows RTs averaged over all days and *S*s. The value on the left represents the mean of all correct responses to physically identical letters. The values for "different" responses represent the mean times for letters with different names, letters which have the same name but little physical similarity (Aa and Bb), and letters with the same name and considerable physical similarity (Ff and Kk). While there were some practice effects these mean values are typical of each day's performance. Error rate was about 7% on the final day.

The following points should be observed from these data. First, the time for responding "same" is not significantly different from the time to respond "different" for stimuli with different names. This question has led to considerable controversy in the recent literature (Bindra, Williams, & Wise, 1965; Nickerson, 1965). The finding of no essential difference between these two responses has been fairly typical of our data, where the stimulus pair is exposed simultaneously. In addition to Experiment I, the practice data on digit pairs from three experiments show no systematic tendency for "same" to be either faster or slower than "different." These data are shown in Table 3.[2] Much of the

[2] Data from the RT to letters in Experiment II are not included in this table since

TABLE 2

MEAN RTs (MILLISECONDS) OVER ALL SUBJECTS AND DAYS FOR EXPERIMENT I

Same	Different		
	Different letters	Aa + Bb	Ff + Kk
468	464	485	550

TABLE 3

COMPARISON OF SAME AND DIFFERENT RESPONSES WITH LEVEL 1 INSTRUCTIONS

Experiment	Materials	Level of practice	RT (milliseconds)	
			Same	Different
I	Letters	Mean 4 days	468	464
II	Digits	First day	477	481
III	Digits	First day	474	487
IV	Digits	First day	595	579

Note.—Frequency of the two responses is approximately equal in all these studies.

controversy may depend upon the particular population of materials used.

For Experiment II the mean correct RTs are shown in Table 4. The top line represents the results for Level 1 instructions and basically replicates the data obtained in Experiment I.[8] The bottom line shows the results for Level 2 instructions. With Level 2 instructions there are two types of "same," those for physical identity and those for name identity (Aa, Bb, Ee). These values are 71 milliseconds apart. The error rates were 6% for Level 1 and 12% for Level 2 instructions. In general, pairs which had long RTs also had higher error rates.

in this case the probability of same and different responses was not equated.

[8] One exception is that in this condition the time for "same" is much faster than in Experiment I and also faster than the "different" response. This appears to be due to the low probability of a "same" response in this condition. On the practice day and when Level 2 instructions were used there was an approximately even split between same and different. This may lead *S*s to anticipate more "same" responses and thus be fast on these occasions when they do occur. The control experiment, in which response probabilities were equated, appears to confirm this since the RTs to physically identical stimuli closely approximated those obtained in Experiment I.

LEVELS OF PROCESSING

A comparison of data with Level 1 and Level 2 instructions shows clearly that the different instructions lead to differences in the RT. If one considers only those stimuli which have different names (e.g., AB), both the stimulus pairs and the response required are identical at the two levels, but the time to respond increases (see Table 4). This finding is true both in Experiment II where stimuli were identical at the two levels and in the control experiment where response probabilities were held constant.

The results of Experiment II suggest that another distinction beside the level of instruction is necessary. If the

TABLE 4

MEAN RTs (MILLISECONDS) FOR ALL SUBJECTS IN EXPERIMENT II FOR LEVEL 1 AND LEVEL 2 INSTRUCTIONS

Instructions	Same			Different		
	Physical identity	Name identity	Cc	Different letters	Aa + Bb + Ee	Cc
Level 1	428			464	443	553
Level 2	452	523	461	556		

"same" responses with Level 2 instructions are compared, it is clear that those based on physical identity (e.g., AA) are much faster than those based upon name identity (Aa, Bb, and Ee). This difference is about 71 milliseconds. The difference is significant and consistent for every *S*.

Based upon the obtained RTs two different processing nodes can be inferred. The first is based on *physical identity* and includes letter pairs which are identical in form. This is close to Neisser's (1963) concept of stimulus examination. Since both letters are present together in the perceptual field it is logically possible for this match to be made even if the stimuli had never been seen before. Therefore, it is possible for this kind of match to be free of prior learning effects. The second node is based on *name identity*. This involves matching letters which have no obvious physical similarity so that *S* must derive something like the name of the letter in order to make the match. The speed at which a "different" response is made should vary depending upon the level of instruction. If Level 1 instructions are given, a pair may be considered different if it fails to match at the first node. If Level 2 instructions are used, it will be necessary to test at Node 2 before a pair may be classified as different. This analysis corresponds quite well to the data obtained by comparing the "different" responses at the two levels.

The time between the nodes can be estimated by three different subtractive techniques. The first method (Different–Different) is to take the time to respond "different" to all stimuli which have different names in an experiment with Level 1 instructions and subtract that from the "different" responses in an experiment with Level 2 instructions. This comparison is quite clean because the stimuli and responses involved are identical, only the instructions are different. A second method (Same–Different) is to take the time needed to classify identical stimuli as "same" from the time needed to classify stimuli with different names as "different." Both stimuli and responses vary with this procedure. Finally, one may estimate the difference by taking the time for classifying physically identical stimuli as "same" from the time to classify stimuli which are physically different but have the same name (Same–Same method). This procedure involves the same response but requires a decision on which letters are not physically similar. The mean RTs and standard errors for each *S* are shown for the "different" responses at the two levels of instructions in the first part of Table 5. The final three columns show the mean difference between the nodes as obtained by each of the three subtractive methods. The three methods give relatively good agreement on the whole, but it is clear that *S*s show the widest variation with the same–same method. The agreement obtained by these procedures and verified in later experiments gives added support to the notion of two nodes of processing in these tasks. There is, however, less interest in the exact values obtained by subtraction than in the relations between the nodes which can be inferred from more detailed analysis.

ANALOG PROCESSES BETWEEN THE NODES

The discussion so far has identified two nodes of processing. These involve matching based upon physical identity and name identity respectively. Although the time to match at each node differs somewhat among the various letter pairs, even the fastest Node 2 match is more than 50 milliseconds

TABLE 5

TIME (MILLISECONDS) BETWEEN NODE 1 AND NODE 2

Subject	Different				Subtractive method[a]		
	Level 1		Level 2		Different −Different	Same −Different	Same −Same
	M	*SD*	*M*	*SD*			
1	552	15.5	607	28	55	115	10
2	445	10.5	579	15.5	134	105	99
3	394	11.5	445	13.9	51	73	65
4	466	19.7	593	13.8	127	119	111

Note.—Data from Experiment II.
[a] Mean difference between notes, different − different, 92; same − different, 104; same − same, 71.

slower on the average than any Node 1 match. Moreover, the time to respond "different" with Level 2 instructions closely corresponds to the Node 2 "same" RTs. This would be expected if *S*s tested pairs to determine if they had the same name before responding "different." It is not surprising that there is some variability among the times for Node 2 "sames" depending upon the particular letter pair. It has been shown before (Fitts & Switzer, 1962) that the time to name letters depends upon their frequency in the language, etc.

However, it is possible to obtain times which lie between Node 1 and Node 2. This occurs when a stimulus pair is not physically identical but has considerable similarity. Consider the pair Cc. The time to respond "same" to Cc in Experiment II is about 19 milliseconds longer than the average response times to CC and cc. This increase is apparent in all four *S*s, and is significant over *S*s by a correlated *t* test ($df = 3$). Moreover, it is confirmed in the control replication. The value of 19 milliseconds is very small, but the similarity of C and c is also great since they differ only in size while the other patterns also differ in shape. It would not be difficult to obtain stimulus pairs which would be less similar and these would be expected to show greater increases over the Node 1 times. In fact this is demonstrated with Gibson Figures in Experiment III (see Table 8).

The increase in processing time for a pair like Cc over Node 1 matches may come about in two ways. It might be an average of trials in which *S*s respond to Cc as if the two were identical and trials in which the response is based on deriving the names, or it might mean that less processing is required on each trial to arrive at "same" for Cc than for less similar pairs. If the former were the case, it would be expected that the relative variability of Cc would be greater than for other same name pairs. In order to test this, the coefficient of variation for Cc (*SD*/mean) was computed. This value is not higher than that found for other same name pairs. Thus it appears classification of Cc is not due to an average of first and second node responses but that the amount of processing required for Cc classification is less than for the other nonidentical pairs.

Having shown that it is possible to obtain RTs which lie between the first and second node, it may be useful to compare these data with a quantitative treatment of similarity presented in a previous paper (Posner, 1964). In that paper similarity between pairs of patterns was manipulated by statistical distortion rules. The *S*s first learned to associate the same name separately to each member of the pair. In later RT work it was shown that the time to classify a pair as "same" was a linear function of the rated similarity (Posner, 1964). In that study, RT performance and level of learning were confounded. Although *S*s had learned to call both patterns by the same name to a criterion of two perfect trials, the learning could not be called complete. The present study demonstrates that with lifetime learning of the names, differences due to depth of processing still remain. Letter pairs like AA represent physical identity, while letter pairs like Aa appear to have little or no physical similarity, thus requiring the judgment to rest entirely on the learned correspondence. Clearly Cc lies somewhere in between these two extremes. The earlier work (Posner, 1964) provides a psychophysics of similarity, while the present study shows that similarity effects in classification remain even with highly overlearned material. Taken together, they show that RT for classification is affected by the similarity of the pair, even after a lifetime of calling two stimuli by the same name.

There are at least two fundamental mechanisms which might account for times intermediate between the nodes. The first is basically serial and suggests that physical identity and name identity are at the ends of a continuum involving the degree of similarity between the pair. The second view is basically parallel and suggests that the naming process goes on independently of any matching on the basis of similar features. If *S* succeeds in matching on the basis of similar features he simply terminates prior to obtaining the name. Information related to these two basic models is considered below.

RELATIONSHIP OF THE NODES

Our data do not allow specification of whether physical identity matches and naming matches involve different levels of the same mechanism or two different mechanisms. However, it is possible to specify somewhat the relationship between the nodes. This material may serve to constrain the types of models which would be appropriate.

The first question is: Do the times for first-node processes change when embedded in instructions at differing levels? The data of Experiment II provide a tentative answer to this question, but only for low levels of practice and for a situation in which *S*s are switched back and forth between nodes. In this case, the first node responses do increase when embedded in second level instructions. The increase is 24 milliseconds and a *t* test of the mean times for the four *S*s shows that this increase is significant statistically ($p < .01$). It should be noted that while the stimuli were identical at the two nodes, the frequency of "same" responses required was twice as great at Node 2. However, the control experiment with response probability held constant confirmed this basic finding. On the first day the Node 1 responses were 17 milliseconds higher at Level 2 than at Level 1. This declined somewhat over days of practice, but the improvement differed among *S*s. By the last day only one of the four *S*s showed Node 1 responses at Level 2 to be longer than at Level 1. Thus it appears that this small effect can be further reduced by practice.

An analysis of performance with Level 3 instructions (Experiment II) shows the Node 1 responses to have a mean of 455 milliseconds over the 2 days of training. This represents no further increase in Node 1 RT in going from Level 2 to Level 3 instructions. However, when this condition was run, *S*s had more practice (Days 4 and 5) than for Levels 1 and 2 (Days 2 and 3).

In summary, it does appear that RTs for Node 1 responses are affected by higher levels of processing but the effect is relatively small and has been demonstrated only between Nodes 1 and 2. Moreover, as might be expected, higher levels of training further reduced this effect.

A second question concerning the relationship between the nodes is: Does having a common name affect the time to classify the pair as "different" at Node 1? For example, does it take longer to call Aa physically different because they have been paired with the same name? If name effects can be shown on the first node, this would be strong evidence against purely perceptual processes being involved at this level. It is difficult to know which particular pair of letters to take as representative of the second node because it is impossible to have a pair of letters which has both the same name and different names. Thus the comparison of times always involves other factors which differ between letter pairs.

TABLE 6

MEAN RT FOR ALL LETTER PAIRS AT LEVEL 1, EXPERIMENT II

	A	B	C	E	a	b	c	e
A	397							
B	449	421						
C		547	465					
E	442	527		452				
a	420		487		459			
b	462	470		434	477	422		
c		395	553		492	421	409	
e	457	410	489	440	504		472	388

Table 6 shows the mean RT to all letter pairs (irrespective of order) from the Level 1 instructions of Experiment II. If, for example, Aa is compared with other "different" combinations involving A and a, it appears to be one of the fastest responses. However, it must be noted that these two letters involve a size difference and this may work to their advantage. This same comparison can be made for Bb and Ee. Such comparisons fail to provide evidence that RTs for these letter pairs are slowed by the common name. This result is also true of Aa and Bb in Experiment I when they are compared with the appropriate control letters. Of course, the time for Cc is longer than any other pair, but in this case a common name is confounded with great physical similarity. Table 6 may, therefore, be taken to indicate that there is no consistent increase in RT at Node 1 from overlearned naming responses.

If the two nodes represent the ends of a single serial process the complexity of that process may be affected by the types of letters within the list. That is, having letters which are similar but not identical may require certain processes of stretching and rotation to be added to the processing between the nodes. If this is so, RTs at Node 2 (name identity) will be longer for a list which contains pairs like Cc which require matching on the basis of similarity but not identity.

In order to consider this question, an experiment was run involving three *S*s (Experiment V). Each *S* worked through two lists of cards on each day. Each list was one-half the standard pack (44 cards), as in Experiment II, except that in one list all Cc pairs were omitted, while the other list had six Cc pairs. A comparison of the times for all second node responses except Cc was made between the two lists. In every case the times for the list containing Cc pairs were no longer than for the lists without Cc pairs. This finding leads us to reject the hypothesis that analog processing involved in matching two similar letters is added serially to the processing necessary in deriving the names.

Unfortunately, rejecting the model mentioned above still leaves a number of possibilities. For example, the processes which allow matching of similar items may only be invoked on those trials where a similar pair occurs. This would imply that a more primitive process first detects *similarity* and that the process which governs the matching of similar but nonidentical pairs occurs only on those trials. Another possibility is that the processes which allow matching on the basis of physical identity or similarity may be entirely parallel to those which concern derivation of the name. Thus having to perform these processes together would not lengthen the time. Finally, the processes which lead to matching of similar letters may be identical with the processes which lead to a derivation of the letter's name so that they always occur whether or not letter pairs like Cc are in the list. After all, naming itself involves matching the new input to stored information about the appearance of a letter. Each of these models implies a variety of empirical predictions which go beyond the scope of this paper.

ROLE OF LEARNING

Letters are patterns which are highly familiar both in terms of perceptual form and names. Thus the data presented so far represent highly overlearned classifications. In order to assess the role of such lifetime learning in first and second node processes, the classification of letters was compared with the classification of letterlike forms (Gibson, 1965). In Experiment III four *S*s were given 2 days of trials with Level 2 instructions using the standard pack described in Experiment II (see Table 1). On the next day, they were given a few minutes of learning trials with a population of paired forms shown in Figure 1. The learning trials were sufficient for the *S*s to learn to give a number (1, 2, 3, 4) to each pair (see Figure 1) to a criterion of three correct trials. After the learning, which took from 4 to 6 trials, *S*s were given 4 days of RT trials with the forms. The RT task with the forms was identical to the Level 2 instruction task that was discussed previously for the letters.

The results for the second day of letters are shown in Table 7 and the results for the first day of Gibson forms are shown in Table 8. It should first be noted that the results of Experiment III with letters are in substantial agreement with the results reported previously. The major difference is that the second node "different" response is in this case somewhat faster than most of the second node "same" responses. This lack of a stable "same"-"different" relationship was also noted earlier. The shift from letters to Gibson figures shows little if any change, either in the RT to physical identity or in the RT for the "dif-

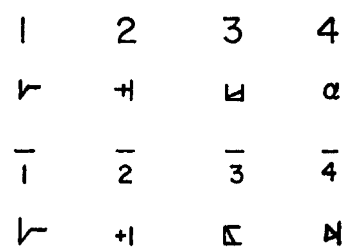

FIG. 1. Gibson figure pairs used in Experiment III. (Labels refer to designations shown in Table 9.)

TABLE 7

COMPARISON OF RTs FOR LETTERS

Letters	Physical identity	Same				Different
		Aa	Bb	Cc	Ee	
Second day	451	542	603	407	597	530

Note.—Data from Experiment III.

TABLE 8

COMPARISON OF RTs FOR FORMS

Gibson figures	Physical identity	Same				Different
		$1\bar{1}$	$2\bar{2}$	$3\bar{3}$	$4\bar{4}$	
Day 1	450	450	463	553	610	538
Average of 4 days	421	440	438	501	551	500

Note.—Data from Experiment III.

ferent" response. These findings indicate that lifetime familiarity with the letter forms does not speed the rate at which a perceptual match is made. This surprising result is in accord with results reported for thresholds (Robinson, Brown, & Hayes, 1964) and for RT (Hochberg, 1966) using words, forms, and nonsense stimuli. Familiarity does not improve the perceptual matching task at all. Unfortunately, the close correspondence between the letters and forms in their "different" responses cannot be interpreted so clearly. In the case of the Gibson figures, only one of the stimulus pairs given the same name was perceptually unrelated. This was done to keep the learning task simple and error rate very low. Since this was not the case with the letters, it would not be fair to compare the Node 2 results directly. It is certainly to be expected that as the difficulty of the learning task was increased by assigning more dissimilar pairs to the same name, the Node 2 processes for the figures would be increased over those for the well-learned letter responses. However, it would take considerable training to obtain functions with sufficiently few errors when the learning task was made more difficult.

The four pairings of Gibson figures used in this study represent three different types of perceptual transformations (size, break, rotation) and one randomly selected pair. Table 9 compares the mean RT over 4 days for the "same" response to the transformed pairs (e.g., $\bar{1}$, 1) with the mean RT

TABLE 9

MEAN RT FOR VARIOUS PAIRS OF GIBSON FIGURES

Subject	Type of transformation							
	Size		Break		Rotation		Random	
	$1\,1 + \bar{1}\,\bar{1}$	versus $1\,\bar{1}$	$2\,2 + \bar{2}\,\bar{2}$	versus $2\,\bar{2}$	$3\,3 + \bar{3}\,\bar{3}$	versus $3\,\bar{3}$	$4\,4 + \bar{4}\,\bar{4}$	versus $4\,\bar{4}$
1	415	438	467	466	430	524	464	588
2	405	460	424	424	424	509	416	618
3	412	433	414	434	425	504	408	555
4	401	430	408	426	404	466	399	554
M	408	440	428	437	421	501	421	579
M_{diff}	32*		9		80**		158**	

Note.—See Figure 1 for pictures of figures.
* $p < .05$.
** $p < .01$.

TABLE 10

MEAN RT AND TIMES FOR LEVEL 3 INSTRUCTIONS

Experiment	Same				Different
	Physical identity	Name identity	Vowels	Consonants	
II	442	550	551	663	653
IV	549	623	699	904	801

for the "same" response to the two physically identical components of the pair (e.g., $\bar{1}\ \bar{1} + 1\ 1$). In the case of the size, rotation, and random pairings these mean differences are significant statistically ($p < .05$). The size transformation has an absolute difference of 32 milliseconds, which is quite similar to the 19 milliseconds by which Cc exceeds the mean of CC and cc. The break does not show a significant increase over its physically identical controls. For this pair one *S* shows no increase, one shows a decrease of 1 millisecond, and two show increases of about 30 milliseconds. Thus the break is the only transformation which gives evidence for constancy in terms of the RT criterion. This method appears to be a good one for determining the overall similarity of various types of perceptual transformations. The results further support the analysis of the analog processes between nodes which was outlined earlier.

A THIRD NODE

In the Neisser and Beller (1965) experiments *S*s were asked to search for an animal name. Many different names and even more perceptual patterns belong to that category. For example, DOG, dog, and cat. At its simplest, a category or concept allows a number of different stimuli to be correctly classified by the same response. The name A is itself a category which allows a and A, among other patterns to be so classified. The name A may also be an instance of more complex categories, such as the class "vowel." The class "vowel" is defined for most of us by rote, although a linguist would be able to derive a rationale for such classification.

To assess the processing involved in a higher order classification, two experiments were run with Level 3 instructions (respond "same" to both vowels or both consonants). The first was conducted on the last two days of Experiment II using the same *S*s and materials. The mean RTs for the second day of this procedure are indicated on the first line of Table 10.

To determine if the responses based on a common category lead to longer times than those based on a common name (Node 2) the subtractive methods are applied to the data. The results are shown in Table 11. In general the data are rather orderly except for the estimate obtained by subtract-

TABLE 11

MEAN INTERNODE TIMES FOR LEVEL 3 INSTRUCTIONS

Method	Experiment II[a]	Experiment IV[a]
Different – Different	97	
Same – Different	103	178
Same – Same		
Vowels	1	76
Consonants	113	281
Average	57	178

[a] Node 2 to Node 3.

ing Node 2 "same" responses from the "same" responses based upon vowel identity. For that case, the results give almost a zero difference. This comparison, however, is weak since only a few responses at each level are obtained from each *S*. In addition, with only 2 day's practice, there are still a fair number of errors in the data. Moreover, since the letter population is small, only a few particular combinations are included at each level and these are not the same at the two levels.

Another experiment was run to obtain a better estimate of the differences in times for matches based on common rule and those for common names. In this study (Experiment IV) four *S*s responded at Level 3 on each of 4 days. The only difference from previous studies was that a letter population of three consonants and three vowels was used (see Table 1). The total number of "same" responses at the three levels was 48 while 36 responses were "different." The "same" responses were 12 each at Nodes 1 and 2 and 24 at Node 3.

The mean RTs obtained in this study for the final day of training are shown on line 2 of Table 10 and in Figure 2. Error rate on this day was 11%. The first point of interest is the relatively long RTs of these *S*s in all conditions. This apparently was a matter of *S* sampling since the same inflation of overall RTs is apparent on the practice day (see Table 3). The difference between the first and second nodes for these *S*s, estimated by the same – same method, was about 74 milliseconds, quite similar to that previously obtained by that method (Experiment II). The difference between Node 2 matches and those based on rule identity can be estimated by the same – same and by the same – different method. These methods give, on the

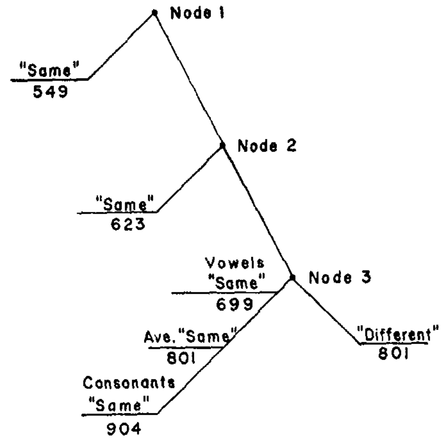

FIG. 2. Tree diagram for Experiment IV. (Numbers refer to mean RTs on last day for all *S*s. For description of nodes see text.)

average, the same result of about 180 milliseconds. This is much longer than was obtained in Experiment II, but is far more stable since more data are available. The difference between consonant and vowel pairs which was pointed out previously is also striking in these data. The exact correspondence of the mean "same" and "different" responses at Node 3 is not (see Figure 2) characteristic of any one *S*, but only of the pooled data.

Thus it appears that matches based on common name are reliably faster than those which are based on a common rule (vowel-vowel or consonant-consonant). On this basis, rule identity may be considered as a third node of processing. One way of conceiving of the differences between Nodes 2 and 3 is to suggest that the output of the naming detectors is fed into a system which searches for vowels. Since there are so many consonants in the alphabet, it is reasonable to suggest that a consonant pair is probably defined by the absence of a vowel and thus takes much longer. In fact this seems to correspond to the verbal definitions obtained from *S*s.

An alternative to such an hierarchical hypothesis is that the difference between those nodes is merely a matter of practice and would go away given sufficient training on identification of vowels and consonants. This hypothesis is consistent with the observed differences in speed for vowels and consonants. It is also suggested by the lack of any differences between the nodes in Experiment II, where only the vowels A and E were used. However, Figure 3 shows practice data from Experiment IV for all nodes and also for differences between nodes. While there is considerable practice effect evident in that data, there is no evidence of a reduction in the Node 2 and Node 3 difference over days. Since these estimates were obtained by the same – different method, they are quite stable. It appears likely, therefore, that the Node 2 to 3 differences, like those between Nodes 1 and 2, are hierarchical characteristics of information processing and are not due merely to amount of practice. Of course, it is also possible that more practice than provided here is required to show evidence for a reduction between nodes.

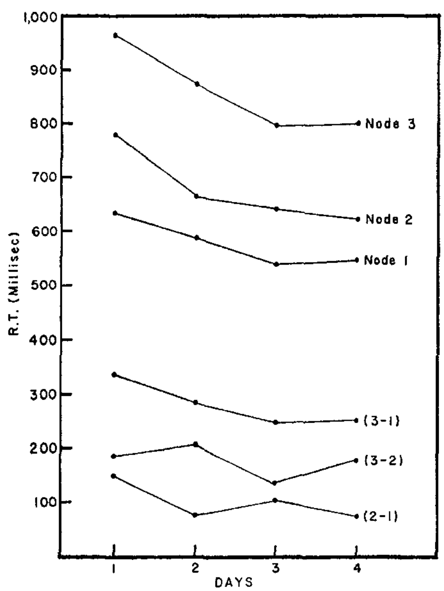

FIG. 3. Practice data for Experiment IV. (Lower curves refer to differences between nodes. Differences between Nodes 3–1 and 3–2 obtained by same – different subtractive method, for Node 2–1 same – same method was used.)

CROSS MODALITY MATCHING

One of the earliest learned correspondences between two different energy patterns is the association of a visual stimulus with its auditory name. Thus the visual digit 1, for example, becomes associated with the auditory name. This correspondence is similar to the one between A and a, but is perhaps even more familiar.

Figure 4 illustrates some data from an earlier unpublished experiment conducted at the University of Wisconsin by Kenneth Welton and the first author. The study compared the times required to respond to pairs of visual digits presented one to each eye, pairs of auditory digits presented one to each ear, and a pair of audio-visual digits. In each case the onset of the digits was as close to simultaneous as we could make them. In fact, the visual digits were perfectly simultaneous, the visual-auditory pair involved a 20-millisecond delay with the auditory always leading, while the auditory pair involved asynchrony of 0–40 milliseconds with a mean of about 20 milliseconds. In each case *S* was required to press one of two keys to respond "same" or "different" to the pair.

Two separate experiments were run. Each involved five *S*s working on each of 5 days. They received 30 trials daily with each of the three modality combinations. In the first experiment *S*s were told to say "same" if the two stimuli were the same digit. Within each 30 trials, 15 of the pairs were the same digits and 15 were different digits. The second experiment involved Level 3 instructions with "same" defined as both odd or both even. For this level no identical pairs were used and 15 of the 30 trials required "same" responses. No response-time feedback was provided in these experiments. The digits were displayed visually on in-line displays or played from a tape recorder over a headset. Digits from 0 to 9 were used.

The results are shown in Figure 4. The three lower lines represent the Level 1 task where *S*s were to respond "same" if the same digit was presented over both channels. The audio-visual pair is about 50 milliseconds slower than the visual pair and about 80 milliseconds slower than the auditory pair. The extra time required by audio-visual pairs over those for the same modality pairs could not be accounted for by the asynchrony of the stimulus presentation. Moreover, this value closely approximates the times between Node 1 and Node 2 discussed in previous studies. The ordering of the lower three curves in Figure 4 is true of each *S* on each day of practice.

On the basis of the material presented so far in this paper, it seems reasonable to attribute the extra time required by audio-visual pairs to the learned conceptual correspondence of the audio-visual energies in comparison to the actual physical identity of intramodality pairs. Of course audio-visual pairs can only be equated at Node 2. On the other hand, one might also attribute this difference to some type of "switching" time between modalities. In fact, that was the original goal of this study. The top three curves suggest that a switching-time explanation is not appropriate. These curves provide the same input, but involve Level 3 instructions (respond "same" if the

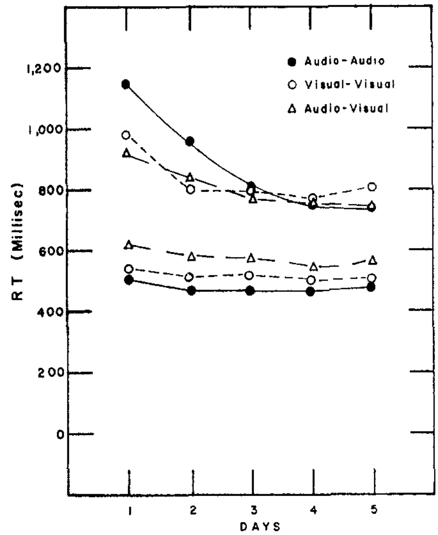

FIG. 4. Mean RT for cross modality experiment. (Lower curves refer to Level 1 instructions, upper curves to Level 3 instructions—see text.)

digits are both odd or both even). The difference between audio-visual pairs with identity instructions (Node 2) and audio-visual pairs with odd-even instructions is 180 milliseconds on the fifth day. This corresponds to the differences observed on the fifth day of Experiment IV. For this task the audio-visual pairs are just as fast as the same modality pairs. This argues that when all of the tasks involve learned conceptual classifications there is no additional time involved in using two different modalities and is not consistent with a "switching time" interpretation.

CONCLUSIONS

This paper provides a general experimental paradigm for observing different levels of processing. The same stimuli and responses can be used to study matches based upon physical, name, or rule identity. This technique can be used to bridge the gap between the very early stage of perception and the complex classifications underlying learned concepts. The construct *node of processing* refers to the basis on which the match is made. Depending upon the node involved, processing times may vary between 450 milliseconds and 900 milliseconds.

The times for different processing nodes correspond quite well to the tree structure shown in Figure 2. The ordinal relationship between the nodes and, to a considerable degree, the times themselves remain relatively constant with different levels of instruction and for different subtractive techniques. This reliability and generality argues for the utility of viewing processing in terms of discrete tests conducted at each node based upon a particular definition of "same." It is possible, however, to obtain times between Node 1 and Node 2. These occur when two stimuli are not identical but are similar. This evidence suggests the presence of analog processes between the nodes which allow matching on the basis of the degree of physical correspondence of the stimulus pairs. Experiment III shows that this technique can be used to scale the similarity between the two stimuli (Sternberg, 1967). Matching stimuli with size or rotational differences give times which lie between those matches based on identity and those which are based upon the stimulus names (Node 2).

Perhaps the most striking feature of the results is that the rate of matching at Node 1 does not change with the familiarity of the stimulus pair. This result has also been obtained by Hochberg (1966). This cannot be logically true for Node 2 since the identity of two perceptually unrelated patterns can only be established by learning. However, with the levels of practice employed in these studies there is little evidence that the relationship between the nodes changes with practice beyond that necessary to establish the correspondences.

Both the consistency between various methods of calculating the time between nodes and the relative stability of the node differences with practice and level of instruction argue for the utility of the subtractive method. However, one must be cautious about the meaning of the values obtained. It is tempting to infer from these data that the mechanisms involved in matching operate serially. That, for example, *S* first tests for physical identity and only failing there derives the names and tests them. Indeed, recent studies in choice RT have been able to infer the serial nature of recognition and choice from the additivity of components (Taylor, 1966). No such analysis is intended from our data. It is possible that increasing times for the different nodes might result either from serial or parallel processes. In addition, some aspects of the processing may be parallel and others serial. Judging from introspective accounts it seems reasonable that all *S*s derive the name of the letters before proceeding to analyze whether they are both vowels or both consonants. This process may well be serial. However, the fast times for matching letters which are similar but not identical may argue that this process goes on in parallel with the task of deriving the letter names. Tests of these notions will require much more experimentation.

Quite apart from a detailed specification of the mechanisms responsible for matching, it is likely to be of interest to study the independent variables which affect matches at different levels. The process of matching has been of interest all the way from the psychophysiology of habituation to the analysis of complex cognitive behavior. Recent analyses of attention (Egeth,

1967) and of cognition (Miller, Galanter, & Pribram, 1960) have rested upon the idea of hierarchies of discrete tests performed upon stimuli. This paper provides one technique for examining such tests at various levels.

There has been particular emphasis on the importance of comparison and recognition as elementary units of more complex cognitive processes (Miller, Galanter, & Pribram, 1960; Price, 1953). Miller et al. argue that the TOTE (test-operate-test-exit) unit, which involves a comparison between goal and present state, might replace the reflex as the proper unit for human information processing. There has been a paucity of evidence that such a unit can be meaningfully isolated from ongoing cognitive tasks.

Experiment II showed that the comparison processes at the first node remained relatively stable when embedded in more complex second and third node judgments. It is so typical for component times to increase when embedded in tasks of greater overall complexity that this stability is striking. If the perceptual comparison process remains relatively stable it may be possible to use it as a unit in the analysis of many cognitive skills in much the same way as the reflex serves as a unit of analysis within S-R theory. The present experiments seem to provide some hope that a stable empirical referent can be found for at least the comparison portion of the abstract TOTE process.

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