REACTION TIME FOR NUMERICAL CODING AND NAMING OF NUMERALS

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REACTION TIME FOR NUMERICAL CODING AND NAMING OF NUMERALS

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I hereby recommend that this dissertation prepared under my direction by James D. Windes entitled REACTION TIME FOR NUMERICAL CODING AND NAMING OF NUMERALS be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

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Date 7/27/66

After inspection of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

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*This approval and acceptance is contingent on the candidate's adequate performance and defense of this dissertation at the final oral examination. The inclusion of this sheet bound into the library copy of the dissertation is evidence of satisfactory performance at the final examination.

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ABSTRACT

Recent studies have provided support for the conclusion of several early psychologists that conventional names or symbols can be verbally identified faster than the simple objects or features they designate. Since the naming responses are identical for both types of identifications, investigators have generally attempted to account for the latency difference in terms of differences in the subject's experience with one type of stimulus as opposed to the other. One early hypothesis, also favored by contemporary psychologists, held that more response conflict existed for concrete stimulus features than for their conventional printed designations.

Whereas most previous studies thus controlled for possible response differences, but not stimulus differences, in comparing latencies for the two types of identification tasks, the study reported in this paper attempted to control in one experiment for both stimulus and response differences. The method used was based on a technique originally devised to test for the additional delay that might be produced in making

color-naming responses by presenting color names printed in inks of different colors. Instead of color stimuli, however, number stimuli were used in this study.

The research was divided into two separate experiments. The first required the naming of the single numerals 1, 2, and 3 under one task condition and the naming of corresponding quantities of cross-shaped figures under the other. The second experiment used the same numerals in groups of one, two, and three for both a numeral-naming condition and a quantity-naming condition. For three of the stimuli in the second experiment (1, 22, and 333), the same verbal response was required to the same stimulus under both the numeral-naming and the quantity-naming conditions.

Although the results of the first experiment showed reaction time to be faster under the numeral-naming task than it was under the quantity-naming task, this difference was not statistically significant.

In the second experiment, however, reaction time in naming the quantities of numerals was significantly slower than it was for naming the numerals themselves. This was true even for the subset of stimuli which required the same naming responses to the same stimuli under both task conditions. Nevertheless, under both the numeral-naming condition and the quantity-naming condition, the time required to respond to the stimuli in this subset was significantly faster than the time required to respond to the other stimuli, which lacked numeral-quantity equivalence.

It was concluded that sets of stimuli which combine both concrete and symbolic number characteristics affect the latency of number-naming responses in the same way as stimuli which combine concrete and symbolic color characteristics affect the latency of color-naming responses. It was further concluded that, in addition to greater response conflict, greater identification-task conflict and a larger number of coding operations required in making some types of identifications, might produce longer reaction times for naming objects under some conditions as compared to others.

INTRODUCTION

It has long been recognized that reaction time is significantly related not only to various physical parameters of the stimulus, such as its intensity, size, duration, etc., but also to variables outside the subject's immediate physical environment. One such variable is that of stimulus information, which varies with the probability of occurrence of a stimulus in relation to other possible stimuli. With no physical change in the stimulus itself, choice reaction time to that stimulus may still change if the probability of its occurrence is changed.

Thus, not only are the physical aspects of the stimulus and response known to be related to reaction time, but also certain features of the sets of which they are members. In addition to features of these sets as established by the conditions of an experiment, moreover, features associated with the subject's past experience may play a part. For example, the relative familiarity of stimulus sets, and of larger sets from which they are taken, has been shown to affect reaction time (Fitts and Switzer, 1962).

It remains to be seen whether any general interpretation can be given to all the various types of set-characteristics and contextual factors that have been found to affect reaction time. Interpretations in terms of information theory have proved to be more difficult than once might have been supposed. This difficulty shows up clearly in some recent studies that will be described on the pages that follow. These studies are concerned with choice reaction time for naming responses, to stimuli taken from sets of conventional symbols like letters and numerals.

Psychological studies of reaction time for naming different types of stimulus materials, however, have a history almost as long as that of experimental psychology itself. For this reason, the historical background of the present study can be complete only by including the findings of some of the early investigations, in addition to the more recent ones.

HISTORY

Since the early studies of J. M. Cattell in the 1880's, there has been evidence that conventional names or symbols for simple objects can be reported faster than the objects themselves. Cattell (1886a) reported that the time for naming colors was about the same as that for naming pictures (over 1/2 sec.), but that these times were about twice as long as those for naming words and letters. From various experiments, he concluded that a single color or picture can be recognized faster than a word or letter, but takes longer to be named. He accounted for the differences in reaction time as follows: "This is because in the case of words and letters, the association has taken place so often that the process has become automatic, whereas in the case of colors and pictures we must by a voluntary effort choose the name."

Bourdon (1908), using himself as his only subject, compared reaction times for naming small numbers of luminous points, Arabic numerals, and the words corresponding to the numbers and numerals. He used an ingenious mouth switch to trigger a Hipp chronoscope, and measured individual reaction times for each stimulus.

Although he found that the numerals and words could be named consistently faster than the corresponding groups of points, he concluded that the differences were negligible.

Cattell's and Bourdon's studies led Brown (1915a, 1915b) to carry out two studies of naming times, one for colors and color words, and one for quantities and corresponding words and numerals.

Brown interpreted Cattell's hypothesis as predicting that sufficient practice would make it possible to report simple objects or qualities as fast as their corresponding names or conventional symbolic designations. In the first study, Brown (1915a) found that practice slightly decreased the reporting times for both colors and their printed names, but only up to a certain point, after which the improvements leveled off. Brown used a modified form of a color-naming test devised by Cattell, and concluded that, even after 12 days of practice, there was no indication that the ratio of color-naming times to that of word-naming times was approaching unity.

In the second study, Brown (1915b) obtained similar results using small groups of printed marks, Arabic numerals, and their printed names. Contrary to Bourdon's analysis, Brown concluded that the time required to name the number (i.e., quantity) of marks in a small group was significantly longer than the time required to name the corresponding word or Arabic numeral. After allowing his subjects to practice both tasks for 11 days, he concluded: "This experiment agrees with color naming in the essential point that the ratio between the time required to name an object and the time required to name its symbol resists the action of practice."

Until recently, almost all direct comparisons of reaction times for naming simple, concrete stimuli and their corresponding names or conventional symbols, since the studies carried out by Warner Brown, have been restricted to the use of colors and color-words. Woodworth and Wells (1911), Peterson, Lanier, and Walker (1925), Lund (1927), and Ligon (1932) all performed experiments comparing the times for naming colors and for naming the corresponding words, and confirmed that the same verbal responses could be elicited faster by color-words than by the colors themselves. However, they disagreed as to the relative importance of practice in accounting for their findings, and some pointed out that the notion of practice itself could be interpreted in various ways.

Peterson, et al. (1925), for example, proposed that the difference was due not so much to more practice per se in responding to words as opposed to colors, but rather to more practice in making only one kind of response to the words while making many different kinds of responses to the colors:

> To the written words "red," "blue," "green," etc., the subjects have as a rule given in the past but the one response of pronouncing (vocally or subvocally) the names of these colors; whereas on seeing the colors red, blue, green, etc., they have responded in many different ways, as grasping and eating, handling, perceiving and admiring, etc.

Peterson's suggestion, which may be termed the "response-conflict hypothesis," held that "one specific response-habit has become associated with each word, while in the case of the colors themselves a variety of response tendencies has been developed."

The response-conflict hypothesis has continued to be looked upon favorably by several contemporary psychologists, even though its early origin sometimes goes unmentioned. The following quotation from Morin and Forrin (1965), for example, bears a striking resemblance to that of Peterson, et al. (see above):

> The dominant response to a numeral, as to a letter, is its name. Similarly, the dominant response, of high associative strength, to a picture of a dog . . . is the word "dog." But whereas a picture of a dog may readily be renamed --"mutt," "canine," "Rover"-- an 8 is an 8 is an 8, and it is uncommon to call it anything else. For numeral-numeral associations there are few, if any, competing responses, and such as may exist are minimal in strength.

Morin and Forrin, of course, were not restricting their hypothesis to account only for differences between naming times for colors and color-words. These writers had explored the relationship between stimulus information and reaction time for naming responses using letters, pictures, drawings, colors, and geometric figures. They found that, despite the high familiarity of all the stimuli, only in the case of the letters did reaction time fail to increase with increases in the sizes of the stimulus sets.

Like Lund (1927) and Ligon (1932), Morin and his associates reasoned that, if practice was responsible for the differences, then the reaction time for young children in naming symbols should be similar to that of adults in naming simple concrete stimuli, i. e, it should increase with larger stimulus sets. Accordingly, Morin and Forrin (1965) tested choice reaction time for children in the first and third grades, using a numeral-naming task with stimulus sets of different sizes. They found that the mean reaction time for third-grade students was significantly shorter than that for first-grade students. However, like adults, the children in both groups did not show an increase in naming times with an increase in the number of stimulus alternatives.

In another study, Morin and Forrin (1962) found that choice reaction time for the naming of numerals was lengthened by the inclusion in the stimulus-response sets of geometric symbols given an arbitrary numerical designation. They interpreted this finding as an indication that, even though associations may be highly overlearned or compatible, their latencies may be increased by the presence in the stimulus-response sequence of associations of low compatibility. In a subsequent study (Morin and Forrin, 1966), they showed that requiring subjects to remain silent to a given subset of numerals, or to respond with the single designation "No" to members of that subset, produced longer reaction times to numerals that were named than would be predicted from properties of the stimulus sequence alone. Again they interpreted their data as supporting some sort of response-conflict hypothesis.

There have also been other studies recently of naming responses using stimulus materials other than colors and their names. Fraisse (1960) used geometrical figures (square, triangle, hexagon, octagon) and their four corresponding names. He found significant differences not only between the latencies for figure naming and word naming, but also between those for triangle and square naming on the one hand and hexagon and octagon naming on the other. Fraisse inferred that a "supplementary coding" is required for subjects to furnish names of concrete stimuli.

Fitts and Switzer (1962) suggested a similar difference in coding processes to account for findings such as those of Mowbray (1960) and Brainerd, et al. (1962). These latter investigators, like Morin and Forrin in the studies referred to above, found no increase in reaction time for naming numerals when the number of stimulus alternatives was increased. Fitts and Switzer suggested that a "direct association mechanism" might operate in the case of naming conventional symbols, while a "search or statistical decision mechanism" might operate for other types of stimuli.

In the same article, Fitts and Switzer reported that reaction time for naming members of small, familiar subsets of numerals or letters (e.g., 1, 2; A, B, C) was faster than for naming these stimuli in larger, familiar sets of which they were normally a part. Latencies for small, unfamiliar subsets (e.g., 2, 7; E, P, B), however, were about as slow as for the larger sets.

The notion of response conflict as a cause of increased latency in making naming responses continues to be advanced by psychologists. Some, such as Berlyne (1957) and Garner (1962), have even suggested that response conflict might be the most important source of increased choice reaction time in general. Garner points out, however, that response conflict itself may exist for a variety of reasons. The results of some of the studies cited above suggest that the basis for this conflict may lie not only in the nature of the stimuli and responses, and relations between them, but also in the nature of the relations between these elements and the over-all sets or classes of which they are members.

Naming a stimulus object or quality almost always involves identifying, and perhaps classifying, that object or quality. Besides Fitts and Switzer (1962), Oldfield and Wingfield (1964, 1965) have been concerned with the possible role of classificatory systems in memory, and their possible relation to latencies in naming objects. In their work with both normal and brain-injured subjects, Oldfield and Wingfield found that a high correlation existed between the time taken to name an object and the frequency with which its name occurred in a language. They were thus led to the conclusion that storage mechanisms involved in object naming are organized according to a classificatory system, and that access is gained to items in the store by the use of a "key." Their findings also led them to conclude that the store is so arranged that the more frequently required items are the most quickly and easily accessible.

However, Oldfield and Wingfield's explanation could hardly account for the greater speed with which, for example, color names are identified in comparison to the actual colors, since the names are identical and occur with equal frequency. At least, this would seem true if the presumption is made that the significant items stored in memory according to a classificatory system are items specifically leading to a particular naming response. This presumption, however, is questionable; might two objects not still be classified differently even though the same naming response was used for both classifications? Must one presume that, because we respond with "red" to the color red and also with "red" to the word red, that the color and the word are being classified in the same way, i.e, as belonging to the same class?

A clue as to how this type of question might be explored experimentally can be seen in the method devised by Stroop (1935a) to test further the latency differences between color naming and color-word naming. Stroop noted that a printed word naming a color might also be made into a colored object, so that reaction time for color naming and color-word naming could be measured using the same stimulus items. He presented color words (i.e., names of colors), printed in inks of different colors, so that no word was printed in the color it named. He also presented words in black ink, and neutral symbols in colored inks, so that he could compute the reaction-time differences for naming words in colored inks and in black ink, and for naming the colors of words and the colors of neutral symbols. Using percentage differences, Stroop concluded that the interference of word-naming tendencies on the color-naming task was much greater than the interference of color-naming tendencies on the word-naming task.

Stroop also favored Peterson, *et al.*'s response-conflict hypothesis, and later (Stroop, 1938) carried out a series of experiments designed to test the hypothesis. He did not use the interference technique referred to above, but instead had one group of subjects give only naming responses to a group of nonsense syllables, and had another group give various types of responses, including sorting, collecting, tapping and checking responses. Although the subjects in both groups all practiced an identical number (1200) of total responses, the scores for the first group were found to be consistently shorter, and Stroop concluded that "reaction time to stimuli is shorter when one response habit has been established than when several different response tendencies have been developed."

Using Stroop's interference technique, Klein (1964) had subjects name the colors of words grouped into different semantic categories (nonsense syllables, rare words, common words, color-related words, words naming colors other than the stimulus colors, and last, words naming the stimulus colors). He found that, as hypothesized, the conflict was least in naming the nonsense syllables, and increased by steps as the closeness of the word-meanings to the colors increased, until finally, a marked increase in conflict occurred for the words naming colors taken from the set of stimulus colors itself. From this experiment, Klein concluded that the speed in naming the color of a printed word depends on the word's meaningfulness generally and upon its closeness of meaning to the relevant color-name responses.

In another experiment, Klein had his subjects respond both to the colors and to the verbal content of the color words, one response following the other. Using a subtraction procedure, he inferred that naming colors in the word-then-color sequence was easier to do than merely naming the colors of the words as in the standard task. Like Fraisse (1960) and others (see above), Klein also concluded that some sort of extra "coding operation," not required in naming a word, is required for assigning a concrete stimulus its proper name.

Thurstone and Mellinger (1953) and Jensen (1965) have used factor analysis on various scores obtained from tests of the type devised by Stroop. Jensen analyzed eleven different scoring formulas, and concluded that three basic factors could account for all the different scores: a color-naming factor, an interference factor, and a reading-speed factor. He also concluded that "whatever it is that causes color naming per se to be more difficult than word reading, it is not at all the same kind of difficulty that makes for slowness on the color-word interference card."

Apparently, the interference method devised by Stroop has been used only in the case of colors and color words. Those who have used it, moreover, have not included as stimuli words which named the same colors as the inks in which they were printed. They have used words printed in black ink, and words having conflicting color-name features, but not individual words having the same colors as they named. (Klein used only words which named colors of other words in other sets, or colors of other words in the same set.)

However, the use of the interference technique in this fashion affords no real testing of the possibility that physically identical stimulus objects might be classified differently even though identical naming responses were used, and further, that conflicting tendencies to classify or code a stimulus in different ways might exist in addition to, or in the absence of, conflicting tendencies to produce different naming responses. The question arises, in other words, as to whether the psychological process of classifying an object can be adequately expressed in terms of making a particular naming response to a particular stimulus item, and none of the studies cited above make any direct attempt to answer it.

Many of the studies, especially those of Oldfield and Wingfield (1964, 1965) and Klein (1964), strongly suggest the ordering of items in memory storage according to some sort of hierarchically organized classification system. Moreover, many investigators, from Cattell (1886) to Oldfield and Wingfield (1965), have pointed out that a thing must be identified before it can be named, and acts of identification may or may not be the same for given naming responses. The operations of identification and classification, therefore, may be regarded separately from that of naming, even though the first may never occur without the last occurring also. Yet, in the studies cited above, the measuring of latencies for different identifying or classifying activities is invariably confounded with the measuring of latencies for reacting to different stimuli, or using different naming responses, or both.

The present study attempted to test for possible reaction-time differences between different types of classifying operations that were not associated with different types of naming responses or stimulus conditions, and used stimuli other than colors and color words.

METHOD

Subjects

Thirty-six undergraduate male students from the University of Arizona served as Ss, eighteen being used for each of the two experiments. Each S was paid $1.00 per session for his work in five experimental sessions that lasted approximately 30 to 45 minutes each.

Apparatus

An Industrial Electronic Engineers three-unit in-line readout assembly (Series 130) was used to present stimuli consisting either of Arabic numerals (1, 2, 3) or crosses (+). Both the numerals and crosses could be made to appear in groups of one, two, or three identical figures. The stimuli were projected onto a viewing screen as light figures against a dark background. The readout assembly was mounted on a display panel 3 ft. from S in a sound-resistant room. The room was darkened, with indirect lighting sufficient for S to see the viewing screen on the display panel. S's head was held in position by a chin rest mounted on a tripod.

White noise to mask extraneous sounds was presented throughout the course of the experimental sessions. Presentation of the stimuli was programmed through the use of a California Technical Industries 8-channel paper tape reader (Model 220), with successive outputs pulsed by two Hunter Decade Interval Timers. The timers were set to pulse at constant intervals of 1 sec. duration, and S himself controlled a floorswitch to pass current into the tape reader. The tape reader stepped as soon as the floorswitch was closed and again after that each time a pulse was emitted by the timers. The tapes were programmed randomly to allow either 2 or 3 steps after the closing of the floorswitch before the stimulus was exposed. Since S could close the floorswitch at any point before the next pulse from the timers, and he had no way of knowing when this would be, the actual foreperiod preceding the exposure of the stimulus could vary from very near 1 sec. upwards to 2 sec. when the tape was programmed for 2 steps, and from very near 2 sec. upwards to 3 sec. when it was programmed for 3 steps. S thereby not only initiated his own foreperiods, but also was responsible for a random variation in their duration beyond that produced by the way the stimulus tapes were programmed.

The tapes were also punched so as to allow each stimulus to remain exposed for an interval of 2 sec., irrespective of the duration of the foreperiod or of _S_'s vocal response. The presentation of a stimulus caused a Hunter Klockounter to begin measuring _S_'s vocal reaction time in milleseconds. _S_'s vocal response activated a Grayson-Stadler Voice-Operated Relay (Model E7300A) to stop the Klockounter and enable _E_ to record the reaction time. _E_ monitored _S_'s voice response and all sounds made in the experimental room by means of a two-way intercom that _E_ controlled.

Procedure

The research reported in this paper has been divided into two separate experiments, which will be referred to as Experiment I and Experiment II.

The stimuli in Experiment I consisted of single numerals (1, 2, or 3) under one condition, and of crosses (+, ++, or +++) under the other. In Experiment II they consisted of single and multiple numerals (1, 11, 111, 2, 22, 222, 3, 33, 333) under both conditions. Since there were three different possible positions for the single-figure stimuli, each of these was programmed to appear randomly an equal number of times in each of the three possible positions on the viewing screen. Likewise, since each of the double-figure stimuli could occupy either of two possible positions (without separating the figures), they were programmed to appear randomly in each of these positions an equal number of times.

In both experiments, half of the Ss were assigned the task of naming numerals according to their identities, and half were assigned the task of naming the quantity of figures presented (i.e., subitizing them, Kaufman, et al., 1949). Both experiments thus compared the two different tasks according to a between-subjects design, unlike most experiments reported previously. This design enabled each S to have more practice in performing only one type of task, thus removing one of the possible sources of response conflict which several investigators have hypothesized as being a significant factor in studies of this type.

All Ss sat for the same total number of experimental sessions and trials per session. Sessions were held for each S on successive days, except on two occasions in which two of the sessions were separated by a period of about 10 hours on the same day. A total of 136 reaction-time trials were made at each session, with random orders of stimulus presentations predetermined according to the programmed tapes. Two different tapes were used, so that S had a short rest period halfway through each session. The first 9 trials at the beginning of each tape were for warmup only, and only the data collected during the last two sessions, exclusive of the warmup trials, were used in the analysis of results. The first three sessions were regarded as practice sessions.

The designs used for analysis of the data from Experiment I and Experiment II are shown in Table I and Table II, respectively.

In Experiment I, the first task condition (T_1) required the naming of the single numerals 1, 2, and 3. The second (T_2) required the naming of the quantities, or subitizing, of the figures in the stimuli +, ++, and +++. R_1, R_2, and R_3 refer to the different response conditions defined by the responses "one," "two," and "three," respectively.

In Experiment II, the same set of stimuli was used in both task conditions. In the first condition (T_1), the Ss were required to name the numerals presented, irrespective of their quantity. In the second condition (T_2), they were required to name the quantity of numerals presented, irrespective of their identities.

R_1, R_2, R_3 again refer to the three different response conditions, while K_1, K_2, and K_3 refer to conditions defined by the stimulus sets (1, 22, 333), (2, 33, 111), and (3, 11, 222), respectively. The set for K_1, unlike those for K_2 and K_3, contains numerals in quantities equal to the quantities designated by the individual numerals. Each of the stimulus sets was formed to include each type of numeral and each type of quantity.

It should be noted that, except for K_1, the actual stimulus-response pairs are not the same across both task conditions. For K_1, but not for K_2 and K_3, the identical naming response is required for the same stimulus across both task conditions: under both T_1 and T_2, "one" is the correct response to 1, "two" the correct response to 22, and "three" the correct response to 333.

TABLE I

EXPERIMENTAL DESIGN OF EXPERIMENT I

Task	Subject	Response		
		R_1	R_2	R_3
T_1	1 2 3 4 5 6 7 8 9			
T_2	10 11 12 13 14 15 16 17 18			

TABLE II

EXPERIMENTAL DESIGN OF EXPERIMENT II

		Response								
		R_1			R_2			R_3		
		Stimulus Set			Stimulus Set			Stimulus Set		
Task	Subject	K_1	K_2	K_3	K_1	K_2	K_3	K_1	K_2	K_3
T_1	1									
	2									
	3									
	4									
	5									
	6									
	7									
	8									
	9									
T_2	10									
	11									
	12									
	13									
	14									
	15									
	16									
	17									
	18									

RESULTS

Experiment I

Mean reaction-time scores for the Ss under each experimental condition were calculated from the scores remaining after elimination of those associated with response errors. (The highest error ratio for a single experimental condition was 9 out of a total of 216 scores, for condition $T_2R_2K_2$ in Experiment II.) The results of the analysis of variance are shown in Table III; Figure 1 shows the mean reaction times for each of the three response conditions under the two different task conditions.

Figure 1 shows that the numeral-naming group was faster than the quantity-naming group, but the difference between the two groups was not statistically significant. The response effect was significant ($F(2,32) = 38.13$ $p < .001$), and despite the differences in the types of stimuli used for the two different naming tasks, the interaction between the task and response conditions was not significant.

In an effort to compare the times at which the different vocal responses "one," "two," and "three"

TABLE III

SUMMARY TABLE FOR EXPERIMENT I

Source	df	Sum of Squares	Mean Square	F
Task (T)	1	7,005.53	7,005.53	1.74
Subjects w. groups	16	64,476.91	4,029.80	
Response (R)	2	14,843.07	7,421.54	38.13***
T X R	2	168.84	84.42	.43
Subjects w. groups X R	32	6,229.26	194.66	

***$p < .001$

Figure 1.--Mean reaction time for three naming responses to single Arabic numerals and to corresponding amounts of arbitrary symbols.

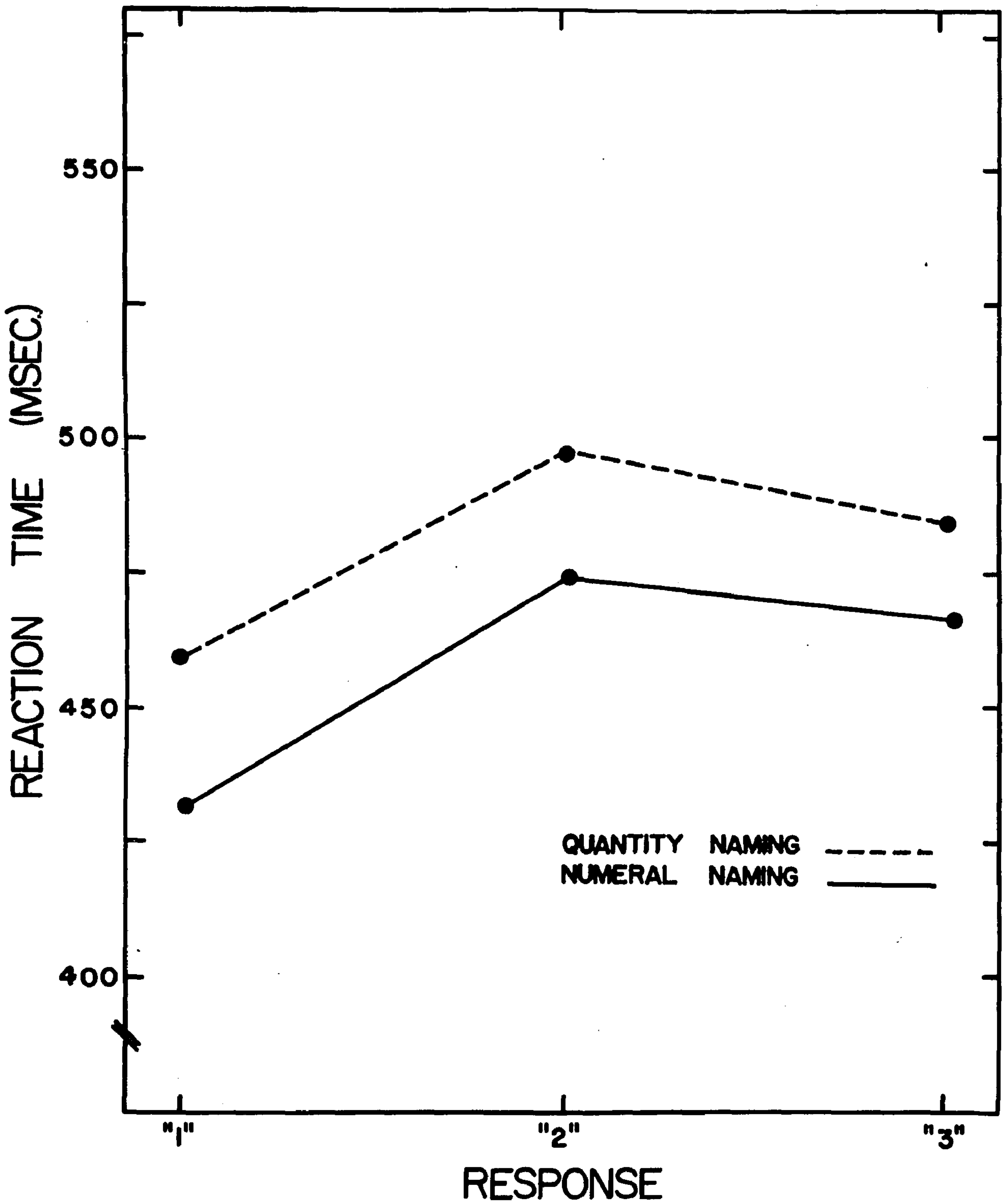
550
500
450
400
REACTION TIME (MSEC.)
QUANTITY NAMING
NUMERAL NAMING
"1"
"2"
"3"
RESPONSE

Figure 1

activated the voice-operated relay, the writer fed each signal as produced by his own voice through an amplifier into an oscilloscope, along with the signal produced by the closing of the relay circuit. Photographs of the resulting traces showed that each response triggered the relay after less than about 50 msec., with "one" requiring about 20 msec. and "two" and "three" requiring about 30-40 msec. The times for other individuals, of course, would show characteristic variations from these times, but there is no reason to believe that the writer's response times were atypical in any particular way.

Experiment II

It is evident from Table IV and Figure 2 that the results of Experiment II bear important differences from those of Experiment I, as well as some interesting similarities. The time required for the numeral-naming task (T_1) was clearly shorter ($F(1,16) = 17.30$, $p < .001$) than that required for the quantity-naming task (T_2). As in Experiment I, significant response differences were found; some, but not all of which can be accounted for by the different sensitivities of the relay.

TABLE IV

SUMMARY TABLE FOR EXPERIMENT II

Source	df	Sum of Squares	Mean Square	F
Task (T)	1	298,282.00	298,282.00	17.30***
Subjects w. groups	16	275,920.01	17,245.00	
Stimulus Set (K)	2	11,678.66	5,839.33	37.86***
T X K	2	3,451.06	1,725.53	11.19***
Subjects w. groups X K	32	4,935.70	154,24	
Response (R)	2	44,813.23	22,406.62	38.64***
T X R	2	5,439.41	2,719.71	4.69*
Subjects w. groups X R	32	18,558.01	579.94	
K X R	4	2,009.79	502.45	8.66***
T X K X R	4	430.54	107.64	1.86
Subjects w. groups X (K X R)	64	4,714.15	58.03	

*$p <$ .05
***$p <$ .001

Figure 2.--Mean reaction time for three naming responses to multiple Arabic numerals under two task conditions, one requiring the identification of individual numerals and the other requiring the identification of the amount of numerals presented.

(The individual curves represent different stimulus sets as defined in the text.)

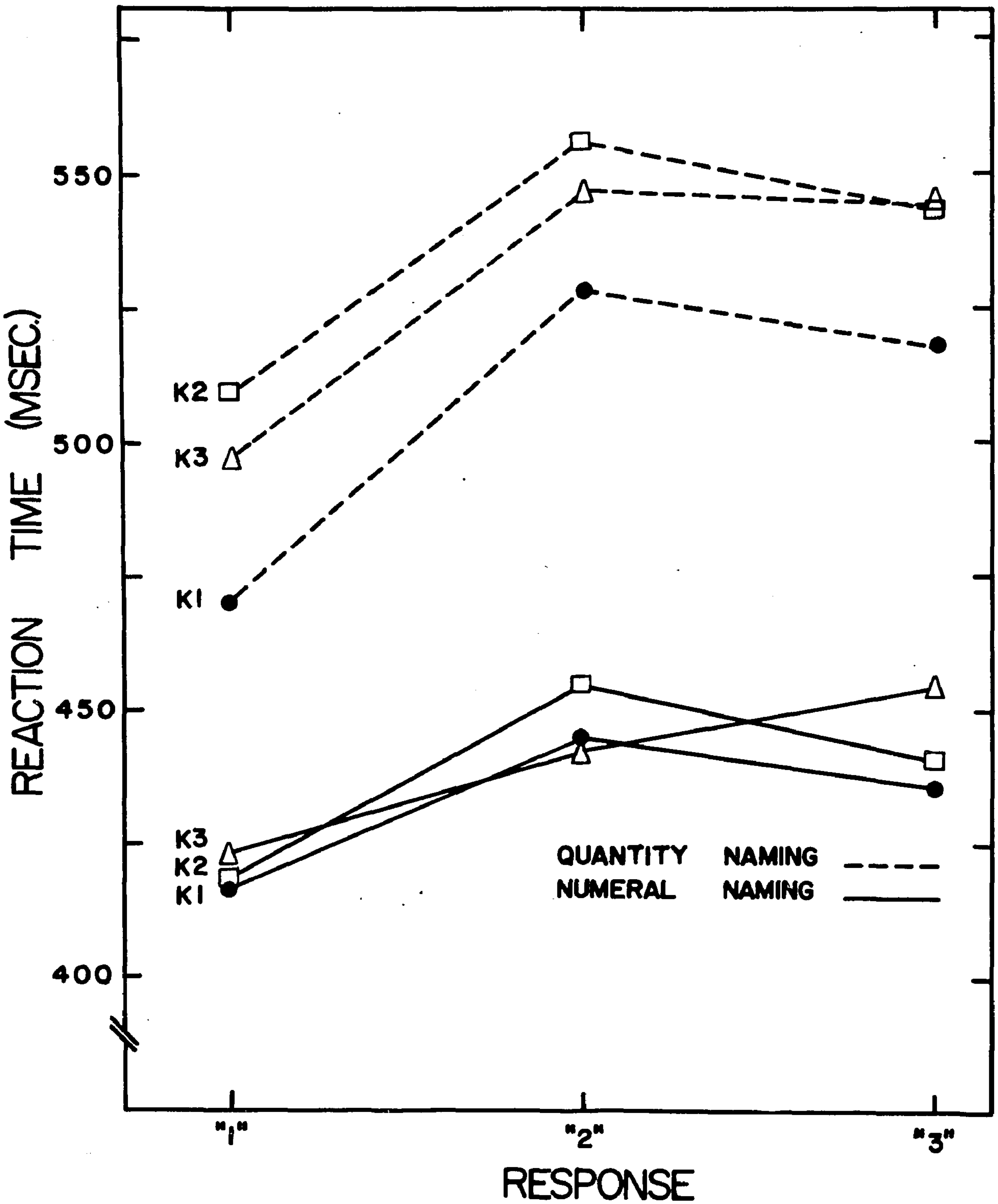
REACTION TIME (MSEC.)
550
500
450
400
K2
K3
K1
K3
K2
K1
QUANTITY NAMING
NUMERAL NAMING
"1"
"2"
"3"
RESPONSE

Figure 2

In an attempt to form a somewhat clearer picture of the differences responsible for the significant stimulus-set and interaction effects, separate analysis of variances tests were carried out on the data included under conditions T_1 and T_2, and *t* tests were used to compare the stimulus-set differences separately under T_1 and T_2.

Table V summarizes the analysis of variance for T_1 (numeral naming) and Table VI does the same for T_2 (quantity naming). The *t* tests confirmed the analysis given in the tables, that significant differences existed between the stimulus-set conditions across both task conditions, and revealed further that although both numeral naming and quantity naming took significantly longer under K_2 and K_3 than they did under K_1 ($df = 8$, $p < .05$), the differences between K_2 and K_3 were not significant either for numeral naming or for quantity naming. K_1, it will be recalled, refers to the condition in which the compatible numeral-quantity stimuli 1, 22, and 333 were used, while incompatible numeral-quantity stimuli were used in conditions K_2 and K_3

A further *t* test confirmed that it actually took longer to subitize the numerals in 1, 22, and 333 with the responses "one," "two," and "three" respectively than it did to name them directly with the same responses (*t* = 5.15, df = 16, $p < .01$). Although the other tests showed that the names and quantities in these compatible numeral-quantity combinations could both be named faster than in the other, incompatible combinations, this fact is overshadowed by the finding that responding "one" to 1, "two" to 22, and "three" to 333 took more time for the subjects subitizing the numerals than for those naming them.

Figure 3 compares the numeral-naming and quantity-naming groups in Experiment I with those in Experiment II. Since the total number of practice trials was the same in both experiments, and 9 different numeral-quantity combinations were used in Experiment II as opposed to 3 in Experiment I, one might have expected the greater amount of stimulus information in Experiment II to have produced longer latencies for numeral naming as well as for quantity naming. However, this was not the case, since no significant difference in numeral-naming times for the two experiments was found by *t* test.

TABLE V

SUMMARY TABLE FOR TASK T_1 (EXPERIMENT II)

Source	df	Sum of Squares	Mean Square	F
Stimulus Set (K)	2	1,240.38	620.19	6.81**
Response (R)	2	9,515.03	4,757.52	16.55***
Subjects (S)	8	95,162.39	11,895.30	
K X R	4	1,732.46	433.12	10.22***
K X S	16	1,457.55	91.10	
R X S	16	4,600.12	287.51	
K X R X S	32	1,355.82	42.37	

**$p < .01$
***$p < .001$

TABLE VI

SUMMARY TABLE FOR TASK T_2 (EXPERIMENT II)

Source	df	Sum of Squares	Mean Square	F
Stimulus Set (K)	2	13,889.34	6,944.67	31.95***
Response (R)	2	40,737.61	20,368.81	23.35***
Subjects (S)	8	180,757.62	22,594.70	
K X R	4	707.87	176.97	1.69
K X S	16	3,478.15	217.38	
R X S	16	13,957.89	872.37	
K X R X S	32	3,358.33	104.95	

***$p < .001$

Figure 3.--Comparison between Experiments I and II of mean reaction time for three number-naming responses under two task conditions, one requiring the identification of individual numerals and the other the identification of the amount of figures presented.

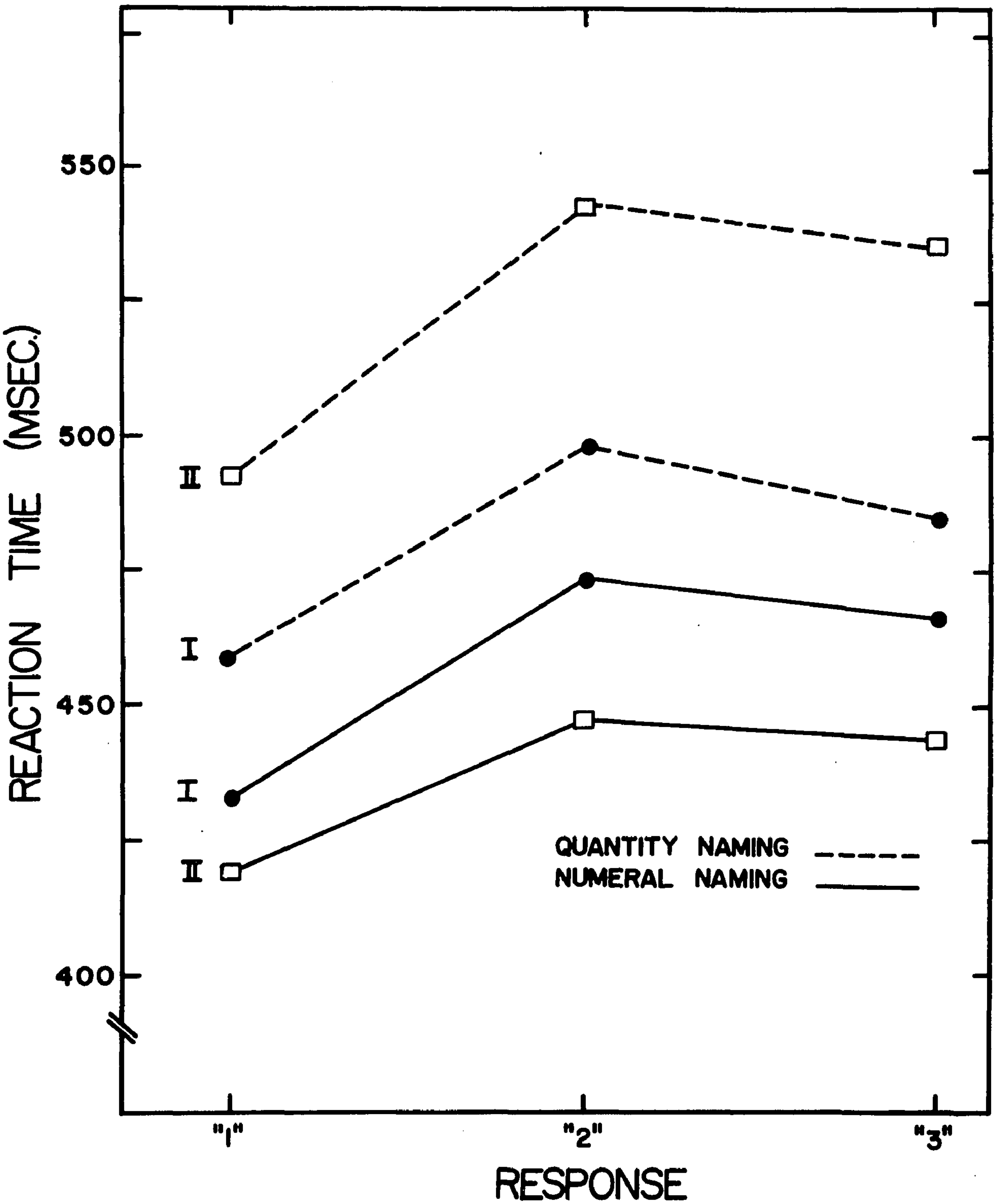
550
500
450
400
REACTION TIME (MSEC.)
II
I
I
II
QUANTITY NAMING
NUMERAL NAMING
"1"
"2"
"3"
RESPONSE

Figure 3

DISCUSSION

The results of the present study offer no clear answer to the question of whether small visual quantities can be named as fast as corresponding Arabic numerals. In particular, Experiment I falls short of conclusively supporting Brown's (1915b) conclusion that small quantities of neutral symbols cannot be named as fast as the corresponding Arabic numerals, just as colors cannot be named as fast as corresponding color words.

Experiment II, however, shows that sets of stimuli which combine both concrete and symbolic number characteristics affect reaction time in much the same way as those which combine both concrete and symbolic color characteristics. The results demonstrate that naming the quantity of a small group of Arabic numerals takes significantly longer than naming the numerals themselves, just as other experiments (e.g., Stroop, 1935) have shown that naming the color of the ink in a color word takes significantly longer than naming the color word itself. The Stroop-type of interference effect, therefore, may be a general type of phenomenon for various types of perceptual identifications and various types of naming responses, and not one peculiar to color identifications and color-naming responses alone.

In addition, however, the inclusion in Experiment II of numeral-quantity combinations which did not disagree or conflict in their concrete and symbolic values revealed something about this type of interference effect that the other studies have not. Whatever the source of the longer time required for naming the quantities of numerals rather than the numerals themselves under condition K_1, it cannot be interpreted as due simply to numeral-quantity disagreement in the particular stimuli in this set. For the stimuli having membership in the set for K_1 lack numeral-quantity disagreement; the quantity designated by the numerals in each stimulus is identical to the quantity of numerals in that stimulus. (The set for K_1 is composed of 1, 22, and 333.)

On the contrary, the longer time required for naming the quantities must be interpreted as due at least in some degree to the presence of numeral-quantity disagreement in other stimuli which might have occurred but did not. In some way, the occurrence of the compatible stimuli in the context of the incompatible ones produced a significant effect on reaction time. This contextual effect, moreover, cannot without difficulty be described in terms of different probabilities of occurrence for the other stimuli and responses which might have occurred, since these probabilities were the same under both task conditions, so far as the conditions of the experiment were concerned.

The fact that significant differences in reaction time between K_1 and the other two stimulus-set conditions also occurred, however, under both task conditions, indicates that the lack of numeral-quantity disagreement in the particular stimuli did have some effect also. Apparently, the absence of numeral-quantity conflict in the stimulus sets for condition K_1 did permit both faster quantity-naming and faster numeral-naming responses than did the presence of such conflict in the other sets, even though the presence of conflict in the other sets made the latencies for responding "one" to 1, "two" to 22, and "three" to 333 slower for the quantity-naming task than for the numeral-naming task. Obviously, if numeral-quantity agreement had existed for all the stimuli, it would have been impossible to determine whether the subjects used in the different task conditions were in fact performing different tasks. For, in this event, all the stimulus-response pairs would have been identical.

Assuming that further experimental efforts with various different types of stimulus materials will bear out the findings reported above, how might the process which leads to a particular perceptual identification and naming response be conceived so as to account for these findings and some of the other findings referred to at the beginning of this paper?

Confining this discussion to naming responses only, it would seem that a stimulus which leads to such a response may do several things. It may not only enable a person to make a certain specific perceptual identification and specific naming response, such as "blue," "round," "small," or "three," but may also lead him to attempt one general type of perceptual identification rather than another, such as one according to color, shape, size, or quantity. Before one can identify something as, say, red, and not blue, green, or some other color, he may have to set out to identify its color and not its shape, size, or some other general feature; and which of these identification tasks he proceeds to undertake may depend, among other things, upon the particular stimulus object itself. (These other things might include previous instructions and knowledge of the set or range of possible stimuli.) The important point is that, once a stimulus is exposed to a subject, it may provoke him to attempt one or more different general types of identifications, each of which may or may not lead to different specific identifications and naming responses.

Klein (1964) refers to this attention-catching capacity of a stimulus as its attensive power, borrowing Titchener's term, and associates it with the semantic relationships of a particular stimulus to others in the context of a particular naming task. The attensive capacity of a particular word or numeral stimulus to provoke its identification according to its verbal or numerical content, instead of according to its concrete sensory characteristics as assigned, would be associated with conflict between different identification tasks as described above. For example, the stimulus 22 might lead a subject assigned the task of identifying the quantity of numerals to identify the numerals themselves, thereby producing a situation of identification-task conflict with no concomitant response-conflict.

It would seem as if our memories were organized to include, in addition to a multitude of different "file-cards" for matching against sensory inputs, a collection of different "file-cabinets." Each cabinet would correspond to a different general type of identification task, and each cabinet might contain cards which are different or identical to the cards in other cabinets. Thus, it might take longer to decide which cabinet to get into, to identify one type of stimulus rather than another, and also take longer to retrieve a card from one cabinet than it would from another, even though identical cards were retrieved from both cabinets.

The fact that reaction time was faster for both assigned tasks of quantity-naming and numeral-naming when compatible numeral-quantity stimulus sets were used suggests that perhaps both tasks were actually performed under both of the assigned task conditions. If it be assumed that both tasks were performed to some degree under both task conditions, then the execution of both tasks would produce less interference if they both called for the same naming response than they would if they called for different naming responses.

However, the fact that reaction time was faster for one of the assigned task conditions (numeral-naming) than for the other suggests that, though both tasks may have been performed to some degree under both assigned conditions, the task actually assigned may have been initiated before the other. If it required more decision-making operations to identify quantities than numerals, the achievement of both tasks would be more likely to occur at about the same time when quantity-naming was assigned than when numeral-naming was assigned, producing more interference from the simultaneous readying of different responses when quantity-naming was assigned than when numeral-naming was assigned.

The analysis above, then, emphasizes three different sources of delay in naming different kinds of stimuli: (1) identification-task conflict (or classification conflict--between attempting to identify a stimulus according to its color, size, or some other general feature rather than another), (2) identification-task differences (which refers to absolute differences in the number of decision-making or coding operations required for some identification tasks in comparison to others), and (3) response conflict (which refers to competition between different naming-response tendencies as readied after performing one or more identification tasks).

SUMMARY

Reaction times for making three naming responses under two different task conditions have been compared in two separate experiments. One task condition required the naming of numerals, and the other required the naming of quantities. The first experiment used the single Arabic numerals 1, 2, and 3 for the numeral-naming task and groups of one, two, and three arbitrary figures for the quantity-naming task. The second experiment used the same Arabic numerals in groups of one, two, and three for both tasks.

The results of the first experiment showed a difference between numeral naming and quantity naming that was not significant. The conclusion of Brown (1915b), that small visual quantities, like colors, cannot be named as fast as their conventional printed designations, was thus not confirmed with a statistically reliable difference.

The results of the second experiment showed a significantly slower reaction time for naming the quantities of numerals in the different groups than for naming the numerals themselves. This was found to be

the case even for the stimuli 1, 22, and 333, which all called for the same naming response under both task conditions. The results also showed, however, that reaction time for responding to the other stimuli, which did not consist of numerals in quantities equal to those named by the numerals, was slower under both task conditions than it was for responding to the compatible numeral-quantity combinations.

The hypothesis of response conflict as the most important source of differences between latencies for naming concrete stimulus features and for naming the corresponding words or symbols which designate them was discussed in connection with the findings of the present study. It was concluded that, in addition to response conflict, an interpretation in terms of identification-task conflict and identification-task differences might also be useful in accounting for the findings.

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