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Limits on the use of category in visual search/

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LIMITS ON THE USE OF CATEGORY IN VISUAL SEARCH

A Thesis Presented

By

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Abstract

The first experiment replicated the basic finding that a target in a visual array can be found more efficiently when it is distinguished by both semantic class (in this case, letter or digit) and identity than when it is distinguished by identity alone (Jonides & Gleitman, 1972). Three further experiments were run to further examine under what conditions this advantage could be obtained. The findings were that if an explicit or implicit identification was required by the response, then the advantages in having the target distinguished by class disappeared. It was found, however, that in at least one case the effect of semantic class could be induced with appropriate instructions and practice. The data supported a model which suggests that subjects can use different processes to classify and/or identify visually presented stimuli.

INTRODUCTION

Kolers (1972) has termed classification as the fundament upon which cognition is built. Much of the current cognitive literature is intended to examine what role classification plays in thinking and consciousness. For instance, most literature on memory search and retrieval deals with how information is semantically classified for storage and retrieval. There are so many examples that it is surprising that visual search and pattern recognition studies have dealt with the classification issue only narrowly, generally using experiments designed to be analyzed in terms of the physical properties of the stimulus. This was perhaps a result of the historical trend toward atomism in psychology, and has been furthered by the work done in physiological single cell recording and in computer pattern recognition research. Much modeling of information processing for tasks that are largely perceptual assume that decisions are based whenever possible on the physical properties of the stimulus, there being many important examples of this, such as the pandemonium model of Selfridge (1959), or the attentional models of Treisman (1969) and Broadbent (1958).

Intuitively, however, most people when they see an orange, immediately classify it with its name and perhaps into the superclass of fruit, and this awareness often seems as strong as awareness of its existence as a sweet smelling, orange colored sphere. To try to reconcile this view with the data

of pattern recognition, some investigators have generated more semantically oriented models such as the analysis-by-synthesis approach to speech perception. On occasion, these models have been offered in opposition to the feature oriented models. One case in point is Norman's (1969) attentional model, which was similar to Treisman's except that it assumed that auditory input was filtered according to both its semantic and physical features at the same stage. Experiments dealing with rapid visual search and encoding have followed a similar pattern in that recently some have dealt with semantic issues. In particular some researchers have found evidence that characters are immediately classified as well as identified, at least in the case of the letter and digit categories. (The terms "classified" and "categorized" will be used interchangeably to denote higher order classification than naming.)

A number of studies that deal with the general issue of classification were done by Posner and his colleagues. Posner & Mitchell (1967) demonstrated that subjects could base a same-different judgment not only upon physical features, but also upon name identity and rule identity (vowel or consonant) matchings in relatively short times (400-900 msec). Other research (Chase & Posner, 1965; Posner, 1969) showed that the physical matches were affected by visual factors such as visual similarity, while the name matches were affected primarily by factors related to the letter name, in particular the presence of other letter names in short term memory. Posner, Lewis, &

Conrad (1972) concluded that since the response times for physical and name matches were systematically affected by different factors, different informational codes must be generated by different, isolable subsystems on the basis of the physical input. They hypothesized that there were parallel levels of analysis (some of which were semantic) of all visual input. They also suggested that levels which took less time to complete were more primitive or basic. Somewhat more directly relevant to the present work are studies that involve immediate classification on the basis of membership in the categories of letter or digit. The letter-digit classification is interesting because it involves extremely well learned long term semantic categories. As such, it may provide clues to the type of object identification used in everyday life, and perhaps to some of the processes used in reading.

One of the first efforts in this direction was by Sperling (1960), who found no effect of category. He presented 4 x 4 arrays of stimuli that consisted of two letters and two digits in each row for extremely short intervals. When subjects were asked to report only letters or only digits, there was a gain over the "immediate memory" task for only one out of five subjects. However, some of Sperling's later research (Sperling, Budiansky, Spivak, & Johnson, 1971) did find a different type of category effect. Subjects saw arrays of letters, one of which contained a digit target in the array. Sperling found that subjects were as likely to be correct when the identity

of the digit was not specified as when it was. He suggested that this meant that the characters were compared to memory representations of all ten digits in parallel.

Lively & Sanford (1972), using the Sternberg memory search task, concluded that subjects could encode the visually presented probe in terms of its semantic category. Subjects were given memory sets made up purely of consonants or digits, and were probed with both consonants and digits. They found a fairly large slope for a graph of the RT-memory set size function when the probe was not of the same category as the memory set. However, this slope was smaller than that found when the probe was of the same category (but not a member of the memory set). This led them to conclude that both the memory set and, more importantly, the probe were encoded and compared by both name and category.

Ingling (1972) found evidence she took as showing classification early in perception. She had subjects locate particular letters or digits in long lists made up of either letters or digits. Both categories of target were sought in both categories of list. The results were that both letters and digits could be found more quickly in a list made up of members from the other category. Ingling further found that choosing targets in such a way as to vary the physical similarity of the target to the background did not affect the main result. She concluded that classification could precede identification early in perception, and that the failure of

the similarity manipulation established that the classification effect was not due to the categories being distinguishable by salient visual features.

Brand (1971) also found that visual search could be done semantically based on class rather than on identity. She used a task similar to that used by Ingling (1972) with two additional manipulations. One was to run a condition in which subjects searched for a unknown letter or digit in a list made up of members from the other category. She found that this latter search was somewhat slower than the search for a specific target, but still faster than the search for a specific target of the same class as the background. From this and from the fact that some subjects claimed that they actually sought "a letter" or "a digit" even when they searched for a specific letter or digit, she concluded that the search was classificatory without prior identification of the target. Her other manipulation was to run some subjects for extra days of practice. Brand had expected that practice could cause adoption of a feature testing strategy, which she seemed to feel intuitively was more efficient. Contrary to expectation, the only subject that had shown evidence for a feature search fell into line with the other subjects, who continued to show the same classificatory strategy. This she attributed to the readiness of this particular categorization as a response, though what level of "response" was not clearly specified.

Posner (1970) likewise, found evidence that letter-digit

classification was a separate level of processing. He used a task in which subjects were to respond "same" or "different" using two different rule identities: in one case to judge same when they were both consonants or both vowels (and respond different otherwise); and in the other case to respond same when they were both letters or both digits. Comparing these cases to a baseline in which the same-different judgment was based on whether both members of the pair had the same name, he found that classification by vowel-consonant took much longer and was affected by the confusability of the letter stimuli. In the case of the letter-digit rule, classification was as fast as the name matches and was only slightly affected by letter confusability. Posner concluded from his data that classification could go on without identification. He further suggested that letter-digit classification and identification went on in parallel, but his evidence for this was admittedly weak.

Dick (1971) found evidence he took to show that identification precedes classification. He presented subjects with single stimuli chosen from sets (equally divided letters and digits) of sizes 2, 4, 8, and 16. Half the subjects named the presented stimuli and half named the category into a voice key. For all set sizes of potential stimuli, RT for the identification task was shorter than for the classification task.

Jonides & Gleitman (1972) demonstrated that how the subject labels the characters is important. They presented cir-

cular arrays of 2, 4, and 6 characters and looked at RT as a function of set size. They found flat functions (essentially zero slope) when the target was a digit in a background of letters or a letter in a background of digits. The combined slope across the two conditions in which the target was of the same category as the background was 26 msec/item. Their critical manipulation was to identify the character "O" as either a letter ("oh") or a digit (zero") for a subject. When "O" was the target, a mean slope of 24 msec/item was found when the specified category was the same as the background and a flat function was found when it was different. The result proved that the classification effect could not be due to simple feature differences between categories. They suggested two possible explanations. One was that it may take fewer features to determine membership, but it would appear that their data rejects this explanation. The other was that the processing repertory was flexible enough to allow category tags to be immediately accessible from the percept, as suggested by Posner (1970).

Egeth, Jonides, & Wall (1972) presented circular arrays varying in size from 1 to 6. The arrays consisted of letters with, on half of the trials, a target defined as any digit. They found a 26.0 msec/item slope for target absent responses but a 3.9 msec/item slope for target present responses. They took the slope for target present responses as evidence for parallel processing of the visual display for target present

or "yes" responses.

Lastly, in a fine study, Nickerson (1972) failed to find an advantage due to category with the use of an accuracy measure. He presented letters and digits that were degraded by visual noise at levels from no degradation to a point where the characters were nearly unidentifiable. Two tasks were used, one in which subjects had to identify the characters and one in which subjects had to classify them as letter or digit. The basis for comparison between the two experiments was to convert the responses from the first task into correct and incorrect classification responses. For instance, if the stimulus was a 5, an identification of "five", "three", or any other digit was called a correct classification, and the naming of any letter an incorrect classification. The hypothesis supported by several other researchers that classification precedes identification predicts that classification performance should be as good as or better than that in the identification task; to the contrary, classification on the identification task was more accurate, suggesting that identification is the more fundamental process.

The problem that the present research addressed itself to was what role the act of classifying and identifying play in early perception. Three different approaches have been taken to model the phenomenon; physical feature models, sequential models, and two-process parallel models. There is also a fourth approach that will be dealt with here, the semantic

feature model.

The physical feature models suggest that there are certain perceptual features that define either or both of the two classes of characters. For example, Ingling (1972) suggested that the digits she used had more small curved lines than the letters she used. According to the feature hypothesis, the effects of category result from the fact that a search for a digit can be a search for a character with a large number of small curved lines, carried on prior to identifying which digit it is. However, models that claim that categorization takes place through this type of physical feature analysis can be rejected on several grounds. First, there are so many features in common between letters and digits that to account for the large advantage of using classification the distinguishing feature(s) would have to stand out greatly. Since several researchers have tried and failed to find such a feature or set of features, it seems unlikely that one exists. Second, different experiments have manipulated the physical similarities between the categories and found that there were no systematic effects on performance in the classification task. These include Ingling (1972), who varied target features, Nickerson (1973), who looked for a relationship between-and-within-class similarities, Posner (1970), who looked for possible within class pairwise similiarities, and Jonides & Gleitman (1972), who looked at the overlap in characters between the categories.

The second type of model (sequential) suggests that identification and categorization are done one after the other, with the second utilizing the information from the first. In fact, the usual way of thinking of letter-digit classification is one form of the sequential model, that one first identifies a character based on the physical input, and then uses this name in determining its category. This model was supported by Dick (1971) in that he found that it took considerably longer to classify a single character than to identify it. Most of the data cited above seems to contradict this hypothesis in that for larger display sizes and in the same-different task, performance from tasks in which classification could be used was at least as good as or better than performance from tasks in which only identification could be used. This identification-first sequential model could, however, be salvaged if, as suggested by Ingling (1972), use of category reduces the information load on the system and thus produces enough efficiency in later stages to make up for the loss of time due to an additional encoding stage. In fact, Jonides & Gleitman (1972) present some evidence that there may be an additional encoding stage for classification as the zero intercepts for the different class target conditions were higher than those for the same class target conditions. However, this interpretation was somewhat tenuous by their own admission. Even this modification has difficulty accounting for all the data, in that studies such as those of Brand (1971) and Ingling (1972) where

so many additional stages are necessary that it is difficult to see how without reverting to an assumption of an unlimited capacity parallel system for this information transformation there could be any gain in RT over straight identification performance.

The other sequential model is that classification is done first and then this information is used to facilitate identification, a possibility mentioned by Ingling (1972), and Nickerson (1973). This model accounts for RT advantages of using classification easily, but has trouble explaining the data obtained by Dick (1971) and Nickerson (1973). This model will be dealt with in greater detail below.

The third type of model assumes that letter-digit identification and classification are two separate stimulus analysis processes and further assumes that they are independent and acting in parallel. This is to say that the percept can elicit two internal codes generated by two different, separate processes. This approach was taken by Posner (1970) and Brand (1971). It raises two interesting theoretical questions, first, why the classification process should be faster in most situations but not in others (e.g., Dick, 1971), and second, whether information from one process can be used to facilitate the other, thus mimicking a sequential model. The first question is interesting in that many studies (Sternberg, 1967; Chase, 1969) it has been shown that such a memory comparison can take considerable time. Some mechanism must be postulated

to account for the rapid classification search. The second question will be dealt with empirically below.

The fourth approach, the semantic feature (opposed to visual) feature model, assumes that classification does not go on separately from identification, but is part of the same process. Since strictly physical feature models have been rejected with some confidence, it is certain that in this type of visual search task what the subject at some point processes is a semantic representation of the stimuli. In other words, both physical and semantic information is sent to higher, decision-making levels of processing. The search, according to this theory, is through semantic codes that can be expected to differ greatly between the classes of letter and digit. As such, the categorical part of the code constitutes a highly discriminable feature of the stimulus, which allows for a very rapid search. An analogy could be made to searching for a red "A" in a background of blue letters, which Smith (1962) showed can allow a very rapid search.

This last theory fits nearly all of the existing data nicely. It can explain the advantages of using classification in visual search, and can also explain some results that have been ignored. For instance, Posner's (1970) data show RT for the letter-digit same-different task to be very close if not identical to that for the name same-different task. The main evidence against this theory is introspective or difficult to interpret. Both Brand (1971) and Posner (1970) state that

some of their subjects reported becoming aware of the category of the characters without knowing their identity. However, other subjects (Brand, 1971) reported becoming aware of category and identity at the same time. The Nickerson (1973) study presents a difficulty, since on the surface this theory ought to predict that "explicit" classification should have been as good as "implicit" classification (i.e., identification) since they would be part of the same process. However, Nickerson points out that the percentage of responses for each class approximates percentage of stimuli of each class in the latter but not in the former task, making the data difficult to interpret.

The present series of experiments were performed to explore the limits of the use of categorical information in visual search tasks. In particular, the parameters characteristic of categorical visual search were examined, and several variations of the basic paradigm (searching for a target of either the same or different class in a field of letters or digits) were employed to determine what processing is involved in the subject's performance on the task. In particular, the "scanning rates" for different display and response situations were compared within and between experiments to see under what conditions the flat (virtually zero slope) or parallel type functions found by Egeth, et al., (1972) and Jonides & Gleitman (1972) could be obtained.

EXPERIMENT I

Experiment I was a replication of some of the conditions run by Jonides & Gleitman (1972). It was felt that in order to interpret subsequent experiments it was necessary to replicate their data, particularly because of our use of the standard H-P character set, which is sometimes dissimilar to standard typeset. In addition to looking at qualitative features of the data, estimates of the slope parameters were also needed for precise evaluation of further experiments.

Subjects. Subjects were 16 faculty and graduate students from the University of Massachusetts Psychology Department. All were naive concerning the objectives of the experiment.

Stimuli. Stimuli were drawn on a Hewlett-Packard 1300A X-Y plotter driven by a HP 2114B computer. Figures were size 2 standard HP characters, each approximately .4" high and .3" wide (about 30' deg. and 20' deg. of visual angle). Characters appeared at various positions on a circle centered on a fixation point (see Figure 1). For set size 2, characters appeared at opposite ends of the horizontal diameter of the circle. For set size 4, there were figures at each end of

Insert Figure 1 About Here

the horizontal and vertical diameters of the circle. Set size 8 consisted of eight characters spaced so as to subtend an equal arc between them, with two figures on the ends of the

horizontal diameter of the circle. Set size 6 consisted of the three uppermost and three lowermost characters of the size 8 display. All letters except I and O and all digits except 1 and 0 were used. Center to center separation of figures along a diameter of the circle was approximately 1.6" (about 2^{o} deg.).

Design. Four between subjects conditions with four subjects in each were defined according to target class and background class (both being either letter or digit). The letter targets were E, P, T, and W, and the digit targets were 2, 3, 6, and 9; every target was randomly chosen and used with both letter and digit backgrounds. Subjects ran through six blocks of 50 trials, the data from the first block being discarded as practice. Each subject had the same target throughout the six blocks. Set size was randomized within a trial block, as were the non-target characters used on each trial. The target appeared randomly on 50% of the trials, and its position in the display was also randomly chosen. Both *yes* and *no* response times were taken for each subject, half of whom had the *yes* response on their dominant hand.

Procedure. Subjects were informed of the task requirements of their condition and instructed to respond as quickly as possible without making any errors. Each subject was run individually in a dimly lit room. Trials began with a cross of duration 600 msec situated at the center of the display circle. The display onset was 400 msec after the offset of

the cross. The computer measured RT as the duration between the display onset and the time the subject pushed either of two buttons, at which time the display was turned off. Feedback concerning the correctness of the response was displayed after each trial, and a 1.5 sec rest period was given after the feedback before the next trial came on.

Results

The data are displayed in Figure 2 and 3, and in Table 1. For the different target condition positive responses, very

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Insert Figure 2 & 3 About Here

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low RT slopes across set size (6.26 msec/item in the digit in letter case, and 6.38 msec/item in the letter in digit case) were found. These slopes did not differ significantly from

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Insert Table 1 About Here

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zero. For negative responses in these conditions, highly positive slopes of 19.0 msec/item for the digit in letter condition and 15.8 msec/item for the letter in digit condition were found. In the digit in digit condition, a slope of 21.7 msec/item for the positive responses was found, and the positive response slope for the letter in letter condition was 37.6 msec/item. The latter seemed spuriously high as one subject had a slope of 60.5 msec/item. For the other subjects, the slope in the letter in letter condition was 30.0 msec/item. The slopes for negative responses was 51.1

msec/item for the digit in digit condition and 45.3 msec/item for the letter in letter condition. The variance of positive responses (and slopes) was much higher for negative responses than for positive responses, and higher when the target was not of the same class as the background characters than when it was.

An analysis of variance in the RTs showed there was no effect of class of target or field that approached significance of class of target or field. Whether or not the target was of the same class as the background was significant ($F(1, 14) = 13.8$, $p < .01$), reflecting the fact that mean RT for the different target class conditions was significantly lower than that of the same target class conditions. Further, the interactions of this factor with response and with set size were significant, ($F(3,42) = 18.2$, $p < .001$, $F(3,42) = 11.9$, $p < .001$, respectively) reflecting significantly lower slopes for different class target conditions and for yes responses. The main effects of set size ($F(3,42) = 6.03$, $p < .001$) and response ($F(1,14) = 35.6$, $p < .001$) were also significant.

The error rate was about 3.5% overall. The breakdown of errors in Table 2 shows several things. The number of errors across target and background conditions was fairly constant,

Insert Table 2 About Here

with somewhat fewer errors being made in the letter in digit condition. Outside of set size 2 (an easy condition), the

number of errors was fairly constant across set sizes, with a slight peak at set size 6. There were many more errors when the target was absent than when it was present, 61 errors against 26 errors.

The intercepts were higher when the target was of a different class than the background, as was found by Jonides & Gleitman (1972). No attempt was made to interpret the intercepts, however, due to the fact that there was some curvilinear trend in the data. In particular, the differences between set sizes 6 and 8 was somewhat larger for some subjects than that between 2 and 4 or between 4 and 6, especially in the same class target conditions, thus opening the possibility of spuriously lowering the intercepts. It could be said that this argument could apply to the slopes also, thus nullifying the whole analysis. However, when the data were subjected to an analysis of variance using only set sizes 2, 4, and 6, and the target class x background class x set size interaction remained significant though the F ratio changed somewhat. Further, the fact that an addition of two items from set size 6 to set size 8 makes much less difference in the different target class conditions than in the same target class conditions, is a valid part of the effect being looked at. It does, however, make the interpretation of the intercepts difficult.

Discussion

These results replicate and extend those of Jonides & Gleitman (1972). They found nearly flat functions for the

different class target _yes_ responses, and these functions have the lowest slope of any in the present experiment. The greater slopes obtained in this experiment may reflect differences in procedure, perhaps the greater number of within subject variables. It would appear, then that slopes for positive responses less than 10 msec/item and not significantly greater than zero can be taken to show a search that uses semantic class as the relevant cue.

The interpretation of the slopes of the negative responses in these conditions is more difficult, since they are much larger and therefore may suggest a serial identity search. Since a classification search should be sufficient to yield a decision, it seems strange that another type of search should be resorted to. However, since subjects had to make both _yes_ and _no_ responses, and since there was a strong set for accuracy, it is not unlikely that they used a rechecking strategy when they did not find the target. In fact, most of them (across all conditions) reported the feeling that they were doing this. That many more errors occurred when the target was absent than when it was present shows some justification for this strategy. It is also not certain that subjects did resort to an identity search, in that they may have used a more extensive classification search (i.e., the same process carried further forward). Thus, the serial type slopes may be an artifact of a need to take more time to build up enough confidence in the response when there are more characters in

the display.

Experiment I failed to answer one important question. Since the responses were simply button pushes, they could have been made on the basis of classification or on the basis of the finding of a name sufficiently different from the others to warrant a quick decision. It was deemed necessary to isolate exactly what kind of interval response (or coding) was actually being made that mediated the "presence" and "absence" responses.

EXPERIMENT II

Experiment II was designed to determine whether the flat functions observed in Experiment I could be obtained when the subjects actually named the target in a classification task. The target was uniquely defined by its class as in the different target class conditions of Experiment I, but for this experiment subjects had to name the target into a voice key. The target changed from trial to trial to be certain that subjects named the target. If a single name response were used throughout, then performance could still entirely be by classification, with the name of the target used in place of a yes as the overt response.

Subjects. Subjects were 8 graduate students in the Department of Psychology at the University of Massachusetts. All were naive concerning the aims of the experiment.

Stimuli. The stimuli were the same as in Experiment I.

Design. Each subject ran in one of two conditions, either

with digit targets with letter non-targets, or with letter targets with digit non-targets. There were four subjects in each condition. Six blocks of fifty trials were run, with the first block being discarded as practice. Target, position of target, non-target characters, and set size were randomly chosen on each trial. The target appeared randomly on 50% of the trials. Set sizes 2, 4, 6, and 8 were used. The responses were either the name of the target or "no" if there was no target.

Procedure. Subjects sat alone in a dimly lit room. Each was informed of the task requirements of his condition, with special emphasis placed on pronouncing the response clearly and correctly. Trials were run in the same manner as in Experiment I except that name responses were made into a voice key. Also, after each trial the correct answer was displayed, and the subject indicated whether he was correct or incorrect by pushing one of two buttons. RT was measured as the time from the display onset to the time an A-D converter was pulsed by the voice key.

Results

Figure 4 shows that the slopes in Experiment II were much greater than in the different class target conditions of Experiment I. The RT-display size functions combined across conditions show slopes of 17.1 msec/item for positive responses and a slope of 26.7 msec/item for negative responses. The positive slope differs significantly from zero ($t(4) = 3.1$,

$p < .05$), as does the negative slope. The target present slope for digit targets was 20.0 msec/item, and the target

Insert Figure 4 About Here

present slope for letter targets was 14.2 msec/item. The target absent conditions had almost identical slopes: 27.3 msec/item for digit targets and 26.2 msec/item for letter targets.

An analysis of variance showed that there was on effect of target category or interaction involving it that approached significance. The analysis showed significant effects of response, ($F(1,6) = 26.5$, $p < .005$), set size ($F(3,18) = 25.1$, $p < .001$), and the interaction of response and set size ($F(3, 18) = 3.75$, $p < .05$). The error data (Table 3) showed much the same pattern as was found in Experiment I in that there

Insert Table 3 About Here

were many more errors when the target was absent than when it was present. There were somewhat more errors for larger set sizes in this experiment. Since large slopes were found in Experiment II, use of a speed-accuracy tradeoff to explain the failure to find the low slopes of the different target class conditions of Experiment I is not possible. Such an explanation would necessarily say that the greater slopes of Experiment II were due to subjects making fewer errors on larger set sizes.

Discussion

The slope of the combined letter and digit target conditions was clearly in the range of the same target class conditions of Experiment I, 17.1 msec/item against 20.4 msec/item. Thus, the slopes of the target present response functions suggest the use of identity rather than category as the basis of the visual search. This hypothesis was strengthened by the closeness of the slope for the digit targets in this experiment to that for the digit in digit condition of Experiment I, 20.0 msec/item against 21.7 msec/item. However, the same function for letter targets had a slope of 14/2 msec/item against 30.0 msec/item (see discussion for Experiment I above) in the letter in letter condition of Experiment I. There is evidence that suggests that the difference is explained by differences in strategy both between and within subjects. Subject 5 in the present experiment had the lowest slope of all (8.8 msec/item), and introspectively described a two stage strategy in which she first located a position where she thought there was a letter and then identified which letter it was. Subject 3 spontaneously reported changing strategies from one where he felt he was naming the characters to a strategy similar to that of Subject 5. The block by block summary output from the computer for him showed a change from a fairly steep slope of 20.6 msec/item for the first three blocks to a nearly zero slope of 2.6 msec/item for the last two blocks of trials.

It was surprising that subjects did not use category as the basis of their search, as all manipulations were identical to those which had shown such a search in Experiment I with two exceptions. First, the subject had to name the target and second the target changed from trial to tial. It thus seemed necessary to be certain that search by classification could be found under these two conditions.

THE EFFECTS OF INSTRUCTION

Since Brand (1971) found that with practice, subjects could change from a search where she thought they were using primarily feature information to a search where they were using category information, it seemed necessary to run some subjects on the naming task of Experiment II for several extra days. The method of running subjects was the same as on the first day, with one exception; they were instructed to locate the target by first detecting the presence of a member of the target category and then naming it. The question was whether, with a different bias, the same subjects could use a classification search. Five of the original 8 subjects were run for 3 extra days. Only five were run since 2 had already shown this strategy, and one was unavailable. All were paid for participation.

Results

Figure 5 shows the changes in slope over days (the first day, under different instructions, was included as day 1 on the graphs). All but Subject 5 showed a sharp drop in slope

Insert Figure 5 About Here

from the first to the second days for the target present function, and most showed a gradual rise after the second day. Subject 5 showed a gradual drop until the last day, when the slope fell off precipitously. The target absent functions were more variable. All except Subject 3 showed a continuous drop until the slopes for the absence functions were nearly as low as or lower than those for the presence functions.

Table 4 shows the absolute RT's for responses over days, and these were somewhat correlated with the slopes. There was a sharp drop for both absence and presence responses under the

Insert Table 4 About Here

new instructions. The mean RT for target present responses showed a slight drop despite the rise in slope for all but one subject. The exception was Subject 5, who showed a 30 msec drop from Day 3 to Day 4. This was his largest change between days and corresponded to the largest change in slope for his RT-display size functions. The RT for target absent responses declined over days for all but one subject, for whom there was little change. On all three practice days, this subject had nearly equal presence and absence RT's, as did four out of five subjects on Day 4.

The RT data were cast into an analysis of variance. Both the day and response effects approached significance ($p < .07$

for both). The lack of significance for the day effect reflected the inconsistency of subject performances. The response effect was not significant due to the change from disparate to nearly equal RTs across days, but the day response interaction was significant ($p < .05$).

The error data showed some surprising changes in one trend over the previous experiment (see Table 3). Even on the first extra day there were more errors when the target was present than when it was absent, 11 errors to 5 errors. This was true across days by a wide margin, 37 errors to 8 errors. Except for display size 8 the number of errors was nearly constant across display sizes, and the number of errors fell off by Day 3, even though there was a decrease in RT.

Discussion

The results seem to show that with appropriate instructions, the slopes of the target present function can reach levels taken to show classification search, even if, as in the case of Subject 5, it takes considerable practice. One possible problem is that the effects of practice were confounded with the effects of instructions. However, it was felt that the sudden, sharp change in slope taken along with the introspective evidence cited above, does argue for a qualitative change in processing after Day 1. Further, the slope of the target absent functions, which had in previous experiments seemed rather large, fell into line with the result found by Jonides & Gleitman (1972), in that the presence

and absence slopes were similar for most subjects. This low slope value for the target absent function indicated a classification search. Finally, in another experiment (Experiment IV, below) in which there were no special instructions to change processing, there did not appear to be any change in processing over two days of practice as there was in Experiment II. This evidence is somewhat tenuous, in that the later experiment involved another task.

EXPERIMENT III

Experiment III was run to verify that the use of the voice key and/or the changing of the target did not determine the type of processing. Also, the Experiment II indicated that in Experiment I, the responses made in the different class target conditions were not based on the identity of the particular target. It was hoped to further strengthen this evidence.

Methods

Subjects. Subjects were 6 graduate students at the University of Massachusetts. All participated voluntarily and were naive concerning the aims of the experiment.

Stimuli. The stimuli were the same as in Experiment II.

Design. The design was exactly the same as in Experiment II, except that the subjects responded "Yes" or "No" depending on whether there was a member of the target class present.

Procedure. The procedure was the same as in Experiment II.

Results

The different class target conditions of Experiment I were replicated, as can be seen in Figure 6. The slope for the target present function combined across both target classes

Insert Figure 6 About Here

was 7.2 msec/item with an intercept of 486 msec. The slope of the target absent function was 23.3 msec/item with an intercept of 474 msec. An analysis of variance showed significant main effects of response ($F(1,4) = 12.8$, $p < .025$), display size ($F(3,12) = 16.9$, $p < .001$), and a significant interaction between response and display size ($F(3,12) = 6.31$, $p < .01$). No effect involving which class was used as the target approached significance.

The error data (see Table 5) showed there were more errors when the target was absent than when the target was present. The number of errors was once again not related to set size.

Insert Table 5 About Here

Discussion

Slopes indicating a classification search were found in this experiment. The slope of 7.2 msec/item for the target present function was very close to the 6.3 msec/item slope for the different class target conditions of Experiment I. The target absent function slope of 23.3 msec/item was only slightly higher than that of 17.4 msec/item for Experiment I.

The error data also followed the same pattern as the different class target conditions. The obvious conclusion to be drawn from this was that the identity search functions found for the first day of Experiment II were not due to the voice key or to the changing of the target from trial to trial. The response was an identification for Experiment II and a classification for Experiment III, and this strongly suggests that these were produced by two separate processes.

Nickerson (1973) suggested the use of response accessability to reconcile the results of Dick (1971) with those of Brand (1971) and Ingling (1972). It appears (his explanation was somewhat unclear) that he wanted to postulate first a model with a response stage in which the name is more accessable to the character than the class, and second, one or more prior stages for which classification is faster than naming, though the difference is not as great as in the response stage. In Dick's experiment, since subjects had to respond to every character they saw, they were faster at naming than at classification. In the experiments of Brand and Ingling, subjects did not have to respond to most characters, so classification was faster. Since the number of characters per response was the same in Experiments II and III, this theory would predict that the difference in processing between them as measured by RT would be an additive (intercept) effect. To the contrary, the index of difference is the slope. However, the response stage was the critical factor in determining what kind of

processing was used. The response required may be more important in determining the control processes (Egeth, et al., 1973) rather than as a question of accessability.

EXPERIMENT IV

Experiment IV was run to see what the limits on classification were, and in particular to see if classification precedes identification. The major manipulation was to use some characters from the target category as background items. For convenience, only digit targets were used in this experiment, since there had not been any significant effects attributable to class in the previous experiments beyond whether the target and background were of the same or different class. Some advantage using classification was expected, as over 70% of the characters seen by the subjects were letters.

Methods

Subjects. Subjects were 8 undergraduates at the University of Massachusetts who received experimental credit for participation. Each subject participated for two sessions on separate days.

Stimuli. The stimuli were the same as in Experiment I with one difference. One or two figures of the target category appeared on some trials as background items.

Design. All subjects ran for two sessions of five blocks of forty trials, the first block being discarded as practice. Each subject had a particular target digit for both experimental sessions. The target appeared on one-third

of the trials, and on one-half of these trials one other digit (never the target) appeared. Of the trials still not accounted for, one-half (or one-sixth of the total trials) had displays with one non-target digit; and on the remaining one-sixth of the trials, two non-target digits appeared. Thus, the probability of a "yes" response given the presence of either one or two digits was one-half, and the overall probability of a "yes" was one-third.

Procedure. Essentially the same procedure as in Experiment I was followed, except that subjects were informed that though most characters would be letters, some digits other than the target could appear.

Results

The results are displayed in Figure 7 and Table 6. The RT-display functions show fairly steep slopes. The target (T) and target plus one digit (T+D) conditions have slopes of 17.1

Insert Figure 7 & Table 6 About Here

msec/item and 17.2 msec/item, respectively, combined across days. Both differed significantly from zero, $t(7) = 2.9$, $p < .025$. The data from the first day showed the T and T+D conditions to have slopes of 20.4 msec/item and 19.5 msec/item, very close to the 21.8 msec/item slope of the digit target in digit background condition of Experiment I. Both these conditions had lowered slopes on the second day. The target absent conditions had steep slopes (for the data pooled across days

data) of 33.0 msec/item for all letter displays (L), 31.6 msec/item for letter plus one digit displays (1D), and 40.5 msec/item for the letter plus two digit displays (2D). The slopes of the 2D were non-significantly the largest on both days.

An analysis of variance showed several effects to be significant. The days differed ($\underline{F}(1,7) = 8.6$, $\underline{p} < .025$) as did the display conditions and the display sizes ($\underline{F}(4,28) = 6.21$, $\underline{p} < .005$), ($\underline{F}(3,21) = 45.21$, $\underline{p} < .001$), the latter being a result of the high slope values. No interaction involving days was significant. The display condition by display size interaction was significant, ($\underline{F}(12,34) = 5.53$, $\underline{p} < .001$). This interaction was due to a difference between the target absent and target present conditions. The two target present conditions did not differ significantly, nor did the three target absent conditions, though the 2D condition was higher in slope values than the other two conditions for most subjects.

Discussion

The data clearly show an identity search. The first day slopes of the T and T+D conditions are nearly identical to the presence slopes of the digit in digit condition of Experiment I. The slopes of the L, 1D, and 2D conditions were somewhat lower than that of the target absent function, but since the absence functions of the identity search condition were the most variable of Experiment I, this difference was neither significant nor unexpected. The mean RT across conditions of

551 msec in the present experiment was very close to the 531 msec obtained in the digit in digit condition of Experiment I.

The even distribution of errors once again rules out the possibility of a speed-accuracy tradeoff. However, on both days the number of errors in the target present conditions was smaller than in the target absent conditions. Given that there were twice as many target absent as target present displays, the differences was quite large. The most likely explanation for this was that subjects may have had some tendency to use classification even though they primarily used an identification strategy. An attempt to counteract this response competition may have created a bias to respond "no" when there was a digit present.

GENERAL DISCUSSION

The results of the present research can be summarized as follows. Experiment I replicated the phenomenon reported by Egeth et al., (1972) and Jonides & Gleitman (1972) of an extremely rapid visual search when semantic class was as much of a distinguishing feature of the target as its identity. With a relatively small number of subjects, two ranges of slopes for the RT-display size curves were established: one of around 21 msec/item when only the identity of the target was unique, and one of around 6 msec/item when both the identity and the class of the target were unique. Nearly all of the subject's data were clearly very close to one or the other; in particular, if the response required an explicit or implicit

identification then the higher slope value was found regardless of whether the class of the target was unique. Experiment II required an explicit identification response in the case where the target was distinguished by class, and, by the above criterion, a search by identity was inferred. However, it did appear that with appropriate instructions (and/or practice) a form of classification search could be used in this task. Experiment III used an explicit classification response under exactly the same stimulus conditions as were used in Experiment II, but in this case a clear case of search by class was found. Experiment IV required an identification since semantic class was a cue only for rejecting most but not all non-target characters. The data showed a strict identity search, with no apparent facilitation due to semantic class. The classification-first and semantic feature models can be rejected for a variety of reasons, and the data of all four experiments are consistent with the two-process parallel model.

The sequential model in which classification precedes and facilitates identification (as suggested by Ingling, 1972) can be rejected on the basis of Experiments II and IV. In Experiment II, for target present responses, this model predicts rejection of non-target characters on the basis of class (i.e., with a small processing time per item) and a constant increment of reaction time added to the RT for each set size for an additional stage necessary to identify the character already classed as being of the target class. In other words, slope

values for search by classification (but with a higher intercept) should have been found for target present responses. This was clearly not the case.

Experiment IV presents evidence against this model in much the same way. If classification was a precursor to identification then it should have been possible to reject non-digits at the rates found for a classification search (i.e., about 8 msec/item), or more conservatively, on the average at faster rates than in an identity search, as would be predicted by a model in which there was a probability mixture of the identification processes either by trials or from character to character. Further, since a digit can only be rejected only on the basis of identity, each digit added to the display should add an increment of RT. If the functions could be relied on to be parallel, this would be equivalent to saying that the T and T+D conditions should be parallel with a higher intercept for the T+D condition, and that the target absent condition would be parallel with a predicted ordering of intercepts of L, 1D, and 2D. Since there was no a priori way to know how the extra digits would interact with the hypothesized rechecking strategy (see Experiment 1), the strong statement about parallelism and intercepts cannot be made, particularly for the target absent conditions. However, this model must necessarily predict the ordering of conditions given above for each set size. The T and T+D conditions were indeed parallel, but the 6 msec/item difference in intercept was very much smaller than

the 20 msec/item scanning rate found for the target present functions for the identity search conditions. The predicted ordering for the target absent conditions was found for display sizes 6 and 8, but attempts at finding significance using a matched t-test yielded no significance better than .25. In fact, for some subjects, the 2D condition was faster than the L condition.

The semantic feature model can be rejected in its general form for much the same reasons as the classification-first sequential model. If semantic class is an identifying feature of a character, then it should "stand out", which is to say, it should serve to point out which characters to analyze further to find their identity, in much the same way classification would direct identification in the classification-first sequential model. Thus, the semantic feature also predicts classification search slopes for Experiment II, and the same ordering of conditions in Experiment IV. If necessary, other experiments could have been run to distinguish between these two models. Neither of these predictions holds for the data. This model is salvageable by assuming that subjects normally attend to only one of the two types of information in the interval coding, and that the response determines which is attended to in a particular task. However, this model would then not be distinguishable from the two process parallel model, which makes the predictions shared by the two in a simpler way.

The present findings are all consistent with the model that suggests that classification and identification are two separate, non-sequential processes (this implies that only one can underlie the response). For Experiment II, this model predicts that since a subject must use one or the other type of information and since identification is required by the task, the high slope value indicative of an identity search would be found. This was obtained. Since Experiment III required a classification response, it was again possible to use classification; this was clearly obtained. In Experiment IV, to achieve the high degree of accuracy found it was necessary for the subjects to at some point identify any digits appearing in the display. Since identification is required and classification is postulated to be a separate process in this model, it predicts that the high value of slopes would be found in Experiment IV. This prediction was consistent with the data. Thus, it appears this model best explains the data, and that the suggestion made by Theios (1974) that "humans have a number of stimulus identification subroutines which they bring into use depending upon the context of the task" draws support from the present study. Further, his suggestion that the response required of the subject is the critical factor in determining processing also appears to draw considerable support, because the most critical manipulation in this research involved changing the response. The question of whether these two processes go on in parallel (as suggested in the

introduction) or whether only one at a time can be used cannot be answered with certainty.

One distinction is important to make. There appears to be a natural mode of processing for this task, but other modes may be possible with practice and/or appropriate instruction, as shown by the data from days 2-4 of Experiment II. When subjects enter the experimental situation they seem to classify and identify separately, but with appropriate instructions they seem to achieve the type of processing predicted by both the classification-first sequential and the semantic feature models for the task. The proper instructions seem to be necessary, both because of the reasons cited in the discussion of Experiment II, and without special instructions no change in processing appeared between days 1 and 2 in Experiment IV. Thus, it appears that some control processes that are at least partially under the voluntary control of the subject are central to the use of letter-digit classification in visual search. As Egeth, et al. (1973) suggested, the classification effect may be important as a way of getting at how control processes direct the flow of information.

The question of why a categorizer should be faster than an identifier in a visual search task still remains. One factor that may, perhaps, be eliminated as a cause is the access to long term memory that this task requires, as it appears that this stage is an (relatively) unlimited capacity parallel process. It must necessarily be true that a class-

ification requires at least as large a feature list (or perhaps set of templates) as an identification. Therefore, if the number of characters to be recognized were a major determinant of RT, a search for a letter target in a digit background would be expected to be slower than for a digit target in a digit background. The opposite is true, suggesting that the number of potential characters to be recognized does not affect the rate of processing and thus that memory access for recognition of these characters is parallel and of unlimited capacity. Jonides & Gleitman (1972) made the related suggestion that the classification effect was due to classification requiring the stimuli be mapped only onto two codes while identification requires mapping onto many different codes. This had some support in that the tasks whose response would require such a mapping did show an identity search in the present study. However, this explanation fails on two counts. First, it suggests that the letter in letter conditions should be significantly slower than the digit in digit conditions. In Experiment I, despite slope differences there was no significant difference in mean reaction time. In Experiment II, the difference was in the opposite direction; the letter in letter condition was nonsignificantly faster than the digit in digit condition. Second, the major index of difference between classification and identification was a change in RT over display size. Since the number of internal labels does not change with display size, the internal mapping cannot by

itself account for the classification effect.

What is probably the best model does involve the difference in internal mapping between classification and identification. Identification involves mapping the characters onto many semantically similar names, while classification involves a mapping onto two semantically very different names. What this might imply is that since the classification process need only deal with two, discriminable names the amount of noise in that system is very low, while in the identification system, there are a given display number of different, but semantically similar names, causing a fairly high level of noise. Thus, the classification system could accurately use a low cutoff relative to the identification system, yielding lower mean RT's. For larger display sizes, the difference in the amount of noise could be expected to be greater due to the larger number of labels involved in the identification system, thus causing a larger slope for the identification task.

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Table 1

Slopes in Msec./Item and Intercepts

in Msec. of Regression Lines of Experiment 1

		Same Class			Different Class		
Response		Digit Target	Letter Target	Average Same	Digit Target	Letter Target	Average Different
Yes	Slope	21.8	30.0	25.9	6.3	6.4	6.3
	Intercept	381	326	354	393	408	400
No	Slope	51.1	45.3	48.3	19.0	15.8	17.4
	Intercept	317	351	334	376	411	394

Table 2

Mean Percent of Errors for

Conditions of Experiment 1

Response	2	4	6	8	Average
		Display Size			
		Same Class Target			
YES	2.1	.5	1.6	1.0	1.3
NO	2.0	4.8	4.4	4.8	4.0
Average	2.1	2.7	3.0	2.9	
		Different Class Target			
YES	1.6	2.1	2.6	2.1	2.1
NO	2.1	2.6	3.2	4.8	3.2
Average	1.9	2.4	2.9	3.5	

Table 3

Mean Percent of Errors for All Days of Experiment 2

Day	Response	Display Size 2	4	6	8	Average
	YES	0	0	0	.4	.1
1[a]	NO	1.6	.4	3.2	4.4	2.4
	Average	.8	.2	1.8	2.4	
	YES	.6	2.6	1.3	2.6	1.8
2	NO	1.9	.6	.6	0	.8
	Average	1.3	1.6	1.0	1.3	
	YES	1.3	2.6	3.2	4.5	2.9
3	NO	0	0	0	.6	.2
	Average	.7	1.3	1.6	2.6	
	YES	.6	0	1.3	3.2	1.3
4	NO	0	.6	0	.6	.3
	Average	.3	.3	.7	1.9	

[a]Day 1 includes data from eight subjects. Days 2-4 include data from five subjects.

Table 4

Slopes and Mean RT's for Practiced

Subjects of Experiment 2

Day	1[a]		2		3		4	
Response	YES	NO	YES	NO	YES	NO	YES	NO
Slope[b]	18.4	28.0	10.5	19.1	11.5	14.1	9.7	11.9
$\overline{RT}$	518	620	444	496	415	448	408	521

[a] Only the five subjects who were run for four days are included in the day 1 entry.

[b] Slopes are in msec/item and $\overline{RT}$ is in msec.

Table 5

Mean Percent Error for

Conditions of Experiment 3

	Display Size				
Response	2	4	6	8	Average
YES	3.2	3.7	1.6	4.3	3.2
NO	7.5	3.7	9.7	4.8	6.4
Average	5.4	3.7	5.7	4.6	

Table 6

Slopes in Msec./Item and Intercepts

in Msec. for Experiment 4

Day		Condition T	T+D	L	L+D	L+2D
1	Slope	20.4	19.5	39.2	33.3	40.5
	Intercept	446	446	376	427	407
2	Slope	14.0	15.2	26.8	30.1	40.4
	Intercept	427	436	381	397	350

[a] See text for explanation.

Table 7

Mean Percent Errors for

Conditions of Experiment 4

Day	Condition	Display Size 2	4	6	8	Average
	T	3.8	0	2.8	0	1.7
	T+D	1.4	1.9	1.4	1.4	1.5
1	L	.2	0	.7	.7	.4
	L+D	0	1.4	0	1.9	.8
	L+2D	.5	.9	.5	.5	.6
	T	.5	2.3	.5	1.4	1.2
	T+D	.5	.9	.9	3.3	1.4
2	L	.2	.2	0	.2	.2
	L+D	0	.9	.5	.5	.5
	L+2D	.9	.5	.9	.5	.7
	Average	.8	.9	.8	1.0	.9

Figure Captions

Figure 1. Display conformation for all experiments. Set size 2 had characters at positions D and E, set size 4 at positions A, D, E, and H, set size 6 at positions A, B, C, F, G, and H, and set size 8 at all positions.

Figure 2. Mean reaction time as a function of display size for Experiment I. The parameters are response (yes vs. no) and same vs. different class targets.

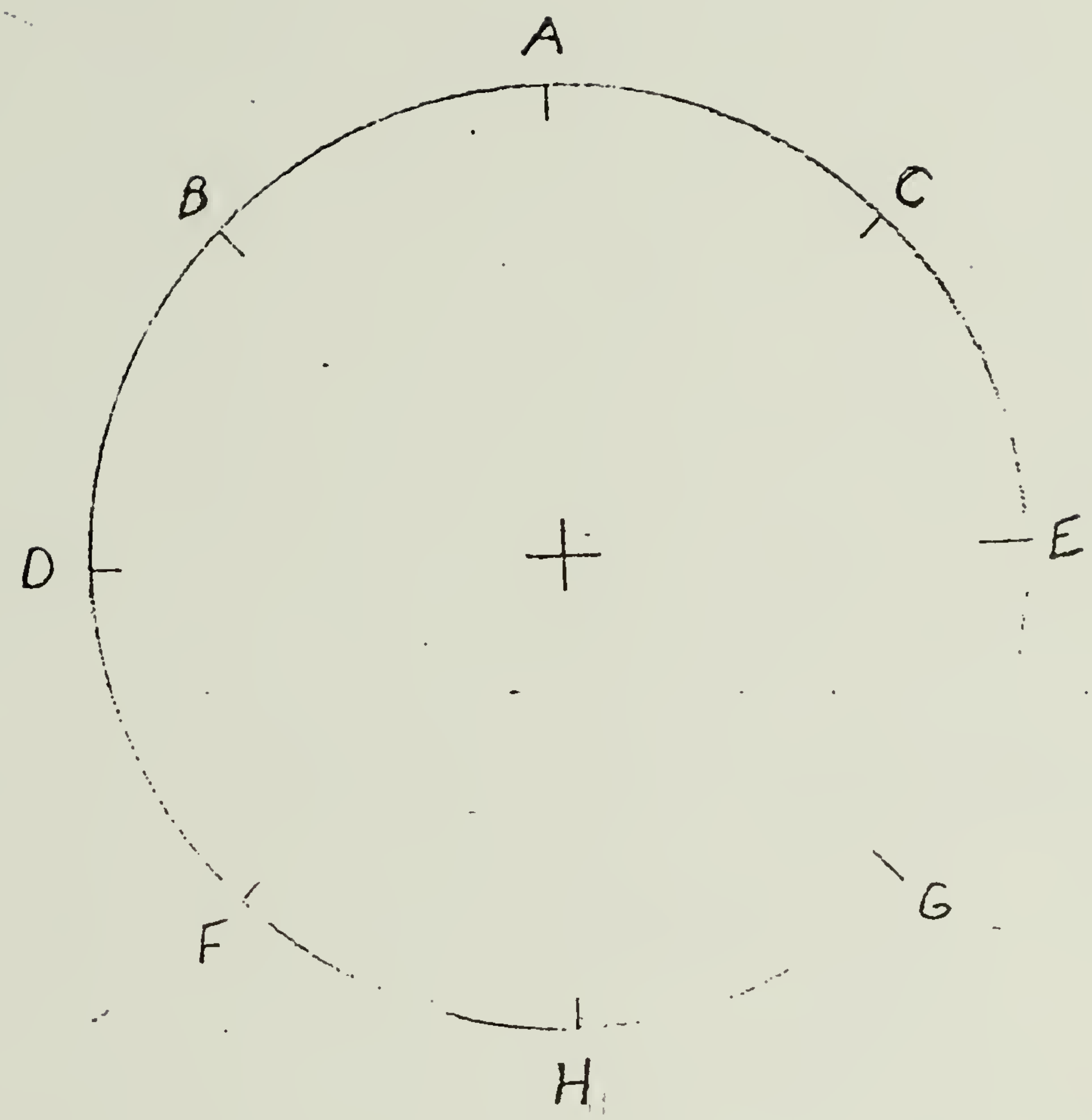
Figure 3. Mean reaction time as a function of display size for Experiment I. The parameters are the different target and background class conditions and response (yes vs. no).

Figure 4. Mean reaction time as a function of display size for Day 1 of Experiment II. The parameter is response (yes vs. no).

Figure 5. Slope values in msec/item as a function of days in Experiment II. The parameter is response (yes vs. no). Only the five subjects who ran for four days are represented.

Figure 6. Mean reaction time as a function of display size for Experiment III. The parameter is response (yes vs. no).

Figure 7. Mean reaction time as a function of display size for Experiment IV. The parameter is display condition (see text for explanation).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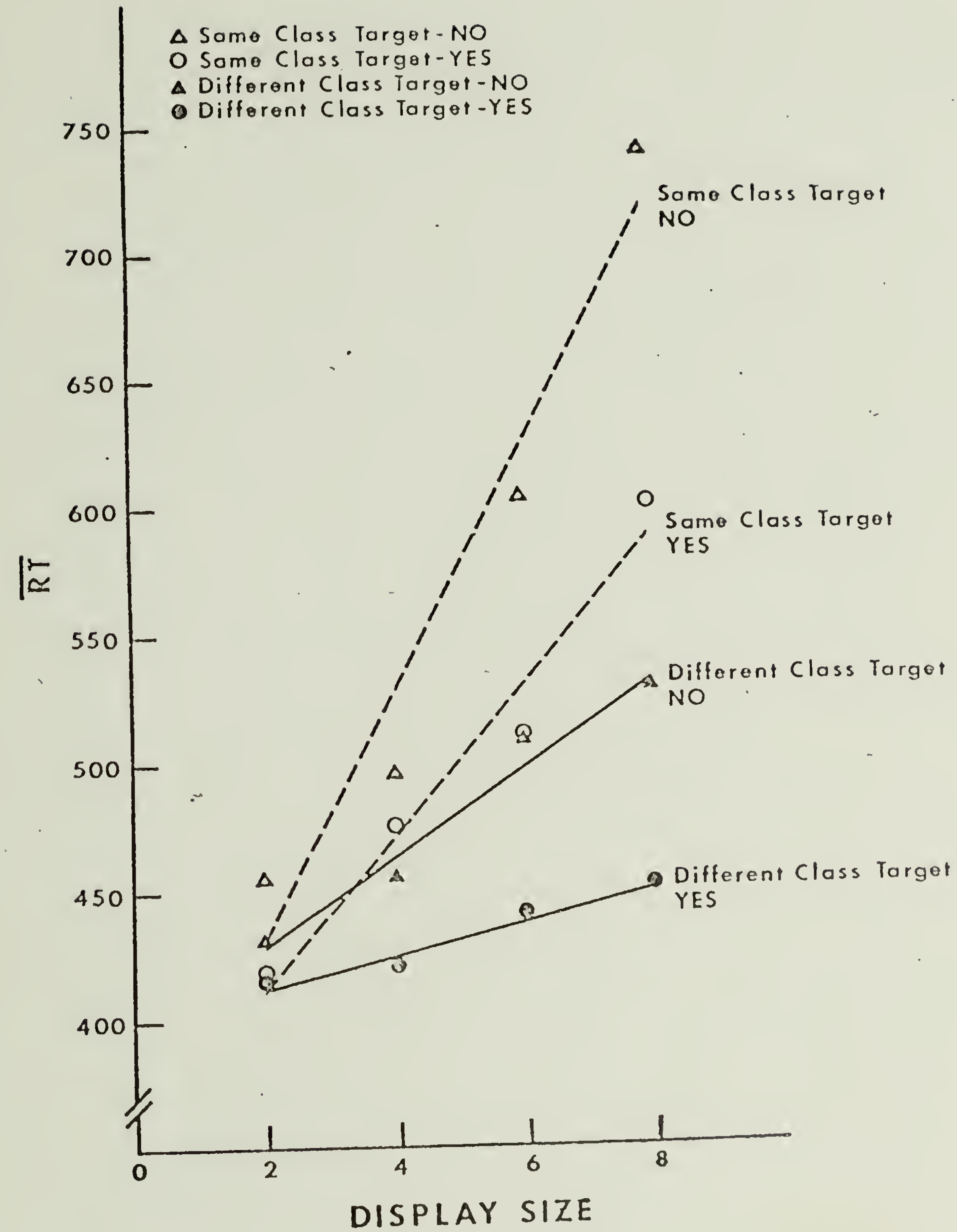

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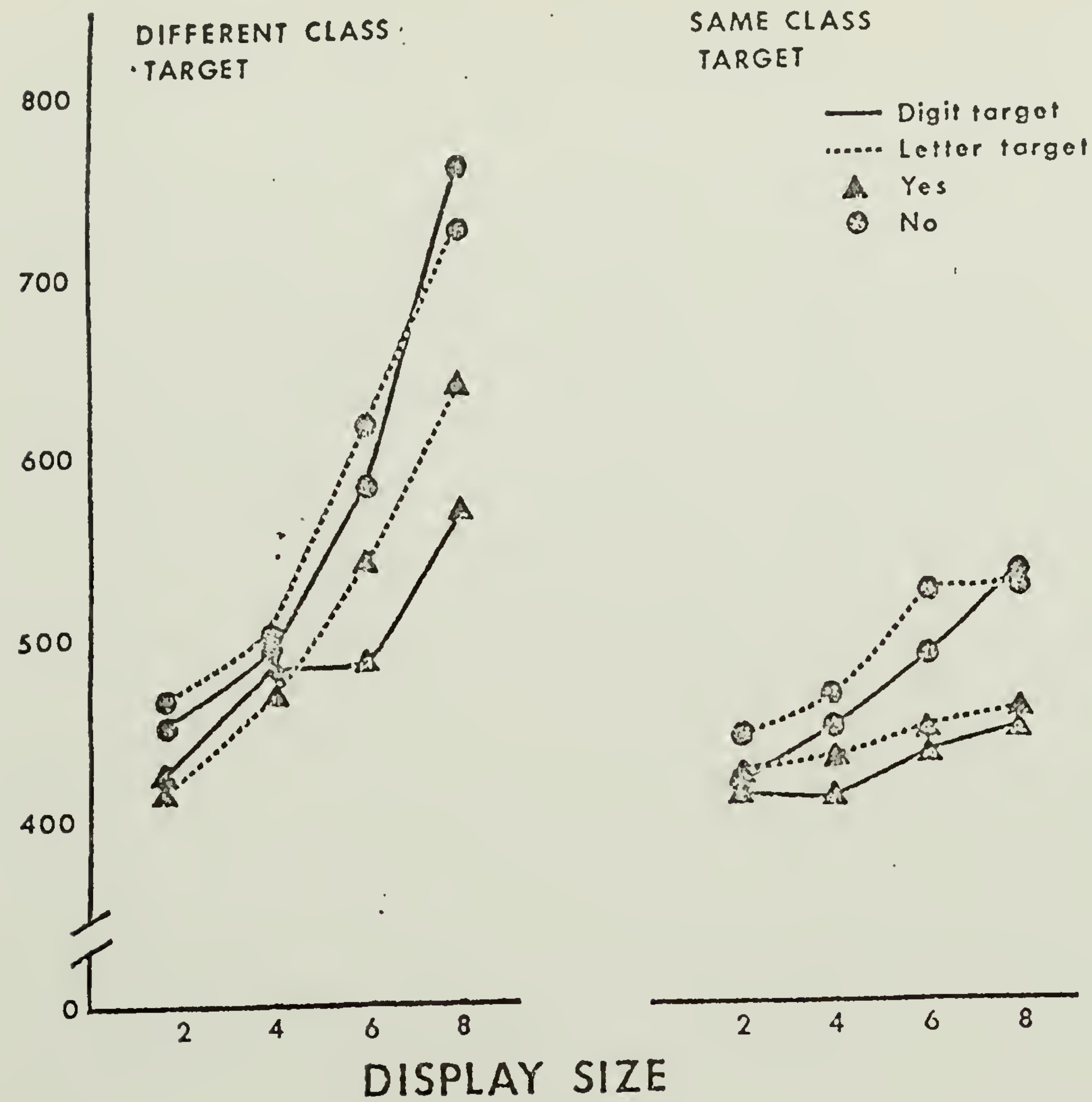
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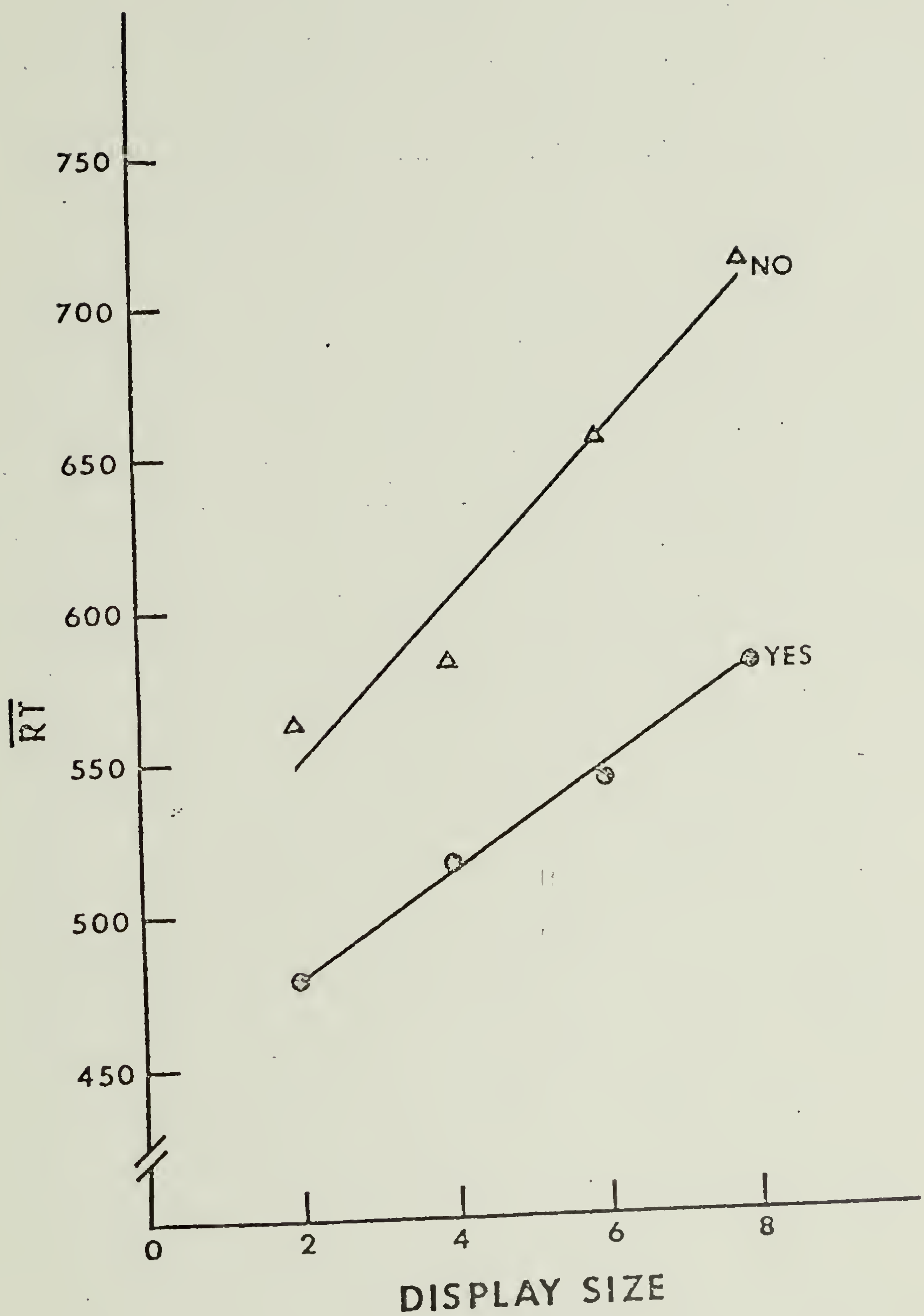
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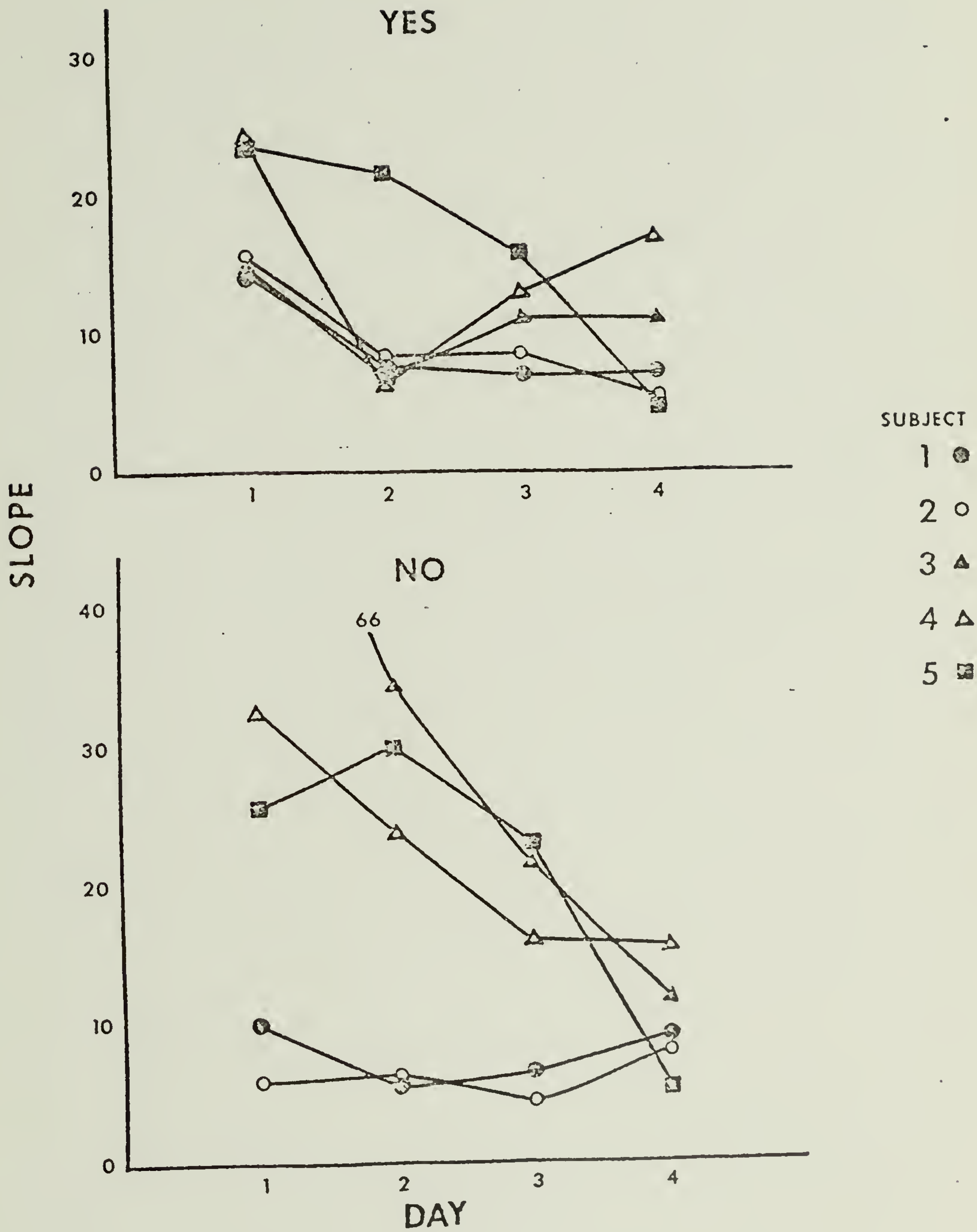
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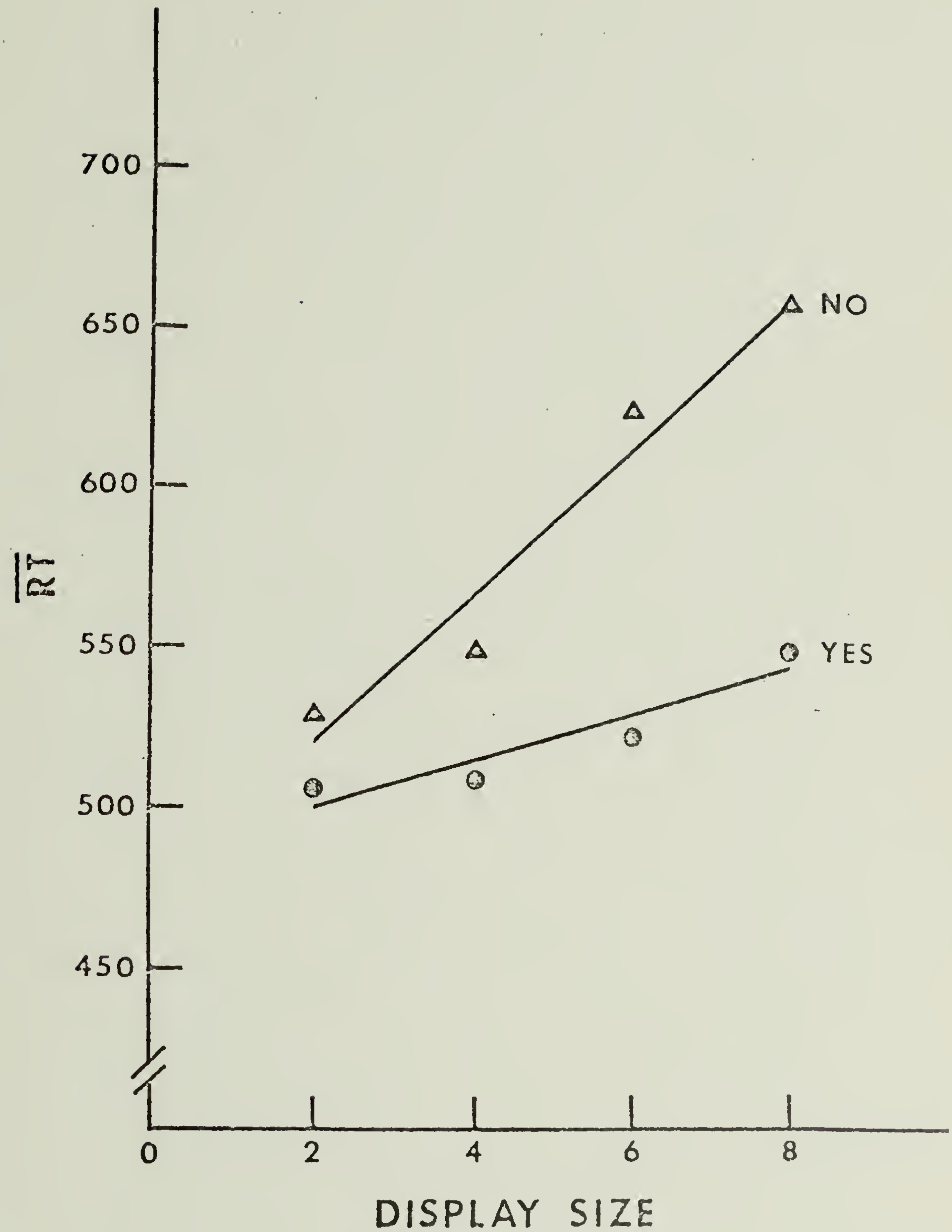

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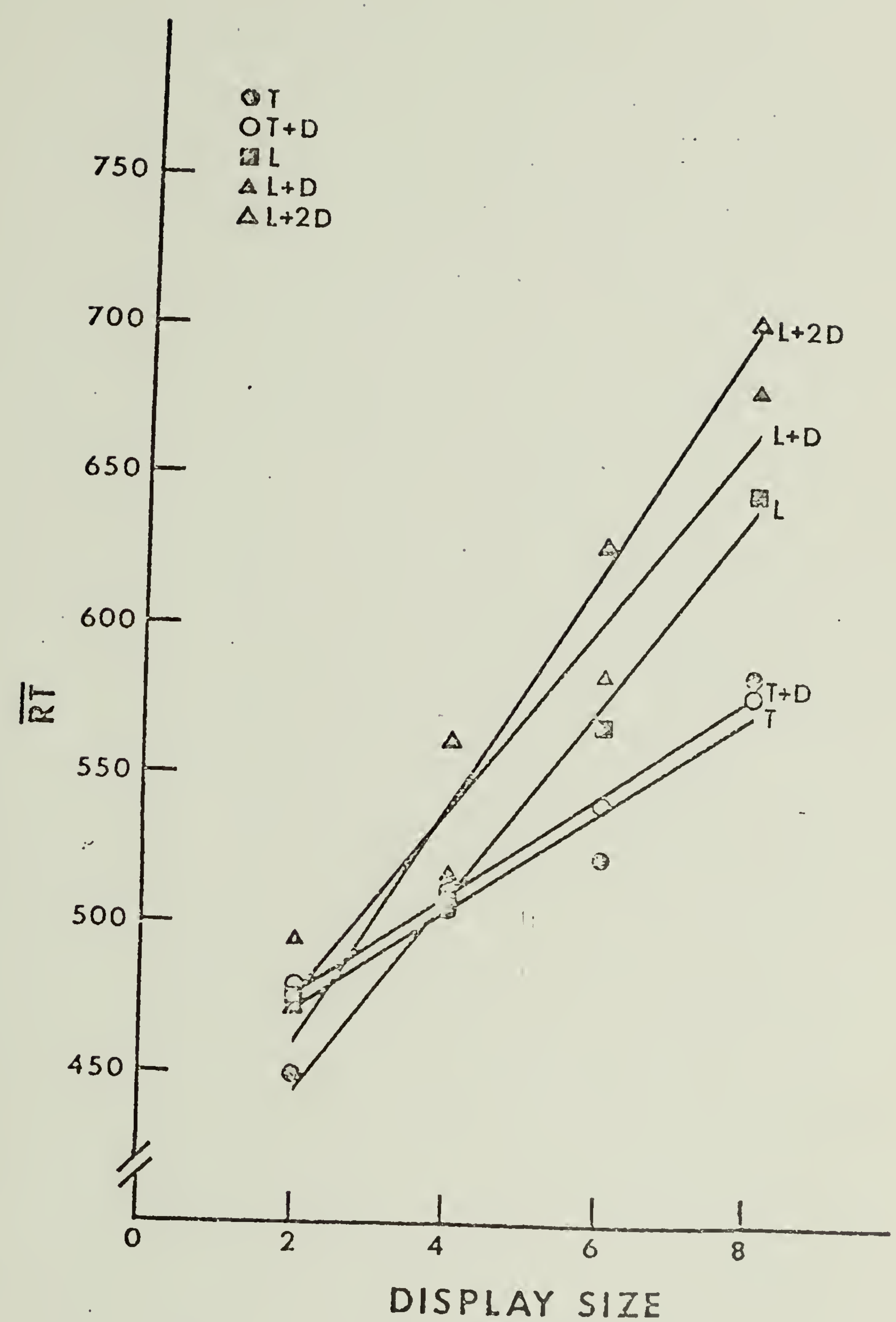

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