

INTERACTION OF TWO SOURCES OF INFORMATION IN TACHISTOSCOPIC WORD RECOGNITION¹

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WHEN A SUBJECT IDENTIFIES a tachistoscopically presented stimulus word, he may be said to be selecting one particular word out of his entire repertory of previously learned words. His success will depend in part on the amount of information that he receives from the tachistoscopic presentation, and in part on information transmitted from other sources. With other such sources held constant, an increase in the frequency of correct responses, as exposure duration becomes longer, reflects the increase in the amount of available stimulus information. It can be added that the amount of information that the subject obtains at any given level of exposure is independent of the amount of information contained in the stimulus word (Miller, Bruner, & Postman, 1954; Tulving, 1963).

The influence of sources of information other than the stimulus word on tachistoscopic identification has been demonstrated in experiments that have manipulated subjects' response sets, hypotheses, expectations, and other similar variables. The relation between response sets, or past experience, and tachistoscopic recognition thresholds has been demonstrated both in the presence (Solomon & Postman, 1952) and absence (Goldiamond & Hawkins, 1958; Smock & Kanfer, 1961) of stimulus information.

It has been shown previously that the recognition threshold of a given stimulus word varies inversely with the amount of relevant information that is available to subjects from the verbal pre-exposure context of the stimulus word (Tulving & Gold, 1963). This finding supports the hypothesis that, by and large, sources of stimulus information are interchangeable with sources of contextual information. However, it is not known how information from different sources is combined in visual recognition. The present experiment was undertaken as a step towards clarifying the relations involved.

Assume that a particular word is presented at 20, 40, and 60 milliseconds, with all other experimental conditions held constant. Presumably the probability of correct responding increases with exposure duration, reflecting the increasing stimulus information available to subjects. Similarly, if subjects are presented with a sequence of words and asked

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to guess what the next word might be, they will show increasing probabilities of correct responding as the length of the sequence increases from, say, 2 to 8 words (Aborn, Rubenstein, & Sterling, 1959; Tulving & Gold, 1963).

The main question to be asked in the present study concerns the nature of the concurrent effects of these two sources of information, when probability of correct responding is used as the dependent variable, that is, as an estimate of the amount of information available to the subject. These concurrent effects could produce three general classes of results:

First, the two sources may function completely independently of one another, and their effects are additive. The additivity and independence hypothesis would predict that:

$$p_{a,o} = p_a + p_o - p_a p_o \quad (1)$$

where p_a is the probability of correct response at a given level of exposure duration, and p_o is the probability of correct response at a given length of context.

Second, the two sources of information may be redundant, so that the information obtained from one source is contained in that obtained from the other. In the limiting case of complete redundancy:

$$p_{a,o} = p_o, \text{ if } p_o > p_a \quad (2)$$

$$p_{a,o} = p_a, \text{ if } p_a > p_o \quad (3)$$

In either case $p_{a,o}$ would have a smaller value than in formula 1.

Third, it is possible that the two sources interact so as to facilitate tachistoscopic recognition over and above the value to be expected from the independence-additivity hypothesis (formula 1). This possible result could be written as:

$$p_{a,o} > p_a + p_o - p_a p_o \quad (4)$$

It should be noted that we have excluded the illogical case of $p_{a,o} = p_a + p_o$, which cannot be accommodated by the probability model.

METHOD

General Design

Eight levels of duration of exposure (0, 20, 40, 60, 80, 100, 120, and 140 milliseconds) were orthogonally combined with four lengths of context (0, 2, 4, and 8 words) to yield thirty-two combinations of values of the two variables. Probabilities of correct responses were obtained for eighteen words under each of these thirty-two conditions. Four groups of Ss were used in the experiment. Each group worked with one of the four context lengths, but were presented with all eighteen words at all levels of exposure duration in an ascending order. There were 25 Ss in each group. The estimates of response probability under each of the 32 combinations of exposure duration and length of context were thus based on 450 responses, 18 words \times 25 Ss.

Stimulus Words and Contexts

Twenty-eight eight-letter, three-syllable nouns were selected from among the fifth thousand most frequently used words in written English (Thorndike & Lorge, 1944, General Count 15-19). Each of the 28 words was used in the construction of a nine-word sentence in which the experimental word was the final member. The eight words preceding the final critical word in each sentence were regarded as the eight-word context for that word. The 28 contexts were mimeographed on answer sheets, with a blank space following each context. The answer sheets were given to 20 graduate students in psychology with the following instructions: "Fill in the blank with the word which best fits the space." The percentage of correct guesses of target words for each of the 28 experimental contexts was calculated, and 18 experimental target words and six practice words, covering a wide range of guessing probabilities, were selected for the main experiment. The 18 experimental target words and the eight-word contexts are shown in Table I.

TABLE I
VERBAL CONTEXTS AND TARGET WORDS

| |
|---|
| Countries in the United Nations form a military <i>alliance</i> |
| The political leader was challenged by a dangerous <i>opponent</i> |
| A voter in municipal elections must be a local <i>resident</i> |
| The huge slum was filled with dirt and <i>disorder</i> |
| The ten Canadian provinces united to form a <i>dominion</i> |
| The light bulb was discovered by an American <i>inventor</i> |
| June sixth was the date of the allied <i>invasion</i> |
| The talented young violinist eventually became a professional <i>musician</i> |
| Occupationally his lack of education was a serious <i>obstacle</i> |
| He was sentenced to hang as a convicted <i>murderer</i> |
| A deadly type of bomb is made of <i>hydrogen</i> |
| Her closest relative was appointed as her legal <i>guardian</i> |
| The hermit retired to a place of lonely <i>solitude</i> |
| Many ethnic groups were represented at the folk <i>festival</i> |
| Honesty and courage are qualities which merit wholehearted <i>approval</i> |
| The first of the seven deadly sins is <i>jealousy</i> |
| Baseball games are covered by the newspaper's sports <i>reporter</i> |
| He built his new house in a desirable <i>location</i> |

By omitting either the first four or the first six words in each sentence, contexts of four and two words, respectively, were constructed for each experimental word. Under the condition of zero context, no information about the word apart from the presentation in the tachistoscope was given to the Ss.

Each of the 18 experimental words and six practice words was typed in double-spaced upper case letters, and then photographed on two-inch glass slides. The same procedure was used in the preparation of a slide containing the eight letters XLOXLOXL. These letters provided a fixation point for the tachistoscopic presentation.

Apparatus

A two-channel projection tachistoscope was employed to present the stimulus words. The first projector showed the pre-exposure field, in which the fixation letters XLOXLOXL appeared, and the second projector showed the critical words. The

fixation letters appeared in the pre-exposure field prior to the presentation of each experimental word. Illumination of the pre-exposure field was terminated when the critical word was exposed. Exposure duration of the critical word was varied in steps of 20 milliseconds from 0 to 140 milliseconds. The letters XLOXLOXL reappeared in the pre-exposure field immediately after the flash duration of the critical word. The stimulus words were projected on a rear-view projection screen from a room adjoining the room in which the subjects were seated. The level of illumination of the screen was constant throughout the experiment.

Subjects

The Ss were 100 female undergraduates. Their ages ranged from 17 to 40 years, with a mean age of 21. They were assigned at random to the experimental groups.

Procedure

Ss were tested in small groups, ranging in size from four to seventeen. Each of these groups contained an approximately equal number of Ss from each of the four context groups. The procedure was identical for all groups. Upon entering the experimental room, Ss were seated according to a pre-arranged plan which counterbalanced the distances from the screen among different experimental conditions. An answer booklet containing the contexts was placed at each of the seats.

The operative part of the instruction was as follows:

"We are interested in finding out how well people can recognize printed English words when they are presented for very brief intervals of time. These words will appear on the screen at the front of the room. You may not always be able to tell what the word is. However, after each presentation, I want you to tell me what you think the word is. Record your answers in the blanks in the answer booklets, working downward. The words presented on the screen actually follow sequences of other words. Some of you will have these sequences printed in your answer booklets. However, others will not. For those of you who do, your knowledge of the sequence may help you to recognize the word on the screen. . . . Before we begin, I will show you some practice words so that you can become familiar with the task. Record your answers for the practice words in the blanks on the cover of the booklet. . . . Remember, you may not always be able to recognize a word. However, I want you to guess each time, even if you do not recognize any letters."

Six practice words were first presented, in a fixed order, at 20, 40, 60, 80, 100, and 120 milliseconds.

Next, a word-like smudge was exposed 18 times at 20 milliseconds. This was assumed to correspond to 0 exposure duration, providing no relevant stimulus information. Each of the 18 critical words was then presented in a fixed order at 20 milliseconds, followed by the same procedure at 40, 60, 80, 100, 120, and 140 milliseconds.

The overhead lights in Ss' room were turned off shortly before the presentation of each stimulus word, and turned on again for Ss to be able to record their response on the answer sheets. An assistant remained with the Ss at all times to ensure that they followed instructions.

RESULTS

The main data are provided by the frequency of correct responses under 32 different combinations of levels of exposure duration and length

of context. Figure 1 shows the percentage of correct responses as a function of exposure duration with the length of the context as the parameter. Each data point in Figure 1 is based on a total of 450 responses (25 subjects \times 18 words).

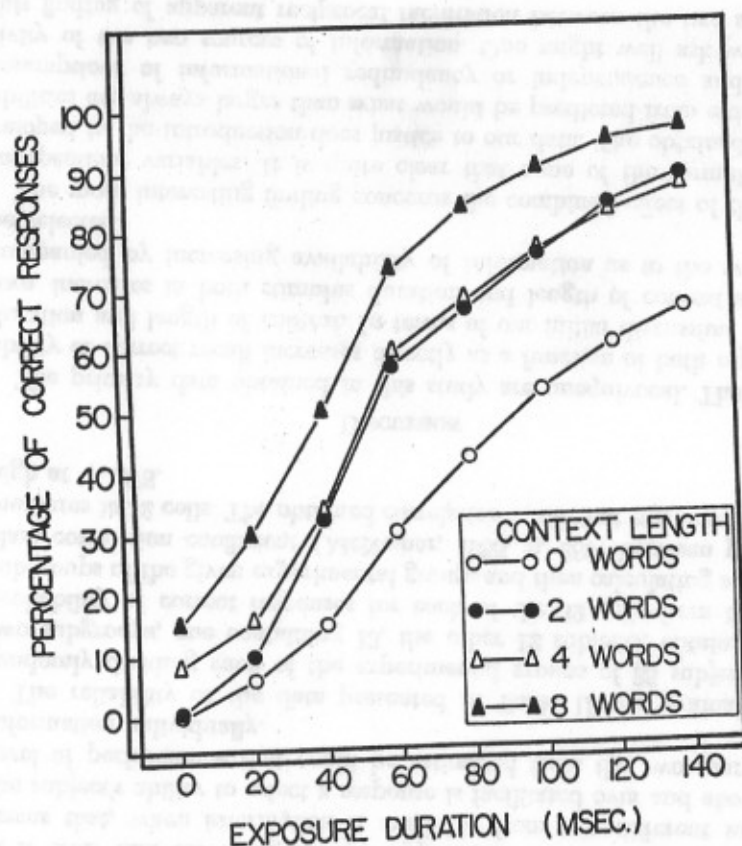


FIGURE 1. Percentage of correct responses as a function of exposure duration for four levels of length of context.

The probability of correct response increases regularly and monotonically with exposure duration for all lengths of context. The effect of context on probability of correct response is also as expected—as the length of context increases, the probability of correct response increases. We note, though, a very small difference between 2-word and 4-word contexts. The analysis of variance of these data yielded highly significant effects attributable to the length of context ($F = 14.35$, 3 and 96 df, $p < .01$) and exposure duration ($F = 442.86$, 7 and 672 df, $p < .01$). The

interaction between exposure and context was also significant at the .01 level ($F = 2.83$, 21 and 672 df). These data clearly show that the probability of correct response depends both on the duration of exposure of the tachistoscopically presented stimulus word and the length of the context associated with the word.

The question of particular interest in this study concerns the way in which the information from two sources—tachistoscopic exposure and context—combines in determining the probability of correct response. The significant interaction obtained in the analysis of variance does not describe the exact nature of the relation among exposure duration, length of context, and probability of the response, beyond suggesting that the effects of the two independent variables are not completely additive. Of the four probability models suggested in the introduction, the data clearly reject formulas 2 and 3. In order to assess the independence-additivity hypothesis—formula 1—the predicted value for each of the cells representing conditions of joint presentation of duration and context was calculated. A comparison between these estimates and the obtained data is presented in Table II.

TABLE II
PROBABILITY OF CORRECT RESPONSE FOR DIFFERENT COMBINATIONS OF EXPOSURE DURATION AND LENGTH OF CONTEXT OF TARGET WORDS

| Exposure duration (msec.) | Length of context (number of words) | | | |
|---------------------------|-------------------------------------|-------|------|------|
| | 0 | 2 | 4 | 8 |
| 0 | .000 | .007 | .082 | .158 |
| 20 | .060 | .100* | .155 | .300 |
| | | .067 | .137 | .209 |
| 40 | .150 | .324 | .336 | .502 |
| | | .156 | .220 | .284 |
| 60 | .298 | .578 | .593 | .729 |
| | | .303 | .356 | .409 |
| 80 | .420 | .667 | .680 | .831 |
| | | .424 | .468 | .512 |
| 100 | .531 | .758 | .784 | .893 |
| | | .534 | .569 | .605 |
| 120 | .602 | .836 | .824 | .940 |
| | | .605 | .635 | .665 |
| 140 | .667 | .884 | .867 | .960 |
| | | .669 | .694 | .720 |

*The upper number in each non-marginal cell represents experimentally obtained probability, the lower number refers to the probability estimated from marginal data according to formula 1.

In the first row in Table II are the actual data from the experiment for four different lengths of context in absence of any stimulus information, that is, under the condition of zero exposure duration. In the first column are the experimental data for eight levels of exposure duration in absence of any context, that is, zero length. Each of the other cells shows in the upper number the experimentally obtained probability of correct response for a particular combination of length of context and exposure duration, and in the lower number the estimated probability of correct response obtained by formula 1 from the marginal probabilities of the table, that is, from the independent levels of length of context and exposure duration. Comparison of the actual data with those estimated from the marginal probabilities shows that the obtained probability of correct response is *always* larger than the estimated probability. It is clear that the independence hypothesis is not tenable. Rather, it seems that, when information is available from two different sources, the subject's ability to select a response is facilitated over and above the level of performance that could be estimated from the two sources of information individually.

The reliability of the data presented in Table II was evaluated by randomly dividing each of the experimental groups of 25 subjects into two subgroups, one containing 13, the other 12 subjects; obtaining the probability of correct responses for each of the 32 cells from the two subgroups of the given experimental group; and then calculating an intraclass correlation coefficient (McNemar, 1955, p. 280) between pairs of measures in 32 cells. The obtained correlation coefficient was reassuringly high at +.978.

DISCUSSION

The primary data obtained in this study are unequivocal. The probability of correct recall increases directly as a function of both exposure duration and length of context. In terms of our initial discussion, therefore, increases in both stimulus duration and length of context are accompanied by increasing availability of information as to the word to be selected.

The more interesting finding concerns the combined effect of the two independent variables. It is quite clear that none of the formulas developed in the introduction does justice to our data. The obtained probabilities are always larger than what would be predicted from either the assumptions of informational redundancy or independence and additivity of the two sources of information. One might well ask whether this finding of apparent reciprocal facilitation between the two sources

of information could be related to availability of information from still other sources.

One such potential source of information that could have combined with exposure duration and context is memory. It will be recalled that all subjects in a particular group were shown the same stimulus words with a given context length at successively higher levels of exposure duration. In that situation a subject might utilize information from any given level of exposure duration on his next attempt at a higher exposure level to identify the same word in the identical context. Thus the subject's memory about the stimulus at previous levels might help at subsequent levels of exposure duration. There are two points that argue against this particular explanation. First, the facilitative effect of the two combined sources of information appears even at exposure duration of 20 milliseconds, that is, on the first presentation of word and context and, thus, before the subject could have received any information to remember. Second, data recently collected in our laboratory have shown that the so-called memory effects in tachistoscopic identification are negligible, and when they do appear they often tend to serve as a source of interference in identifying the correct word. In view of our belief that the observed facilitation of recognition is independent of the effects of memory, and because of absence of other readily apparent sources of information, we must, at least for the time being, confess ignorance as to the mechanisms underlying the phenomenon.

It must be stressed, however, that our findings are restricted to one particular response measure—probability of correct recognition. One of the important shortcomings of this popular measure is that it makes it impossible to estimate the amount of information transmitted. The original amount of uncertainty is not known, and the probability of *correct* response does not include partial information transmitted. We can only safely assume that information transmitted is monotonically related to probability of correct response, but the actual amount of information obtained from the two sources and the function that combines these informational inputs cannot be evaluated.

The restriction of our conclusions to a particular response measure is further illustrated by the fact that a different measure of response actually leads to the conclusion that information from the two sources is additive. A logit transformation of the obtained response probabilities ($\text{logit } p = \log_e (p/q)$) yields the function, $\text{logit } p = a_i + bx$, where p is the probability of correct response, q is $1 - p$, a_i is a constant for each length of context, x is exposure duration, and b is the common slope. This function provides an excellent fit for three context lengths (0, 4, and

8 words), the relevant constants being $b = 4.59$, $a_0 = -9.07$, $a_4 = -7.91$, $a_8 = -7.08$.²

In the present study, both marginal effects (perceptual and contextual constraints) were empirically obtained. However, it is possible to pre-determine the response alternatives rather than estimate them from the data. Fraisse and Blancheteau (1962) and Tulving and Gold (1963) have shown that recognition *thresholds* increase as a function of the number of alternatives presented. In a somewhat different experimental situation Pollack (1959) used this method to manipulate response alternatives, and his data confirm our finding that the independence-additivity model consistently underestimates observed probabilities of correct recognition.

Direct manipulation of original stimulus uncertainty in terms of number of alternatives under varying conditions of availability of stimulus information may lead to better control over, and greater understanding of, the phenomenon under study in the present paper.

RÉSUMÉ

Etude des effets combinés du temps d'exposition et du contexte linguistique sur la probabilité d'identification exacte de mots. Le sujet doit essayer de deviner des mots stimuli présentés au tachistoscope à des temps d'exposition variés (de 0 à 140 msec.) et en présence de contextes linguistiques appropriés au mot à identifier et de longueur variable (de 0 à 8 mots). On observe que la proportion de réponses exactes s'accroît avec la longueur du contexte et la durée du temps d'exposition. Dans des conditions où l'information donnée au sujet provient à la fois de la présentation perceptive du stimulus et du contexte linguistique, la probabilité de réponses exactes est plus élevée que ne le laisse prévoir l'hypothèse voulant que ces deux sources d'information agissent de façon indépendante et additive.

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²We would like to thank Dr. John C. Ogilvie for suggesting and performing this particular analysis.

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ERRATUM

In the article by Irwin Pollack, "Interference, rehearsal, and short-term retention of digits," published in the December, 1963, issue the following changes should be made:

page 388, line 3: *negative* should read *positive*
page 388, line 10: -0.96 should read $+0.96$