Psychological Review
1970, Vol. 77, No. 6, 557–567

PERCEPTUAL PROCESSES AND FORGETTING IN MEMORY TASKS[1]

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A quantitative model of the effects of perceptual processing on memory is presented. It is assumed that memory for an item is directly related to the processing of that item and inversely related to the processing of other items. It is also assumed that the amount of perceptual processing decreases during the temporal course of item presentation. Therefore, rate of forgetting is not constant with respect to the retroactive duration or the number of interpolated items. It is shown that increasing the rate of presentation of a list of items not only decreases the perception of the items, but also decreases the rate of forgetting when measured against the number of retroactive items. The theory provides an adequate description of several memory studies using both verbal and nonverbal items.

Perceptual processing refers to the analysis of information in a sensory input used to identify and remember the stimulus. Perception requires an analysis of the sensory input in which physical features are examined in order to identify the item. After identification of the item, further perceptual processing is necessary to remember or store the item. For example, the features of the item could be tagged with certain contextual information so that the presentation of a similar context sometime later will enable the subject (*S*) to retrieve the item. This paper gives a quantitative model of performance in several memory tasks based on assumptions of perceptual processing.

The two main assumptions of the theory describe changes in memory strength as a function of perceptual processing. The first assumption is that memory for an item is directly related to the amount of perceptual processing of that item. Since an item is processed during its presentation, memory strength will increase with increases in the presentation time of the item. The second assumption is that memory for an item is inversely related to the amount of perceptual processing of other items. Accordingly, the amount of interference that a retroactive item produces will increase as the duration of the retroactive item increases.

The first assumption is that the perceptual processing of an item increases its memory strength according to an exponential growth function of time:

$$s(t_s) = \alpha(1 - e^{-\theta t_s}) \qquad [1]$$

where $s(t_s)$ is the memory strength of the item after a presentation time of t_s seconds. Presentation time includes both the duration of the item and the silent interval afterward. Equation 1 indicates that the memory strength of a single item approaches a finite asymptote α at a rate θ.

Each item is assumed to have a number of distinctive features that can be recognized and encoded for memory. The rate at which these features are processed for memory is reflected in the value of θ. An item with more distinctive features would be expected to have a larger value of α. A noisy or unclear item would have fewer distinctive features and, therefore, a smaller value of α. Thus, the value of α can be thought of as an index of discriminability of the item.

The second assumption is that perceptual processing of an item decreases the memory strength of earlier items. It is assumed that the decrement is positively

[1] This investigation was supported in part by a National Institutes of Health Postdoctoral Fellowship (MH 39369-02) from the United States Public Health Service. The author wishes to thank Norman H. Anderson for critical readings of the manuscript and for many helpful comments.

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related to the amount of processing of the current item. From Equation 1, the amount of processing decreases during the presentation time of the item. This means that the instantaneous amount of interference decreases during the presentation time of the interfering item. Of course, the total interference is an increasing function of the duration of the interfering item.

To put this assumption into quantitative form, consider first the case where a test item is presented for study followed by a retroactive interference item. The proportion $\phi(t_I)$ of memory strength of the test item remaining after presentation of the retroactive item for t_I seconds is given by the equation:

$$\phi(t_I) = e^{-\lambda(1-e^{-\nu t_I})} \qquad [2]$$

In Equation 2, the rate of forgetting, $-\lambda(1-e^{-\nu t_I})$, is not constant but is a negatively decelerating function of t_I. The value $\phi(t_I)$ approaches an asymptote, $e^{-\lambda}$, that is greater than zero.

Equation 1 gives the memory strength $s(t_s)$ resulting from a presentation time of t_s seconds. The value $\phi(t_I)$, given by Equation 2, is the proportion of memory strength retained after presentation of a retroactive item lasting t_I seconds. Therefore, the memory strength $s(t_s,t_I)$ of an item presented for t_s seconds followed by a retroactive item presented for t_I seconds is equal to:

$$s(t_s,t_I) = s(t_s)\phi(t_I) \qquad [3]$$

where $s(t_s)$ and $\phi(t_I)$ are given by Equations 1 and 2, respectively.

Next consider the case in which a complete list of items is presented. It follows from Equation 3 that the memory strength $s(t_s,t_I,n)$ of an item of presentation time t_s after n retroactive items each lasting t_I seconds is given by the equation:

$$s(t_s,t_I,n) = s(t_s)[\phi(t_I)]^n \qquad [4]$$

The values of $s(t_s)$ and $\phi(t_I)$ are given by Equations 1 and 2, respectively. Equation 4 indicates that each retroactive item decreases memory of an earlier item to some constant proportion, $\phi(t_I)$, of its memory strength. Furthermore, this proportion is inversely related to the duration of the interfering item.

TESTS OF THE THEORY

In the formal theory, both recognition and recall are determined by the memory strength of that item. In the recognition task, it is assumed that *S* chooses a criterion value and responds yes if and only if the memory strength of the item exceeds the criterion. In recall tasks, *S* responds with the item that has the highest strength value in memory. Thus, both recall and recognition scores are direct functions of memory strength. Examples of translating response probabilities to strength values in recognition and recall tasks can be found in Norman (1966) and Wickelgren and Norman (1966).

This part of the theory is analogous to signal detection theory or Case V of Thurstone's paired-comparison model. Correspondingly, the individual or group recognition or recall scores were transformed to strength values using the tables given by Elliot (1964). The predicted strength values were obtained by estimating the parameter values using a reiterative search routine that minimized the square deviations between the predicted and observed values.

Identification of Pitch

The perceptual processing theory assumes that the identification and encoding of an item can be described as an exponential growth function of memory strength. A test of this assumption comes from an experiment (Massaro, 1970c) in which *S*s were required to identify the pitch of a test tone. On any trial, a high or low tone of 20-millisecond duration could be presented, and *S*'s task was to identify the tone as high or low. A second tone, the masking tone, followed the test tone after a variable silent intertone interval of 0, 20, 40, 80, 160, 250, 350, or 500 milliseconds. It is assumed that the perceptual processing of the test tone could take place during the test tone presentation, during the silent interval afterward, but not during the masking tone presentation. Therefore, memory strength of the test tone should increase during the test tone and the silent interval according to Equation 1.

Three highly practiced *S*s were employed in the study. The experimental conditions were completely random within a given session. The correct identification probabilities were computed for each *S* at each experimental condition. Figure 1 presents the predicted and observed strength values for each *S* as a function of the test tone presentation time before the onset of the masking tone. The theory gives a good description of the improvement in performance as a function of the presentation time.

Table 1 presents the parameter estimates that gave the predicted results in Figure 1. As seen in Figure 1, *S*s differed with respect to their overall identification performance in this task. The level of performance of each *S* is directly related to his parameter value of α given in Table 1. The parameter value α thus provides a good index of identification performance. Furthermore, Table 1 shows that the estimated values of θ differ very little among the three *S*s. In terms of the present theory, the parameter estimates indicate that the pitch discriminability of *S*s differs but that their rates of perceptual processing over time are very similar.

Perceptual Memory

Studying the influences of perceptual processing on forgetting requires the experimental control of rehearsal and encoding strategies. In accord with this, the second tests of the present theory come from nonverbal or perceptual memory tasks (Massaro, 1970a, 1970b, 1970d; Wickelgren, 1966a, 1969). It has been argued previously (Massaro, 1970b) that perceptual and retentive processes might be easier to study in a nonverbal memory task. Examples include recognition memory for the pitch of pure tones or the hue of patches of color. One paradigm employed in studying nonverbal memory is a "delayed comparison task." In this task,

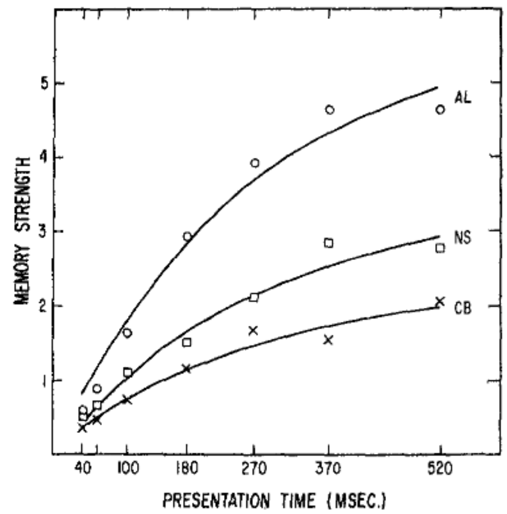

FIG. 1. Predicted and observed memory strength values for three *S*s as a function of the presentation time of the test tone. (Data from Massaro, 1970c.)

a standard stimulus is followed after some interval by a comparison stimulus and *S*'s task is to decide whether the signals were the same or different. The interval separating the standard and comparison stimuli is referred to as the retroactive interval.

In perceptual or nonverbal memory, effective rehearsal such as humming a tone or visualizing a color and verbal encoding are assumed to be minimal (Massaro, 1970b; Wickelgren, 1966a). For example, it has been demonstrated that rehearsal instructions do not improve performance in recognition memory for pitch (Massaro, 1970d; Wickelgren, 1969). When several standard tones are used, *S* is not able to

TABLE 1

PARAMETER ESTIMATES FOR THE THEORY'S PREDICTION (EQUATION 1) OF THE IMPROVEMENT IN IDENTIFICATION PERFORMANCE AS A FUNCTION OF THE PERCEPTUAL PROCESSING TIME AVAILABLE

Subject	Parameter estimate	
	α	θ
CB	2.28	3.81
NS	3.42	3.64
AL	5.75	3.71

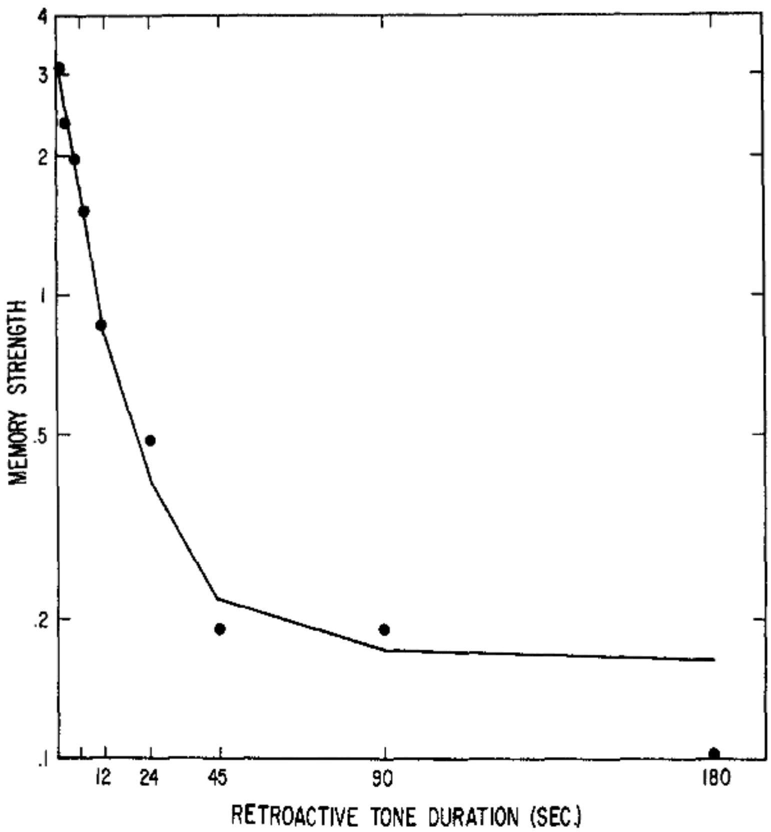

FIG. 2. Predicted and observed memory strength values as a function of the duration of the retroactive interval. (Data from Wickelgren, 1969, Experiment I.)

encode the tones verbally and must rely on the perceptual trace of the standard tone in making his decision. Furthermore, the rate of presentation of tones in the retroactive interval can be decreased without leaving empty or blank intervals as is necessary in auditory verbal memory studies. This is accomplished by increasing the duration of the retroactive tones as the rate of presentation is decreased. Another advantage of the "delayed comparison task" is that the rate of presentation of the retroactive tones can be varied without changing the presentation time of the standard tone. Since retention may not be independent of perception, it is desirable to look at forgetting while holding the perception or acquisition of memory constant.

Using pitch recognition memory, Wickelgren (1969) has provided quantitative support for the acquisition assumption of the theory. He has shown that the increase in memory strength can be described as an exponential growth function of the standard tone's duration. The result provides evidence for the assumption of Equation 1 that the perceptual processing of an item decreases during the temporal course of the item presentation.

The estimated values of θ in Wickelgren's (1969) study, although more variable, were of the same order of magnitude as the estimates of θ found in the pitch identification study described earlier. Accordingly, the rate of perceptual processing during the silent interval after a 20-millisecond tone presentation is similar to the rate of processing a continuous tone. This result demonstrates that, as assumed by Equation 1, the silent interval after a stimulus presentation can be as important for perceptual processing as the stimulus presentation itself.

Qualitative support for the theory comes from another perceptual memory study. Massaro (1970b) covaried the number of retroactive tones and the duration of the retroactive interval in a pitch recognition memory task. The results indicated that both the number and the duration of the retroactive tones contributed to forgetting. This finding agrees with the assumption that the rate of forgetting decreases during the presentation of each retroactive item. Thus, n items will produce more forgetting than $n-1$ items in the retroactive interval duration.

Quantitative tests of the forgetting assumption comes from other perceptual memory studies. Wickelgren (1969) and Massaro (1970a) have studied recognition memory for pitch with a single tone filling the retroactive interval. These studies can be used to determine the rate of forgetting with respect to one retroactive item as a function of the item's duration.[3] The present theory predicts that $s(t_s,t_I)$, the memory strength of a standard tone presented for t_s seconds after a retroactive interval of t_I seconds follows Equation 3. Taking the logarithm of Equation 3 gives

$$\log s(t_s,t_I) = \log s(t_s) + \log \phi(t_I) = \log s(t_s) - \lambda(1 - e^{-\nu t_I}) \quad [5]$$

Equation 5 shows that the present theory predicts that the rate of forgetting is a decreasing function of t_I. If the rate of forgetting was constant, $\log s(t_s,t_I)$ would decrease by a constant amount every second of the retroactive tone. This would make $s(t_s,t_I)$ a linear function of t_I on a semilogarithmic plot. This implication is tested in Figures 2 and 3.

Wickelgren (1969, Experiment I) tested three Ss at nine different durations of the retroactive interval, 1, 2, 4, 6, 12, 24, 45, 90, and 180 seconds. The duration of the standard tone was three seconds. The individual recognition probabilities were averaged over the three Ss and then transformed to memory strength values. Figure 2 presents the observed and predicted memory strength values. The estimated parameter values for the predicted strength values are presented in Table 2 (Experiment I). Figure 2 shows a semilog plot of $s(3,t_I)$ as a function of the retroactive interval. As can be seen in the figure, the rate of forgetting over time is not constant. As noted in the preceding paragraph, if the rate of forgetting was constant, a plot of

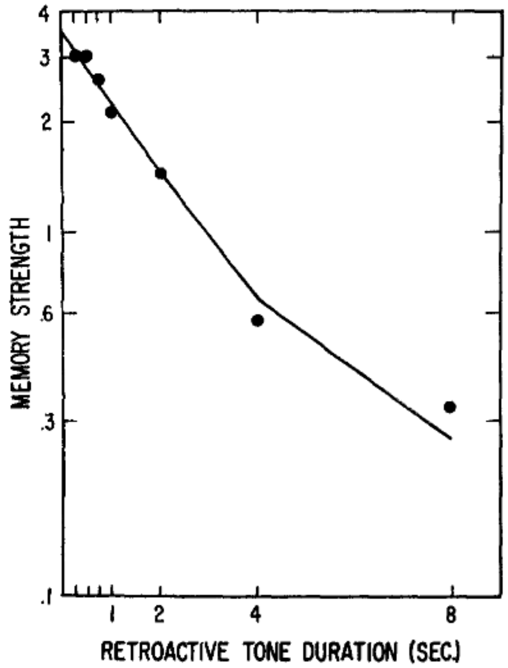

FIG. 3. Predicted and observed memory strength values as a function of the duration of the retroactive interval. (Data from Wickelgren, 1969, Experiment II.)

[3] The author would like to thank Wayne A. Wickelgren for providing the results of his experiments (1969).

TABLE 2

PARAMETER ESTIMATES OF THE THEORY'S PREDICTION (EQUATION 3) OF THE DECREASE IN MEMORY STRENGTH AS A FUNCTION OF THE DURATION OF THE RETROACTIVE TONE

Experiment	Parameter estimate		
	$s(t_s)$	λ	ν
I	3.46	2.96	.052
II	3.62	4.76	.103

log $s(3,t_I)$ against the retroactive interval t_I would be a straight line. In the present theory, the rate of forgetting is a negatively decelerating function of t_I. The results are well described by this assumption.

Wickelgren (1969, Experiment II) also employed somewhat shorter durations of the retroactive tone, namely, .25, .50, .75, 1, 2, 4, and 8 seconds. Figure 3 presents the observed and predicted memory strength values averaged over the three *S*s. The parameter values are presented in Table 2. Figure 3 shows that the rate of forgetting was a decreasing function of t_I even at relatively short retroactive intervals. It should be mentioned that the nonlinearity of the curves shown in Figures 2 and 3 is *not* due to averaging the results over *S*s or a possible floor effect. For every *S* in both studies, the rate of forgetting was not constant, but was a negatively decelerating function of t_I (cf. Wickelgren, 1969).

Massaro (1970a) employed durations of a retroactive tone of .5, 1, 2, and 4 seconds in two pitch memory studies. These results also indicated that the rate of forgetting was not constant, but a decreasing function of t_I. The present theory gave a good quantitative description of the results of both studies (Massaro, 1970a). Therefore, these results and the results of Wickelgren (1969) indicate that with a single stimulus filling the retroactive interval, the rate of forgetting is a monotonic decreasing function of the retroactive stimulus duration. The result supports the assumption that memory for an item is inversely related to the processing of another item.

Verbal Memory

Theories of performance in verbal memory tasks have employed interference or decay as explanations of forgetting. Decay theory assumes that forgetting is due to the passage of time without rehearsal (Brown, 1958; Conrad, 1957). Opposing decay theory, interference theory assumes that forgetting is a direct function of the number and nature of retroactive items (Massaro, 1970b, 1970d; McGeoch, 1932; Melton, 1963; Waugh & Norman, 1965; Wickelgren, 1966b).

One test of these theories is to vary experimentally the rate of presentation and recall of verbal items. Since rehearsal and other control processes of the *S* are not under experimental control in these studies, it is not surprising that conflicting results have been reported. In most cases, slower rates of presentation have facilitated performance (Mackworth, 1962; Moray, 1960; Pollack, Johnson, & Knaff, 1959; Yntema, Wozencraft, & Klem, 1964). The improved performance with slower rates has been attributed to the extra time available for rehearsing and organizing the list (Posner, 1963). A few studies (Conrad, 1957; Fraser, 1958; Posner, 1964) have presented evidence that supports decay theory. The studies finding poorer performance with slower rates simply indicate that some *S*s are not successful in processing the items during the extra time available at slower rates. However, whether the increased forgetting at slower rates was due to decay or interference is not certain. For example, *S*s could employ rehearsal strategies that disrupt memory performance at slower rates (Postman & Philips, 1961; Rohrer, 1949). Therefore, tests of theories of forgetting require experiments that employ explicit instructions to control rehearsal strategies of *S*s.

In the probe recall studies of Waugh and Norman (1965) and Norman (1966), the *S*s were instructed to rehearse only the last item heard and not any earlier items. The authors concluded that the rate of forgetting was independent of time and completely dependent on the number of interfering items. Norman's (1966) study indicated that increasing the rate of presentation decreased the perception or acquisition of the items to be remembered. Since the items were presented for a duration of 100 milliseconds at all rates of presentation, the improved performance at slower rates indicates that perception of the item continued to occur during the silent intervals between presentations. As pointed out by Aaronson (1967), the silent interval after stimulus presentation may be more important for perceptual processes than the stimulus presentation time iteslf. Therefore, if the perception of later items interfered with the retention of earlier items, the rate of forgetting with respect to items should be faster for the slower rates of presentation. A closer look at the data of Waugh and Norman (1965) and of Norman (1966) indicates that this is the case.

Waugh and Norman (1965) studied the effects of rate of presentation in a probe recall task with four practiced *S*s. They presented a list of 15 digits followed by a probe digit that had appeared earlier in the list. The *S*'s task was to recall the digit that had followed the probe during the list presentation. Rates of presentation of one per second and four per second were employed. The theory predicts that the rate of forgetting with respect to items should be faster for items presented at a rate of one per second than four per second. To test this prediction, an analysis of variance was performed on the number of items recalled at each of the nine values of the number of interpolated items under the two rates of presentation.[4] As predicted, the Rate of Presentation × Number of Interpolated Items interaction was significant ($F = 4.99$, $df = 8/24$, $p < .001$).

Since the present theory predicts strength values, the recall scores pooled over the four *S*s were transformed to strength values for 10 response alternatives by interpolating in Elliot's (1964) tables. Equation 4 predicts the changes in memory strength $s(t_s,t_I,n)$ of an item as a function of its rate of presentation and the number of retroactive items before its test. After estimating the four parameter values, the predicted strength values of Equation 4 were transformed into response probabilities to compare with the observed probabilities.

Figure 4 presents the predicted and observed values of the Waugh and Norman (1965) study. The probability of correct recall is plotted against the number of interpolated items (including the probe) as a function of the rate of presentation. The observed values indicate that with few intervening items, recall is better at a rate of one per second than four per second. However, recall is better at a rate of four per second than one per second when the number of intervening items is greater than five. As can be seen in the figure, the theory predicts exactly this result. The parameter estimates are presented in Table 3.

[4] The author would like to thank Donald A. Norman for providing the recall scores of the Waugh and Norman (1965) study.

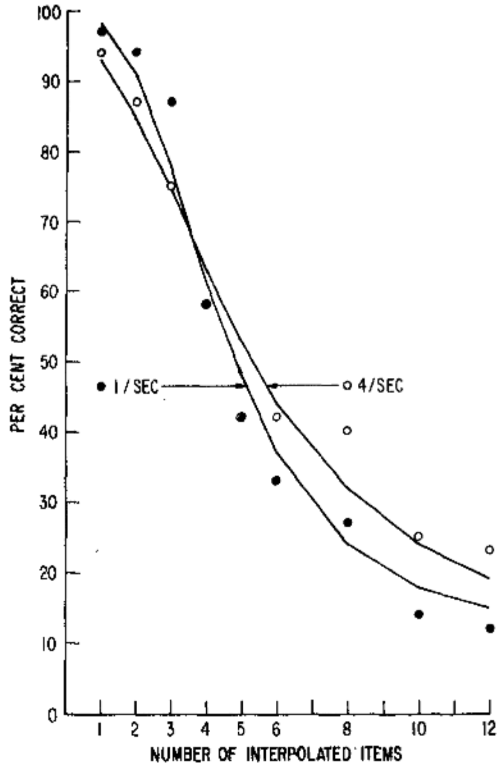

FIG. 4. Predicted and observed correct recall probabilities as a function of the number of interpolated items (including the probe) and rate of presentation. (Data from Waugh and Norman, 1965.)

TABLE 3

PARAMETER ESTIMATES FOR THE THEORY'S PREDICTION (EQUATION 4) OF THE DECREASE IN MEMORY STRENGTH AS A FUNCTION OF THE NUMBER OF RETROACTIVE ITEMS

Experiment	Parameter estimate			
	α	θ	λ	ν
Waugh & Norman (1965)	5.09	5.44	.257	4.69
Wickelgren (1970)	3.48	6.39	.207	3.75

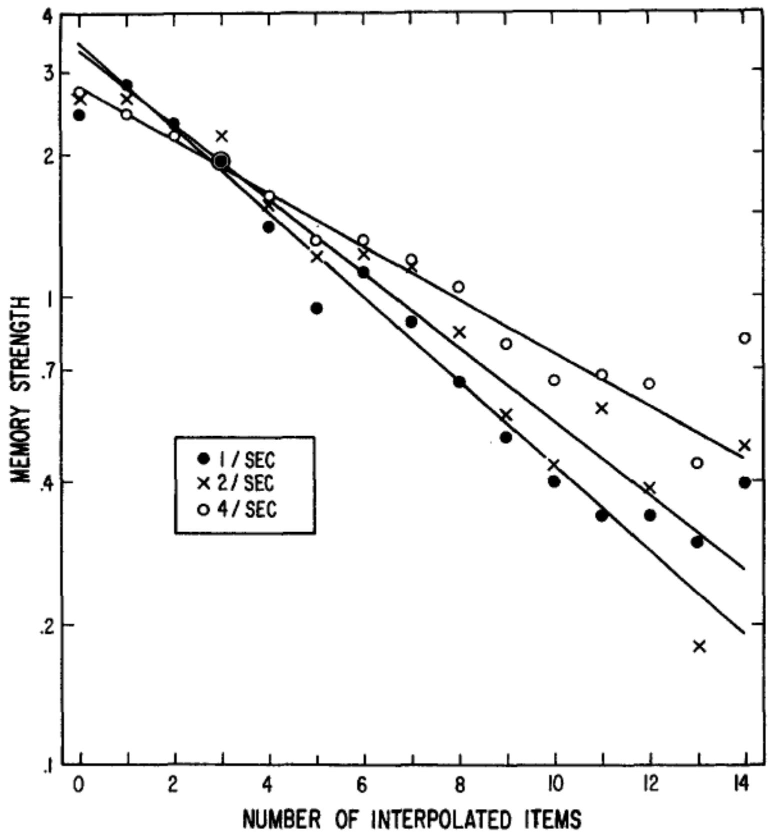

FIG. 5. Predicted and observed memory strength values as a function of the number of interpolated items and rate of presentation. (Data from Wickelgren, 1970, Experiments L and LT.)

Wickelgren (1970) varied the rate of presentation of consonants in a probe recognition experiment. In two experiments, a list of 15 letters was presented at a rate of one, two, or four letters per second followed by a test letter. The *S*s decided whether the test letter appeared in the previous list. The *S*s were instructed to attend to each item as it was presented and not to think of previously presented items. The correct and incorrect recognition probabilities were pooled over the nine *S*s in the two experiments. The memory strength values derived from the recognition probabilities are predicted by Equation 4. Taking the logarithm of Equation 4 gives

$$\log s(t_s,t_I,n) = \log s(t_s) + n[\log \phi(t_I)] = \log s(t_s) - n[\lambda(1 - e^{-\nu t_I})] \qquad [6]$$

Equation 6 shows that for a given value of t_I, each item decreases $\log s(t_s,t_I,n)$ by a constant amount. Thus, $s(t_s t_I,n)$ should be a linear function of n on a semilogarithmic plot. However, since the amount forgotten due to another item's presentation is directly related to t_I, the rate of forgetting with respect to items (n) increases as the presentation time t_I increases.

Figure 5 presents the predicted and observed memory strength values as a function of the number of interpolated items between presentation and test of an item. Consonant with Equation 1, the figure shows that increasing the rate of presentation decreases the perception or acquisition of the items to be remembered. As predicted by Equation 6, the figure indicates that log memory strength is a simple linear function of the number of interpolated items (n).

Furthermore, the slope of the line increases as the rate of presentation is decreased. This result indicates that, as predicted, the rate of forgetting as a function of items increases as the rate of presentation is decreased. Table 3 presents the parameter estimates of the theory for the prediction of these results.

Wickelgren (1970) has proposed an item-time decay account of the results in Figure 5. The main assumption of the theory is that the time decay rate for an item is greater during the acquisition of a new item than during the time between the acquisition of adjacent items. However, since no assumption is made about the perception or acquisition of an item, a storage value is estimated for each presentation rate. This theory, like the perceptual processing theory, also predicts that the rate of forgetting as a function of items increases as the rate of presentation is decreased. More specifically, the item-time decay hypothesis predicts a linear relation between time decay rate and presentation rate. The results, however, show a small but significant curvilinearity (cf. Wickelgren, 1970, Figures 4 and 5). On the other hand, this same nonlinearity is predicted by the perceptual processing model.

Another result of Wickelgren's (1970) also supports the perceptual processing theory. In that study, a tone was presented between adjacent items for *S*s to attend to. This tone increased the rate of forgetting with respect to the no tone condition. In terms of the item-time decay model, this required an increase in the rate of decay both during the acquisition of a new item and between the acquisition of adjacent items (cf. Wickelgren, 1970, Figure 4). Although this result does not disprove the item-time decay hypothesis, it decreases its heuristic value, since both decay parameters are affected by the intervening tone. The perceptual processing model, however, assumes that forgetting is positively related to the processing of new stimuli. Accordingly, an intervening tone which requires attention and, therefore, processing would be expected to increase the rate of forgetting. Wickelgren's (1970) results, then, tend to support the perceptual processing model. Furthermore, the criticism of decay theories in the Discussion section of this paper also applies to the item-time decay model because of the lack of invariance of its time decay parameter with perceptual processing.

Two other verbal memory studies provide evidence for the assumption that retention of an item in memory and perceptual processing of later items are inversely related. First, Norman and Waugh (1968) have shown that both test items and recognition responses interfere with the memory of earlier presented items. A test item decreases memory due to the perceptual processes necessary to perceive the item. A recognition response provides interference because of the additional perceptual processing necessary for searching the items in memory for the test item. Second, Waugh and Norman (1968) indicated that a recently presented and redundant (predictable) item does not decrease the memory of earlier items, although new and unpredictable items do interfere with memory. When *S*s are able to predict the occurrence of an item, presentation of the item requires little, if any, processing for memory. Thus the lack of processing of predictable items preserves the integrity of earlier items in memory.

In the present theory, memory for an item is directly related to the processing of that item and inversely related to the processing of a new item. Thus it is encouraging that the estimated values of θ and ν, the rates of processing, are within the same order of magnitude in the verbal memory studies. The θ values for pitch memory and verbal memory also agree nicely. On the other hand, the values of ν for pitch memory are a small fraction of the values of θ (cf. Tables 1 and 2). In terms of the theory, this result indicates that the rate of processing the retroactive tone was much lower than the rate of processing the standard tone. This is not surprising since the *S*s were not required to remember the retroactive tone and, probably, were not actively processing the tone for memory. Accordingly, the parameter estimates of the theory support the assumptions of perceptual processing.

DISCUSSION

The perceptual processing theory has provided a description of the time course of perception and memory in a number of verbal and nonverbal memory studies. In the theoretical system, perception and memory are interdependent processes. Memory for an item is assumed to be directly related to the perceptual processing of that item and inversely related to the perceptual processing of other items. The theoretical analysis of forgetting is relevant to two important questions concerning memory processes (Melton, 1963). First, are short-term and long-term memory two distinct processes? Second, is forgetting due to the interference of retroactive stimuli or simple passive decay?

In its present form, the theory assumes only one memory. The success of the theory indicates that it is not always necessary to make a distinction between short-term and long-term memory, either on the basis of the time or the number of intervening items between presentation and test. The results described by the theory include recognition or recall responses within and outside of what is usually taken as one's span of immediate memory (James, 1950; Miller, 1956). The pitch memory studies described in Figures 2 and 3 required the recognition of tones that were delayed from .25 to 180 seconds after presentation of the standard tone. The verbal memory studies described in Figures 4 and 5 required the recall or recognition of items after 0–14 items intervening between their presentation and test.

The theory may be considered as an interference theory since it describes forgetting as a function of the perceptual processing of retroactive stimuli. Decay theories (e.g., Wickelgren, 1969) assume that memory decays passively simply as a function of time. Wickelgren's (1969) pitch memory studies showed no effects of similarity or intensity of the interfering tone on forgetting, and this was taken as support for decay theory. However, Massaro (1970d) was able to find substantial effects of the retroactive stimulus. Tones, Gaussian noise, and "blank" stimuli were employed in the retroactive interval in two pitch-recognition experiments. The first experiment showed that Gaussian noise produced about twice as much forgetting as a tone in the retroactive interval. The second experiment showed that tones or noise in the interval produced more forgetting than empty retroactive intervals. Moreover, the evidence indicated that these results could not be attributed to differential rehearsal under the various retroactive interval conditions. These results indicate that forgetting is dependent on the nature of the retroactive stimulus and, therefore, cannot be described by a simple passive decay process.

However, these results are not surprising in terms of the theory presented here. The theory predicts differential rates of forgetting as a function of the processing of the retroactive stimulus. Since a tone, for instance, would require much more processing than a blank interval, the tone would produce more forgetting. As noted earlier, increasing the number of tones in the retroactive interval decreases recognition memory for pitch (Massaro, 1970b). This result cannot be handled by a simple decay theory, but is predicted by the present theory.

The perceptual processing theory also offers a good description of memory studies varying the rate of presentation of verbal items. A further test of the theory would be to vary item presentation times within the same list rather than between lists. Since rhythmic cues would not be available in this task, the results might be more indicative of the time course of the perception and forgetting of discrete items or events.

In conclusion, previous interpretations of decay and interference theory are not sufficient to describe forgetting as a function of time or items. The present theory assumes that perceptual processes are important for both perception and memory. The basic assumption of the theory is that memory for an item is directly related to the processing of that item and inversely related to the processing of other items. The results of both verbal and nonverbal memory studies support the theory.

REFERENCES

AARONSON, D. Temporal factors in perception and short-term memory. *Psychological Bulletin*, 1967, **67**, 130–144.

BROWN, J. Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology*, 1958, **10**, 12–21.

CONRAD, R. Decay theory of immediate memory. *Nature*, 1957, **179**, 831–832.

ELLIOT, P. B. Tables of d′. In J. A. Swets (Ed.), *Signal detection and recognition by human observers*. New York: Wiley, 1964.

FRASER, D. C. Decay of immediate memory with age. *Nature*, 1958, **182**, 1163.

JAMES, W. *The principles of psychology*. New York: Dover Publications, 1950. (Originally published: New York: Henry Holt, 1890.)

MACKWORTH, J. F. Presentation rate and immediate memory. *Canadian Journal of Psychology*, 1962, **16**, 42–47.

MASSARO, D. W. Consolidation and interference in the perceptual memory system. *Perception and Psychophysics*, 1970, **7**, 153–156. (a)

MASSARO, D. W. Forgetting: Interference or decay? *Journal of Experimental Psychology*, 1970, **83**, 238–243. (b)

MASSARO, D. W. Preperceptual auditory images. *Journal of Experimental Psychology*, 1970, **85**, 411–417. (c)

MASSARO, D. W. Retroactive interference in short-term recognition memory for pitch. *Journal of Experimental Psychology*, 1970, **83**, 32–39. (d)

MCGEOCH, J. A. Forgetting and the law of disuse. *Psychological Review*, 1932, **39**, 352–370.

MELTON, A. W. Implications of short-term memory for a general theory of memory. *Journal of Verbal Learning and Verbal Behavior*, 1963, **2**, 1–21.

MILLER, G. A. The magnical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 1956, **63**, 81–97.

MORAY, N. Broadbent's filter theory: Postulate H and the problem of switching time. *Quarterly Journal of Experimental Psychology*, 1960, **12**, 214–220.

NORMAN, D. A. Acquisition and retention in short-term memory. *Journal of Experimental Psychology*, 1966, **72**, 369–381.

NORMAN, D. A., & WAUGH, N. C. Stimulus and response interference in recognition memory experiments. *Journal of Experimental Psychology*, 1968, **78**, 551–559.

POLLACK, I., JOHNSON, L. B., & KNAFF, P. R. Running memory span. *Journal of Experimental Psychology*, 1959, **57**, 137–146.

POSNER, M. I. Immediate memory in sequential tasks. *Psychological Bulletin*, 1963, **60**, 333–349.

POSNER, M. I. Rate of presentation and order of recall in immediate memory. *British Journal of Psychology*, 1964, **55**, 303–306.

POSTMAN, L., & PHILIPS, L. W. Studies in incidental learning: IX. A comparison of the methods of successive and single recalls. *Journal of Experimental Psychology*, 1961, **61**, 236–241.

ROHRER, J. H. Factors influencing the occurrence of reminiscence: Attempted formal rehearsal during the interpolated period. *Journal of Experimental Psychology*, 1949, **39**, 484–491

WAUGH, N. C., & NORMAN, D. A. Primary memory. *Psychological Review*, 1965, **72**, 89–104.

WAUGH, N. C., & NORMAN, D. A. The measure of interference in primary memory. *Journal of Verbal Learning and Verbal Behavior*, 1968, **7**, 617–626.

WICKELGREN, W. A. Consolidation and retroactive interference in short-term recognition memory for pitch. *Journal of Experimental Psychology*, 1966, **72**, 250–259. (a)

WICKELGREN, W. A. Phonemic similarity and interference in short-term memory for single letters. *Journal of Experimental Psychology*, 1966, **71**, 396–404. (b)

WICKELGREN, W. A. Associative strength theory of recognition memory for pitch. *Journal of Mathematical Psychology*, 1969, **6**, 13–61.

WICKELGREN, W. A. Time, interference and rate of presentation in short-term recognition memory for items *Journal of Mathematical Psychology*, 1970, **7**, 219–235.

WICKELGREN, W. A., & NORMAN, D. A. Strength models and serial position in short-term recognition memory. *Journal of Mathematical Psychology*, 1966, **3**, 316–347.

YNTEMA, D. B., WOZENCRAFT, F. T., & KLEIN, L. Immediate serial recall of digits presented at very high rates. Paper presented at meeting of the Psychonomic Society, Niagara Falls, Ontario, 1964.

(Received January 23, 1970)