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A three-component analysis of the modality effect in single-trial free recall

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In single-trial free recall a superiority of acoustical over visual presentation has been observed in the recency part of the serial position curve. The rehearsal-buffer model by Atkinson and Shiffrin (1968) was modified to distinguish between three different explanations that are discussed in the literature. The application of the model allowed some of the parameters to vary across modes of presentation while other parameters were held constant. A model assuming either a precategorical acoustical storage or additional processing for visually presented items gives a better account of the results than does a model derived from a two-store hypothesis.

It has been shown consistently in several studies on short-term memory that mode of presentation affects the probability of correct recall. In particular, auditory presentation is superior to visual presentation in the recency part of the serial position curve. At least three different explanations have been discussed in the literature.

1. The first one is based on results initially obtained by Conrad (1964) and Sperling (1963). This hypothesis asserts that regardless of mode of input all information is recoded into auditory representation. Visually presented items undergo additional processing which may require additional time and result in loss of information. This interpretation has been favored by Laughery (1969), Laughery and Pinkus (1966), and Sperling (1967).

2. The second explanation assumes that information is held in sensory-specific precategorical stores (Crowder & Morton, 1969) for a short period of time. The visual sensory store maintains information for 1 sec or less, while the auditory store can preserve information for several seconds. This leads to the superiority of acoustically presented items at the last few serial positions of a list. Experimental support for this hypothesis may be found, for example, in a study by Craik (1969).

3. The third interpretation has been proposed by Margrain (1967), Murdock (1966, 1967), Murdock and Walker (1969), and Watkins (1972). These authors argue that there exist modality-specific stores even at a level beyond the sensory register. The modality effect is explained by a larger storage capacity of the auditory system. There is, however, some disagreement about whether these stores are precategorical (Murdock & Walker, 1969) or postcategorical (Watkins, 1972).

We do not attempt to summarize the arguments here. It appears that both supporting and contradicting evidence exist for each of the explanations. Instead, we shall try to account for the modality effect with the aid of a formal model. A modified version of the rehearsal-buffer model of Atkinson and Shiffrin (1968) is used for this purpose. It has been questioned by Murdock (1974) whether this model can predict serial position curves in single-trial free recall. Furthermore, Murdock argues that the modality effect is incompatible with the buffer model. The present study investigates this argument in more detail.

The model postulates that in the present experimental environment of single-trial free recall the memory system is made up of three parts: a sensory register, a short-term store, and a long-term store. When presented, an item resides in the sensory register for the duration of the stimulus presentation. Thereafter the item is assumed to decay exponentially with time constant τ. The probability that an item presented at position i is still in the register at the beginning of the test is

$$s_i = e^{-\tau(k-i+1)}, \tag{1}$$

where k is the length of the list and $(k - i + 1)$ gives the number of item presentations, item i included, until the beginning of the test. From the sensory register, the item can be recoded with probability α into the short-term store. The short-term store has a limited capacity

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of a maximum of n items. As long as the buffer is not filled completely, α is assumed to be unity. In order to stay in the buffer, the item has to be rehearsed. It is assumed that from one stimulus presentation to the next the subject rehearses d items. These d items are drawn from the buffer randomly and with replacement. If an item is not rehearsed on a given trial, it vanishes from the short-term store with probability c. When a subsequent item enters the filled buffer, one of the old items is knocked out. Again random sampling is assumed.

From these assumptions, the probability that an item presented at position i in the list will reside exactly j trials in the buffer after the buffer is filled is found to be

$$\beta_{ij} = \begin{cases} 1 - \alpha, & \text{for } j = 0 \\ \alpha[(1 - \alpha/n)(1 - \bar{r}c)]^{j-1}[\alpha/n + (1 - \alpha/n)\bar{r}c], & \\ \text{for } j = 1, \ldots, k - 1 & \end{cases} \quad (2)$$

where k is the length of the list and $\bar{r}$ is the probability that an item is not rehearsed on a given trial, i.e.,

$$\bar{r} = [(n - 1)/n]^d. \quad (3)$$

As in the original formulation of the model by Atkinson and Shiffrin (1968), we assume that information is transferred to the long-term store at a constant rate θ during the entire period the item is in the buffer. Within this experiment no decay from the long-term store is assumed. The probability of a correct response from the long-term store given the item resided exactly j trials in the buffer is

$$\rho_j = 1 - e^{-\theta \cdot j}. \quad (4)$$

At the time of the test, an item may be reproduced either from the sensory register or from the short-term or long-term store. The above assumptions lead to a probability for correct recall of an item presented at position i as given by

$$\Pr(c_i) = s_i + (1 - s_i)[(1 - \sum_{j=0}^{k-i+1} \beta_{ij}) + \sum_{j=0}^{k-i+1} \beta_{ij}\rho_j]. \quad (5)$$

METHOD

Forty auditive (female voice) and 40 visual lists were prepared on video tape. Each list consisted of a random sample of 16 different two-digit numbers subject to the constraints that the two digits always had to be different and that the last digit was never 0, 5, or 7. Fifteen nonpsychology students served as subjects in individual sessions. They were paid for their service. Each subject participated in four sessions consisting of 20 lists. The first 10 lists were presented in one mode of presentation and the second 10 in the other mode, auditive and visual presentation being counterbalanced. The lists were presented at a rate of 1 item/sec, either on a television screen or by earphones. At the end of each list the subject was given 1 min of time for written free recall.

RESULTS

The serial position curves are shown in Table 1. In a first test, the model was fitted against the serial position curve for each mode of presentation separately. Parameters were estimated by an iterative routine (Chandler, 1969) which attempted to minimize the following:

$$\psi = \sum_{i=1}^{k} [F_i - N \cdot \Pr(c_i)]^2/[N \cdot \Pr(c_i)], \quad (6)$$

where F_i is the observed frequency of correct recall for position i in the list, N is the number of list presentations times the number of subjects (i.e., 600), and $\Pr(c_i)$ is given by Equation 5 above.

The results are shown in Table 1. The fit appears to be acceptable and is at least as good as that of the competitive fluctuation model (Flade & Wender, 1974; Murdock, 1972).

The next step compared the three explanations of the modality effect described above in the context of the present model. The revised buffer model was applied to the data in four different ways: Models 0, 1, 2, and 3. These models correspond to the hypotheses mentioned at the beginning. The models were applied to both serial position curves simultaneously, that is, Equation 6 was summed from 1k to 2k. Which parameters were allowed

Table 1
Observed and Predicted Proportions for Visually and Acoustically Presented Lists

	Acoustic		Visual	
Position	Observed	Predicted	Observed	Predicted
1	.43	.41	.47	.44
2	.33	.34	.35	.37
3	.30	.28	.33	.34
4	.24	.24	.27	.24
5	.22	.24	.24	.24
6	.21	.24	.27	.25
7	.25	.24	.23	.25
8	.25	.24	.23	.25
9	.25	.25	.25	.25
10	.28	.26	.26	.26
11	.26	.27	.30	.27
12	.31	.31	.27	.29
13	.34	.37	.29	.34
14	.51	.50	.42	.42
15	.73	.71	.64	.58
16	.94	1.00	.81	.83

Parameter Estimates

α	n	d	c	θ	$\bar{r}$	ψ	df
Acoustic							
1.00	4.4	5.1	1.00	.13	.69	14.9	10
Visual							
.71	2.5	3.4	.63	.17	.87	28.4	10

Table 2
Observed and Predicted Proportions for Models 0, 1, 2, and 3

	Acoustic					Visual				
		Predicted Model					Predicted Model			
Position	Observed	0	1	2	3	Observed	0	1	2	3
1	.43	.43	.42	.43	.43	.47	.43	.45	.43	.44
2	.33	.36	.34	.36	.36	.35	.36	.38	.36	.37
3	.30	.32	.28	.31	.30	.33	.32	.33	.31	.39
4	.24	.24	.25	.27	.24	.27	.24	.23	.27	.29
5	.22	.24	.25	.23	.24	.24	.24	.23	.23	.23
6	.21	.24	.25	.23	.24	.27	.24	.23	.23	.23
7	.25	.24	.25	.24	.24	.23	.24	.23	.23	.23
8	.25	.24	.25	.24	.24	.23	.24	.24	.24	.23
9	.25	.25	.26	.25	.25	.25	.25	.24	.24	.24
10	.28	.26	.27	.26	.26	.26	.26	.25	.25	.25
11	.26	.27	.28	.28	.28	.30	.27	.27	.26	.26
12	.31	.30	.31	.32	.31	.27	.30	.30	.29	.29
13	.34	.36	.37	.39	.37	.29	.36	.35	.34	.35
14	.51	.46	.48	.51	.47	.42	.46	.45	.42	.45
15	.73	.63	.67	.69	.64	.64	.63	.60	.57	.63
16	.94	.88	.94	.93	.88	.81	.88	.83	.84	.88

Parameter Estimates

	α	n	d	c	θ	τ	ψ	df
Model 0	.75	2.8	3.7	.76	.16	.68	115.3	26
Model 1	α_a = .89 α_v = .70	2.5	5.1	.48	.14	.84	62.9	25
Model 2	.84	4.5	5.3	.82	.13	τ_a = .64 τ_v = 31.0	61.4	25
Model 3	.78	n_a = 3.2 n_v = 4.5	d_a = 4.9 d_v = 5.0	.78	.14	.81	109.1	24

to vary between modes of presentations was derived from the three hypotheses. All other parameters were kept constant.

The models were as follows: Model 0 keeps all parameters constant between modes of presentation in order to provide a baseline against which the performance of the other models can be compared. Model 1: The coding probability for acoustically presented items (α_a) may be different from the coding probability for visually presented items (α_v). In particular, Hypothesis 1 predicts $\alpha_a > \alpha_v$. Model 2 postulates a longer duration for items in the acoustical sensory register, that is, $\tau_a < \tau_v$. Finally, Model 3 assumes two separate short-term stores with a greater capacity for the acoustical store, whence $n_a > n_v$. The rehearsal parameter d is also allowed to vary between modes of presentation. Results are shown in Table 2.

DISCUSSION

First, it should be noted that Models 0, 1, 2, and 3 show a poorer fit than the application to single serial position curves. This indicates that the parameters have not remained constant over experimental conditions. Comparing the models in Table 2, however, it is found that Model 3 by far shows the poorest fit, although it has one more free parameter, whereas Models 1 and 2 differ only slightly.

Although no adequate statistical test can be provided, we draw the conclusion that Models 1 and 2 give a better account of the data than does Model 3 but that the evidence is not strong enough to decide between Models 1 and 2.

With respect to the numerical values of the parameter estimates, we would like to mention that they agree with Hypotheses 1 and 2. In particular, the estimates for τ correspond to a probability of recall from the sensory register 1 sec after stimulus offset of .53 for acoustical and of practically zero for visual items. This agrees with estimates of stimulus trace durations as made by several authors. Note, however, that it does not follow from Model 2 that all items in the recency part are recalled from the sensory register. The model merely says that the longer period of time acoustical items remain in the sensory register adds some probability to the recency items, which explains the modality effect. As may be seen from Tables 1 and 2, the recency part of the observed serial position curves is somewhat s-shaped. We were not able, however, to predict this effect even if item displacement from the buffer was characterized by a geometric distribution (cf. Murdock, 1974, p. 209).

To our knowledge, there is one other application of a formal model to the question of the modality effect. This is a two-state nonhomogeneous Markov process. This so-called fluctuation model has been applied to serial position curves by Flade and Wender (1974) and by Murdock (1972). In both cases, the goodness of fit is somewhat worse than that reported in this paper. When comparing his model to the rehearsal-buffer model, Murdock makes the point that his model is more economical since it includes a smaller number of parameters. With respect to the modality effect, however, two arguments can be made in favor of the buffer model. First, as noted above, the numerical values of the parameter estimates are in agreement with the theoretical predictions. This was not always the case with the fluctuation model. Among other things, Murdock's model includes a parameter θ which gives the probability for recalling an item that is in the state of availability. Murdock (1972, p. 114) observed an unexpected change in θ between modes of presentation. A similar change in θ, but surprisingly in the opposite direction, was found by Flade and Wender (1974). Second, and perhaps more important, the buffer model was easily modified to incorporate the three hypotheses about the modality effect. A method of achieving this with the fluctuation model is not as obvious.

In summary, then, the two store hypotheses could not explain the data as well as the other two hypotheses did, at least in the present framework of the revised buffer model. The two-store hypothesis had been proposed by Murdock and Walker (1969) and Watkins (1972). The logic behind the assumption of two stores has already been questioned by Tulving and Bower (1974). The present study, in addition, claims that, when quantitatively compared with the data, the two-store hypothesis does not measure up to its competitors.

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