# Memory Processes and Evoked Potentials*

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ABSTRACT

An EP component with a poststimulus maximum about 250 msec, labeled the Storage Component, is interpreted to be related to the storage of stimulus information in short-term memory. It was obtained by Principal Components Analysis of Evoked Potentials in a letter/number information processing experiment. The Storage Component appeared in a similar form in replications of the experiment in which the stimulus intensity was varied. The Storage Component results led to a memory prediction which was substantiated in a behavioural memory probe experiment. Recall is not as well related to two other, orthogonal EP components (P300 and CNV). Several results in the literature appear to be related to the Storage Component.

Retrieval from short-term memory is discussed in terms of studies using the Sternberg paradigm. Memory scanning rate derived from P300 latency changes with memory set size are faster than, but comparable to, reaction time estimates. An EP experiment dealing with levels of processing and memory is discussed.

A schematic model of some aspects of EPs which may be related to memory processes is presented, and several suggestions for future research are made.

RÉSUMÉ

Une composante du potentiel évoqué, avec un maximum de post-stimulus de 250 msec, désignée sous le nom de 'Composante de stockage', est vue comme liée au stockage de l'information en mémoire à court terme. On arrive à cette composante par une analyse des composantes principales des potentiels évoqués dans une expérience sur le traitement de l'information (lettres/nombres). La composante de stockage apparait sous la même forme quand on reprend l'expérience en faisant varier l'intensité du stimulus. Ces résultats conduisent à une prédiction sur la mémoire, prédiction confirmée dans une expérience de sondage mémoriel. Le rappel n'est pas relié d'aussi près à deux autres composantes orthogonales du potentiel évoqué (P300 et CNV). Plusieurs des résultats rapportés dans la littérature paraissent reliés à la composante de stockage. Le recouvrement de l'information, en mémoire à court terme, est discuté dans le contexte des travaux utilisant le modèle de Sternberg. La vitesse du balayage mémoriel, dérivée des changements de latence du P300 reliés à la grandeur de l'ensemble mémoriel, est plus rapide que les estimés des temps de réaction, mais elle est comparable. Une expérience de potentiel évoqué portant sur la mémoire et les niveaux de traitement est aussi discutée. L'article présente enfin un modèle schématique de quelques aspects des potentiels évoqués, aspects pouvant se relier à des processus mémoriels, et offre des suggestions pour les recherches à venir.

This paper briefly reviews selected research on memory and Evoked Potentials (EPs), and presents some additional data from an experimental design in which a Storage Component of the EP was identified.

Because memory is involved in so many experimental tasks, it is difficult to determine what research should be included in a brief discussion. Clearly, memory is involved in such tasks as comparing numbers presented at different times within a trial (Chapman & Bragdon, 1964), expecting an imperative stimulus after a warning stimulus (Walter, Cooper, Aldridge, McCallum, & Winter, 1964), and guessing which of two stimuli will be presented (Sutton, Braren, Zubin, and John, 1965). Since other information processes were also involved in such early cognitive-EP experiments, the EP effects found, P300 and CNV, do not seem

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to be intimately related to memory per se. However, these and other facets of the EP may be used to investigate some aspects of memory just as reaction time, for example, has been used in memory studies.

EP measures are beginning to be incorporated more frequently as dependent variables in experiments explicitly designed to study memory. Three general groups of such experiments will be discussed here. These examine relationships of EP measures to: (a) problem solving tasks involving differential storage of information; (b) information retrieval times in tasks requiring varying numbers of items to be stored in memory; and (c) storage and recognition of information as a function of level of cognitive processing.

An EP component has been described and tentatively interpreted as being related to information storage (Chapman, 1974; Chapman, McCrary, Bragdon, & Chapman, 1979). It appeared in the same form in replications of the experimental design in which the intensity of the stimulus was varied (Chapman, 1977, 1978; Chapman, McCrary, & Chapman, 1978). A short-term memory prediction based on the EP results was substantiated in a behavioural memory probe experiment (Chapman et al., 1978). Here we summarize Storage Component and behavioural results and relate them to other separable EP components, namely P300 and CNV, which have been implicated in storage and retrieval of information (Adam and Collins, 1978; Donald, Note 1; Ford, Roth, Mohs, Hopkins, & Kopell, 1979; Gomer, Spicuzza, & O'Donnell, 1976; Marsh, 1975; Roth, Kopell, Tinklenberg, Darley, Sikora, & Vesecky, 1975; Roth, Rothbart, & Kopell, 1978; Roth, Tinklenberg, & Kopell, 1977; Sanquist, Rohrbaugh, Syndulko, & Lindsley, Note 2).

## METHOD

### *Experiment I: Letter/Number Information Processing*

The experiment used number and letter comparison tasks in which subjects performed different information-processing operations on different occurrences of the same physical stimuli (Chapman, et al., 1979). On each trial, six stimuli were flashed at interstimulus intervals of ¾ sec: two numbers and two letters in random order preceded and followed by blank flash. All stimuli were flashed at the same spatial location by a Bina View display modified to use a Grass stroboscopic light source (Chapman, 1973). Stimulus duration was approximately 10 microseconds. The stimulus display window (36 × 33 mm) was viewed in a dark chamber by the seated subject at a distance of 160 cm and contained a small fixation mark. Light intensity was controlled by interposing Wratten neutral density filters: .0, −1.0, or −2.0. The middle light intensity (−1.0) was approximately .3 cd/m$^2$ and was about 2.0 log units above the threshold for character recognition.

For half the trials, the subject was instructed to indicate whether the first or second number was larger by appropriately moving a two-way switch, the letters being irrelevant. For the other half of the trials, the subjects compared the letters and indicated the alphabetic order. The numbers and letters were randomly selected (1–6, A-F) and the sequences of numbers and letters were randomized. Each experimental run consisted of 102 trials. During each session a number-relevant run and a letter-relevant run was made at each of the three stimulus intensities. EP data were collected from one subject over a series of ten sessions.

While the subject was performing the information processing tasks, electrical brain activity was recorded from scalp electrodes. Data presented here were recorded monopolarly from CPz (⅓ of the distance from Cz to Pz) using linked ear lobes as the reference. The frequency bandpass of the recording system was .3 to 70 Hz. EP s contained 102 time points (5-msec interval) beginning 25 msec before the stimulus.

EP s were averaged from the EEG for selected number and letter stimuli at each of the four intra-trial positions (n = 34 or 51, further details in Chapman, 1973). For each of these intratrial positions, there were two kinds of stimuli (numbers, letters) which were relevant or irrelevant. The 16 conditions at each of the 3 stimulus intensities can be summarized by a 3-way factorial design: 4 Positions by 2 Stimulus classes by 2 Relevance conditions. From trial to trial, the first number (or letter) occurred in intratrial positions 1, 2 or 3 and the second in intratrial positions 2, 3 or 4. To simplify interpretations, certain EEG data were discarded, so the EP s for intratrial positions 1 and 2 were based only on the first letter or number stimuli within each trial; whereas the EP s for intratrial positions 3 and 4 were based only on the second letter or number stimuli. Storage of stimulus information is needed for the first relevant stimulus in a trial (intratrial positions 1 or 2), in order to compare it with the second relevant stimulus in a trial (intratrial positions 3 or 4).

Our approach to EP measurement is based upon an analysis model that assumes that the EPs are linear, weighted sums of a number of independent components, each with a fixed time course. This general linear model of the EP was formulated as follows (Chapman, 1974; Chapman, et al., 1979):

$$R(t) = S_1 f(t) + S_2 g(t) + \ldots + S_n p(t) + C(t)$$

where $R(t)$ is an EP expressed as some function, $R$, of time ($t$) after the stimulus; $f(t)$, $g(t)$, etc. are the fundamental waveforms of independent components; $S_1$, $S_2$, etc., are component scores (multipliers or gain factors); $C(t)$ is the centroid, which is the set of origins.

Latent components based upon the above model were derived by using a varimaxed Principal Components Analysis (Dixon and Brown, 1979; BMDP4M). The set of EPs collected at each of the three intensities was analyzed separately. Each EP consisted of amplitude measurements in microvolts at 102 time points spanning 510 msec. The data set at each intensity contained 160 EPs (16 conditions by 10 replications). Thus, the 160 EPs formed a data input matrix of 160 cases by 102 variables (time points). Latent components and component scores were computed according to separate varimaxed Principal Components Analyses of each of the three data matrices. Nine to ten components accounted for 95% of the variance in these sets of EPs. The time courses of the components and the weights (component scores) are derived from the data by correlating the responses at every time point, and factoring the resulting correlation matrix of 102 time points with unities retained in the diagonal. Loosely speaking, time points that vary together are identified as belonging to the same component; any time point may belong in part to more than one component. The number of components was limited by the 'eigenvalue = one' criterion, and rotation was performed using the normalized varimax criterion (Kaiser, 1958). The components are orthogonal to each other because this is a restricting condition imposed on the analyses. The first three components of each intensity set are presented here.

*Experiment II: Behavioural Memory Probe*

A memory probe technique was used separately with 52 subjects to test short-term recall of individual stimuli for each of the 16 conditions in Experiment 1. The experimental procedure was the same as for the collection of EPs with the addition of occasional memory probes. The primary task on each trial was to compare pairs of numbers on one run of 102 trials and pairs of letters on a second run. The order of number-relevant and letter-relevant runs was reversed for half the subjects. Practice trials on the primary task were given until ten consecutive trials were correct. The average performance on the primary task was 97.5% correct. The light intensity was approximately 2.8 log units above threshold for character recognition. Within each run of 102 trials, eight randomly located memory probes were selected to test the recall of a letter and a number in each of the 4 intratrial positions.

Without prior warning of when probes would occur, blank flashes were delivered ¾ and 1½ seconds after the stimulus being probed was presented, and the subject was asked what the last character was. These blank flashes were used to mask the probed stimulus and to delay the recall report in order to reduce the effects of very short-term sensory registers. From each subject, one such recall probe was obtained for each of 16 conditions (8 probes each in a number-relevant and a letter-relevant run).

The percentage of correct recalls for each of the 16 conditions was obtained from 52 subjects (29 female and 23 male college students). Percentage of correct responses were converted to probit scores ($z$-score units); 50% and 98% thus became .0 and 2.05 probit scores.

## RESULTS

### *Evoked Potential Results*

The first three latent components computed from separate varimaxed Principal Components Analyses of the Evoked Potentials at each of the three stimulus intensities were similar to EP components previously found in a group of 12 subjects (Chapman, 1974; Chapman et al., 1979). Because of their waveforms and relative magnitudes for the 16 conditions we have labeled them P300, CNV, and Storage Components. These 3 components as a group accounted for 81 to 84% of the variance of the EPs obtained at each of the three intensities. The functional meaning of these three components is briefly summarized first.

Component P300: Stimulus Relevance.

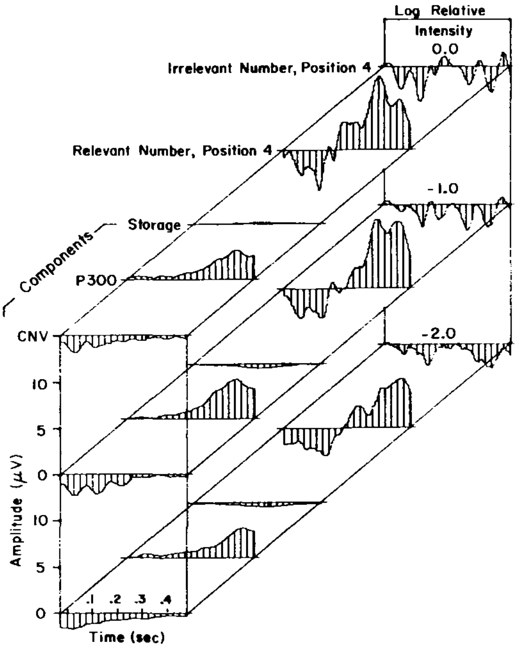


FIGURE 1 Latent components and EPs selected to illustrate CNV and P300 components at 3 intensity levels. The components were obtained by a separate varimaxed Principal Components Analysis of the EPs at each of the 3 light intensity levels (log relative intensities .0, −1.0 and −2.0). Component waveforms are scaled appropriately in microvolts for the EPs to Relevant Number in intratrial position 4; the fundamental time course of the component (rotated factor loadings multiplied at each of 102 time points by standard deviations) was multiplied by the mean component score for that condition. Note the similarity of the latent components across stimulus intensities, in spite of the difference in EPs. The two experimental conditions depicted contrast stimulus relevance (P300) and expected stimulus relevance (CNV), with both these characteristics strong for Relevant Numbers in Position 4, when subject expects a relevant stimulus whose information is used for numerical comparison, in contrast to Irrelevant Numbers in Position 4. EPs obtained from scalp electrode at the central-parietal midline referred to linked earlobes. Vertical stripes on each trace every 25 msec beginning at the stimulus flash. Positive up.

Both in terms of its waveform (Fig. 1) and the broad range of task-relevant conditions which influence its magnitude (Chapman et al., 1979), this EP component is similar to late positive waves, P300 or P3, previously reported (Chapman and Bragdon, 1964). Component scores for P300 clearly distinguish two groups of EPs, those to relevant and those to irrelevant stimuli. The differences are particularly large at intratrial positions 3 and 4, where the second relevant stimulus is compared with the first. Fig. 1 shows that the P300 contribution to the response to relevant numbers in the final position contrasts sharply with that to EPs to irrelevant numbers in the same position.

Component CNV: Expectancy of Relevance. This latent component resembles the Contingent Negative Variation (CNV), both in waveform (Fig. 1) and in its pattern of relationship to various experimental conditions (Chapman et al., 1979). In these responses only later parts of the CNV waveform are seen; these responses begin with the CNV already negative (if a relevant stimulus is expected) and continue through its return to baseline (CNV resolution). If this component behaves like the CNV, then its scores should show the biggest difference between relevant and irrelevant stimuli for intra-trial position 4 where the subjects could have 100% certainty about whether to expect a relevant or irrelevant stimulus. The data support this interpretation. The only consistent separation between relevant and irrelevant stimuli shown by the CNV occurs in the final position.

Storage Component: Information Stored in Short-term Memory. Of particular interest for this paper is the Storage Component (maximum near 250 msec). The task required the subject to store the letter or number information in the first relevant stimulus in memory, in order to be able to compare it with relevant stimulus information occurring a short while later within the trial. If an EP component mapped directly onto the apparent storage requirements of the task, it would be expected to differentiate maximally between relevant stimuli in the first two intratrial positions and all other stimuli. This component satisfied the description with one exception. The magnitude of the Storage Component was more

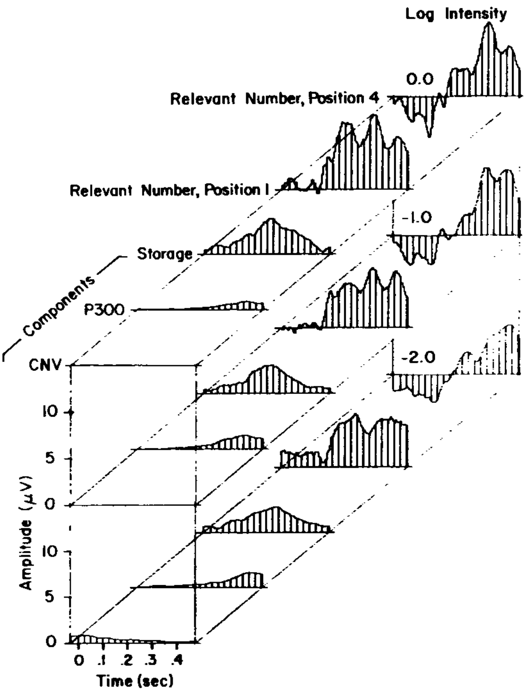


FIGURE 2 Latent components and EPs selected to illustrate Storage Component at 3 intensity levels. Component waveforms are scaled appropriately in microvolts for the EPs to Relevant Number in intratrial position 1. For this experimental condition, the subject perceives and stores the stimulus information which is needed later in the trial. Storage is not required to Relevant Number in Position 4, for which the components are appropriately scaled in Fig. 1. For other details see Fig. 1.

positive for the first relevant stimulus presented on each trial (intratrial positions 1 or 2) than for all other stimuli in all other positions, except irrelevant stimuli in position 1. Extending the storage interpretation to this result led to the hypothesis that, although not required by the task, an irrelevant stimulus in position 1 is stored in memory, whereas irrelevant stimuli in positions 2, 3, and 4 are not. This may be related to short-term memory having a limited capacity, and storage of irrelevant information interfering with processing relevant information.

The separately derived waveforms of these three latent components are similar across the three stimulus intensities. When a relevant stimulus is expected, the CNV component is negative at the time of the stimulus and goes in a positive direction later in the response. When a relevant stimulus occurs, the P300 Component reaches a positive maximum somewhat later than 400 msec. Vertical comparisons in Figure 1 show similar CNV waveforms and similar P300 waveforms independently computed in the three intensity sets of EP data by the varimaxed Principal Components Analyses. Vertical comparisons in Figure 2 show the waveforms of the Storage Components also to be very similar from set to set. At the lowest intensity, the maximum is at 270 msec, and occurs at 250 msec at the other intensities and in an earlier experiment.

The Storage Component was orthogonal to P300 and CNV Components, as well as orthogonal to the centroid (grand average EP of entire data set). The centroids contained a positive peak near 200 msec (P200), which is a prominent feature of visual EPs. P200 tends to change with lowered light intensity, whereas the Storage Component remains relatively constant. P200 may mask the Storage Component in analyses which depend on identifying peaks in EPs, rather than using more powerful techniques.

*Behavioural Memory Probe Results*

The pattern of correct recalls obtained from the 52-subject group is strikingly similar to the pattern of Storage Component scores; there was better memory for relevant stimuli in intratrial positions 1 and 2 and for irrelevant stimuli in position 1. Three interesting features of the data are common to both the Storage Component of the brain responses and the subjects' short-term memory: (a) the first relevant stimulus on a trial (intratrial position 1 or 2) gave higher scores than did the second relevant stimulus (positions 3 or 4); (b) the scores were high for both relevant and irrelevant stimuli in intratrial position 1; and (c) in

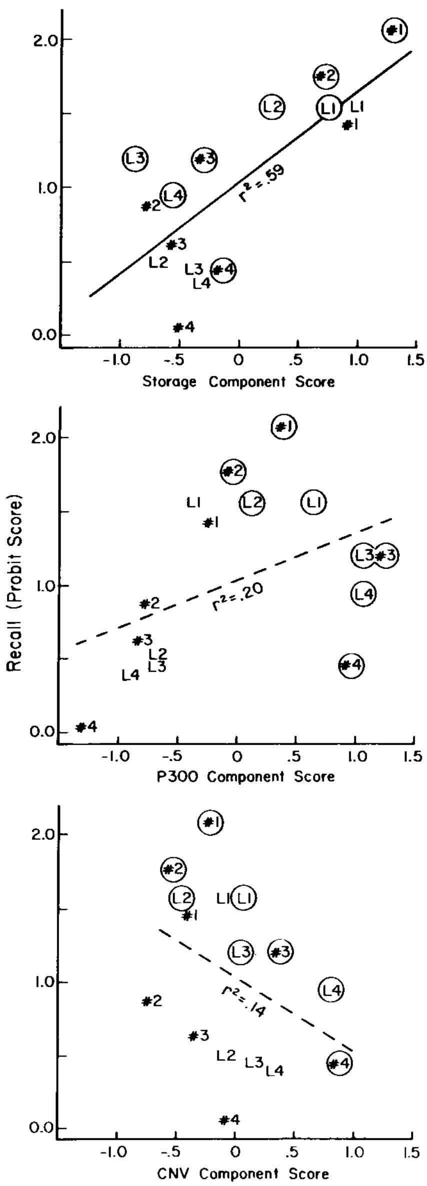


FIGURE 3 Behavioural recall as a function of three EP components. Mean recall by 52 subjects as measured by an occasional, random memory probe ('what was the last character?') while performing the primary task of comparing numbers or letters. Percentage of correct responses was converted to equivalent z-scores (probits). EP component scores are averages over the replications and 3 light intensities. The linear regression lines and proportions of the variance accounted for ($r^2$) are shown. Experimental conditions: letters (L) or numbers (#); intratrial positions (1 to 4); relevant to primary task (circled) or irrelevant (not circled).

position 2, the scores were higher for relevant stimuli than irrelevant stimuli.

Neither the CNV nor the P300 components map as closely onto the recall scores obtained for the same experimental conditions. The relationships between mean recall performance and mean component scores for the experimental conditions are displayed in Figure 3 for each of the components. The Storage Component provides the closest prediction of recall. Both very large and very small P300 scores are associated with low recall performance, and departures from the regression line are larger than for the Storage Component. CNV scores also do not predict very well, largest and smallest component scores again being associated with low recall. The relative accuracy of the three components' predictions of recall performance can be assessed by comparing the proportions of variance for which they can account (values shown in Fig. 3).

## DISCUSSION

### *Storage in Short-term Memory*

The EPs obtained during information processing demonstrate the robustness of orthogonal CNV, P300, and Storage Components in the face of large differences in the physical parameters of the stimuli. That the Storage Component represents neural activity in the stimulus-response sequence that occurs later than the simple processing of sensory input is supported by two findings: (a) its independence of whether the stimuli are numbers or letters; and, (b) that changes in stimulus intensity which are sufficient to alter markedly the overall EP have only a small effect on the Storage Component.

The Storage Component is not related simply to (a) an order effect, (b) amount of processing, (c) general stimulus relevance, or (d) stimulus type (number, letter). The simplest and most direct interpretation is that this EP component is related to the storage of information in the subject's short-term memory. More specifically, the component may reflect the process of reading information out of a sensory register into short-term memory. Not only were the Storage Component scores related to memory storage conditions, but also the timing of this EP component is appropriate for information storage. The maximum of the Storage Component was at 250 msec. This is an appropriate time for storing information needed later, since the literature suggests that the sensory register (icon) is fading about that time (Sperling, 1960; Dick, 1974).

Our tentative interpretation that this EP component was related to storage was based primarily on considering the differential scores for the 1st and 2nd relevant stimuli within each trial (the 'storage' vs. the 'comparison' stimulus). However, finding high Storage Component scores for irrelevant stimuli in position 1 required an ad hoc interpretation in order to maintain the storage identification. Therefore, it was imperative that the storage interpretation be checked by a behavioural experiment specifically designed to assess storage in short-term memory (Chapman et al., 1978).

The storage interpretation was confirmed by predicting recall performance on the basis of the Storage Component of brain responses ($r = .77$). The accuracy of this prediction is impressive, considering that behavioural recall is not solely a function of storage but is generally considered to be greatly influenced by other factors, including retrieval mechanisms. Neither P300 nor CNV did as good a job predicting behavioural recall (Fig. 3).

A number of papers have reported incidental results which may relate to the Storage Component. Their identification with the Storage Component is very tenuous, especially because, in many of these papers, memory was an incidental accompaniment of the experimental designs rather than a major thrust of the experiments. Also, in many of these reports only peaks in the EPs were examined, rather than underlying components extracted by procedures such as Principal Components Analysis. A few examples are given here, not so much for experimental support of the 'storage' interpretation, but more to encourage further research on this possibility.

In an EP study of search in short-term memory using the Sternberg paradigm, Adam and Collins (1978) focused on late peaks, especially P300, whose latency was systematically related to memory set size (see below). In addition, Adam and Collins report a positive peak with a mean latency of 244 msec which 'could be detected reliably in all records for set sizes larger than 3'. The appearance of this EP peak when larger memory sets are scanned and the peak location near 250 msec suggests the possibility that the probe stimulus information is being stored in short-term memory when time consuming scans of larger memory sets are involved. Adam and Collins reported that the latency of this peak, when it could be measured, did not change with set size. This agrees with the idea that the timing of transfer from a sensory register (icon) to short-term memory would not depend on memory set size, but only on when the icon would fade, a constant property of the single probe stimulus.

Friedman, Vaughan and Erlenmeyer-Kimling (1979) obtained a factor, P240, by Principle Components Analysis which we suggest is similar to the Storage Component. Their VEPs were obtained during two versions of a continuous performance task. Their P240 factor was more positive during a running memory task requiring detection of the repetition of any immediately preceding number (Task B), than during a simple target detection task (Task A). The additional memory load required by Task B may cause the stimulus information to be stored in short-term memory.

Friedman et al. also found P240 was large to both signals and nonsignals in both tasks for children at high risk for schizophrenia.

If our interpretation is correct, this suggests the interesting possibility that schizophrenics may be indiscriminately storing information, in contrast to normal subjects whose storage is more selectively modulated by the task.

Squires, Donchin, Herning, and McCarthy (1977) reported an auditory EP component with maximum loading at 250 msec for which they had 'no ready interpretation'. Their 250 msec Factor was related in apparently reliable, but complex, ways to the subject's task (count, ignore), the stimulus probabilities (.9, .1), and to the stimuli (loud, soft tones). In the light of our finding the Storage Component with a maximum near 250 msec, it is tempting to speculate that memory storage crept unwittingly into their experimental design. At least two kinds of information might be stored in this simple counting paradigm: (a) information contained in the stimulus, e.g. its loudness; and (b) the updated number of target stimuli counted. Our storage interpretation of the 250 msec Factor reported by Squires et al. is not easy to assess with their design, since memory was neither directly manipulated nor behaviourally measured in their experiment. However, the storage interpretation in this and other experiments showing a similar EP component could be tested by superimposing a behavioural memory probe (as in Chapman, McCrary and Chapman, 1978).

*Retrieval from Short-term Memory*

Sternberg's paradigm (1966) was designed to give data about the process by which information is retrieved from short-term memory. This paradigm contains two main events: storage of information from a set of stimuli, and retrieval in relation to a test stimulus. The subject first memorizes a short series of symbols. The subject is then shown a test stimulus, and is required to decide whether or not it is one of the symbols in the memory set. The general finding has been that the reaction time for deciding whether or not the test digit was one of those in the memory set was a linear function of the number of symbols in the memory set. This suggested that the time between test stimulus and response is occupied, in part, by a serial-comparison (scanning) process, in which an internal representation of the test stimulus is compared successively to the symbols in memory. Regardless of the detailed interpretation, the empirical findings of a relatively constant amount of time for processing each symbol in the memory set (approximately 40 msec per symbol) provide well-defined characteristics of a process for which neural correlates may be experimentally sought.

Sternberg's paradigm has been used in Evoked Potential studies by several research groups (Roth et al., 1975, 1977, 1978; Ford et al., 1979; Marsh, 1975; Gomer et al., 1976; Adam and Collins, 1978). The general finding is that the size of the storage set affects the brain potentials recorded to the warning signal and the test stimulus (retrieval cue).

Of particular interest is the common finding that the latency of a late positive peak in the neural responses to the test stimulus increases with memory set size, analogous to the increases in behavioural reaction time. The rates of these increases taken from seven published reports are summarized in Table I. Under the 'P300' heading we have included data originally called CNV-resolution (Roth et al., 1975, 1977, 1978) in keeping with Ford et al. (1979), who noted that the measures are likely a composite of $P_3$ and CNV-resolution, but use the $P_3$ label. Taking into account the progress in this research field and differences in experimental details and measurement techniques, a fair amount of consistency has been obtained in the estimates of memory scan rates. For the studies using digits in the varied set procedure, the memory scan rate was about 26 msec per item based on P300 latency, and about 41 msec per item based on reaction time. The consensus is that the P300 occurs before the behavioural response, and has a shallower slope as a function of set size. This suggests that P300 is indexing part of the processes

TABLE I
EP and Behavioural Measures of Memory Retrieval (Sternberg Paradigm)

| | P300 Latency msec/item | Reaction Time msec/item |
|---|---|---|
| Varied Set, Digits: | | |
| Roth et al., 1975 | n.s. | 43 |
| Roth et al., 1977 | est 37 | est 37 |
| Roth et al., 1978 | est 20 | 40 |
| Ford et al., 1979 | Young 27 | 43 |
| | Old 27 | 80 |
| Marsh, 1975 | est 25 | 48 |
| Adam & Collins, 1978 | 22 | 38 |
| Fixed Set, Letters: | | |
| Gomer et al., 1976 | 6 | 14 |

est = Estimated from graph

that reaction time is indexing. It is valuable to have a brain response measure which is not indexing the same processes as the behavioural measure, but is presumably related to the behavioural experiment, and allows investigation of processes in the information processing chain between stimulus and response. Possibly, P300 latency may be a better measure of memory scanning rate than reaction time is. One kind of evidence that estimates based on P300 latency are more fundamental, is finding that P300 latency slope is constant when reaction time slope varies (e.g., young vs. old (Ford et al., 1979)).

An important consideration in relating the latency changes to the theory of scanning items in memory, is the assumption that a constant amount of time is required to scan each item. This assumption leads to a simple additive model which predicts a linear relation between the marker latency and the number of items scanned. Ford et al. (1979) reported that 88% of the variance in P300 latency for the young and 76% for the elderly were accounted for by a linear trend. Gomer et al. (1976) found that '99% of the variation in P300 latency across positive-set size was attributed to a linear trend'.

The rate of scanning items in memory may be faster with more practiced memory sets. Using a fixed set procedure with letter items, Gomer et al. (1976) found considerably faster estimates of scanning rates (6 msec/item by P300 latency; 14 msec/item by reaction time).

The use of P300 latency to study memory retrieval does not imply that P300 itself is a memory process, but only that it indexes a process which occurs at the conclusion of the memory scan; for example, the determination of stimulus relevance.

An intriguing possibility is to find neural activity more directly related to memory scanning itself. Armed with detailed information about the temporal properties gained from the research cited in Table I, the search for such neural activity appears feasible. The aim would be to find repetitive neural activity whose cyclic period corresponds to the slope of the latency function, and whose duration corresponds to the memory set size. For example, five cycles of 30 Hz activity would be expected for trials in which the memory set contained five items and the subject's latency slope was 33.3 msec/item. The well-defined temporal characteristics encourage utilizing a template (matched filter) procedure for data analysis.

*Levels of Processing and Memory*

Incidental learning studies have shown that subsequent retention depends on the tasks subjects are given when the incidentallylearned items are presented. Tasks which can be characterized as inducing semantic processing of the items have shown consistent superiority over others in terms of later retention (e.g., Tressault and Mayzner, 1960; Craik and Tulving, 1975).

These established behavioural effects of levels of processing on memory have been the basis of recent EP research by Sanquist, Rohrbaugh, Syndulko, and Lindsley (Note 2). While their EPs were recorded, subjects judged words according to three criteria: (a) orthographic, (b) phonemic, or (c) semantic. Later, a recognition memory test for the words was given. Two components were reported from a Principal Components Analysis of the EPs: Component 1 was associated with the Late Positive Component (P300); and Component 2 was associated with a slow wave. Component 2 was affected by processing level, and correlated with subsequent memory performance. There is a strong possibility that what is depicted and referred to as a late slow wave is what we have called CNV-Resolution (Fig. 1 here; Chapman, 1974; Chapman et al., 1979). When the level of the baseline at the beginning of the EP has been lost track of, a negative CNV at the beginning of the EP which resolves later may masquerade as a component starting at zero and going positive later. This masquerade is conceptually quite important, because it places the interpretation of slow wave amplitudes on post-stimulus processes when it should be placed on pre-stimulus processes at the time the CNV negativity was initiated. It seems reasonable that pre-stimulus expectancy might influence subsequent memory, but only in an indirect, weak way. The correlations associated larger CNVs with poorer memory performance in both the Sanquist et al. study and in our study (Fig. 3, CNV panel). The direction of this relationship appears similar to finding reduced CNVs, when a short-term memory task is added to a constant-foreperiod simple reaction-time paradigm (Tecce, 1978). Perhaps Tecce's interpretation in terms of a CNV distraction effect can be extended to the levels of processing and number/letter processing experiments. Does greater expectation of a stimulus relevant to the primary task (larger CNV) tend to interfere with retention (secondary task)? The percentage of the memory performance variance accounted for by CNV-resolution (nee slow wave) was only 25% in the Sanquist et al. study and 14% in our study (Fig. 3, CNV panel).

By contrast, the Storage Component in our neural data accounted for 59% of the memory performance variance (Fig. 3, Storage Component panel). Can evidence for the Storage Component be found in the EP data of Sanquist et al.? Findings for only two components were reported, leaving 26% of the EP variance untapped in their preliminary report.

*Schematic Model*

Some aspects of EPs which may be related to memory processes are indicated in the schematic, speculative model in Figure 4. Some early components of the EP, such as P200, may be related to the very short-term sensory register or icon. Numerous sensory studies have shown this part of the response to be altered by physical parameters of the stimulus. Storage in short-term memory has been associated with a positive-going, latent component whose maximum is about 250 msec. EP components directly related to memory scanning during retrieval have not yet been found. However, the end of the scanning period appears to be indexed by the peak latency of P300, which may be indicating that the relevance of the stimulus has been determined. Between the P300 peak and the behavioural response occurs another period whose duration depends on memory set size. Possible processes occurring during this part of short-term retrieval are beginning to be discussed (Ford et al., 1979). The model in Figure 4 is highly schematic and selective. Much remains to be investigated both to test the ideas sketched and to develop new ones. In

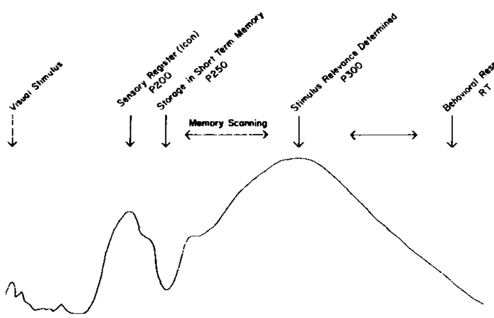


FIGURE 4 Schematic, speculative model of Evoked Potential in relation to memory processes.

these investigations, care must be taken to separate overlapping Evoked Potential components and to provide appropriate behavioural tests of the interpretations.

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