EVENT-RELATED POTENTIAL CORRELATES OF ENCODING AND RETRIEVAL PROCESSES IN HUMAN MEMORY

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EVENT-RELATED POTENTIAL CORRELATES OF ENCODING AND RETRIEVAL PROCESSES IN HUMAN MEMORY

By Hugh Doyle M.A.

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ABSTRACT

In electrophysiological research over the last few years there has been a growing tendency to utilise the Event-Related Potential as a tool in the study of cognitive processes, especially those which are well defined and understood. Over the last few years too, the study of encoding and retrieval processes in human memory has achieved a certain measure of consensus, in that many researchers have suggested that retrieval performance depends largely upon the type of encoding process performed upon the item at presentation, in particular it is suggested that the degree to which the physical characteristics of a stimulus item are analysed will largely determine whether the item can later be recognised and that the degree to which the semantic content of the item is analysed will largely determine whether the item can later be recalled. The present series of experiments sought to determine whether there existed ERP correlates of the two types of encoding process and of the two related retrieval processes, recognition and recall.

In the first experiment, ERPs generated by words which were thought to have been analysed at a physical level, as determined by whether they were recognised 24 hours later, were compared with ERPs generated by words thought not to have recieved such processing, during both initial and subsequent presentation. The ERP encoding data indicated that enhancement was seen in late positive activity generated at Fz by words which were later recognised with a high degree of confidence. This was taken to imply that the enhanced positivity was generated by elaborative encoding processes. The ERP retrieval data indicated: 1) that between 300-500 msec post stimulus, words which were correctly recognised as "old" generated potentials of greater positivity than words which were correctly recognised as "new". This was interpreted as an ERP index of a retrieval process based on familiarity only. 2) Between 500-924 msec post stimulus, items which may have been recognised due to the retrieval of encoding context generated greater positivity than items recognised on the basis of familiarity alone.

In experiment 2, the basic design was repeated with the exception that a cognitive task was interposed between trials to ensure that all processing related to subsequent memory performance was restricted to the recording epoch. ERPs were recorded only during the initial presentation of stimulus items, and those generated by words later recognised were again compared with those generated by items not recognised or recognised with low confidence. The ERP data revealed the same enhanced late positivity at Fz generated by words correctly recognised with a high degree of confidence, although, as in experiment 1, the effect was small.

In experiment 3, ERPs were again only recorded to words during the first presentation, but were this time compared on the basis of whether words had been recalled or not. It was thought that if subsequent recall of items depends on elaborative processing at presentation, this manipulation would ensure that ERPs generated by recalled words would reflect activity selective to elaborative encoding. The recording epoch was also lengthened in order that the ERPs might be sensitive to slow, long latency effects. The data indicated that words which were recalled generated ERPs of significantly greater positivity in the region 800-1400 msec at Fz than did words not recalled

In experiment 4, ERPs generated by words during retrieval were recorded, and in this case ERPs generated by words whose experimentally learned associates were recalled from memory, were compared with ERPs generated by words whose associates were not recalled. It was suggested that since recall depends upon retrieval of encoding context, ERPs generated by words whose learned associates were recalled, should reflect such processing. The ERP data showed that words whose associates were recalled, generated activity of greater positivity than words whose associates were not recalled, from 500 msec onwards at all three midline sites.

It is concluded from these experiments that at encoding, the activiation of elaborative processing is reflected by an enhancement of the ERP activity at Fz from approx. 500 msec onwards, and that at retrieval, 1) the activation of the "familiarity-checking" process generates enhanced positivity at all midline sites between 300-500 msec, and 2) that the "retrieval of encoding context" process generates enhanced positivity from 500 msec onwards. These data are related further in the conclusion to both physiological and cognitive theories of human memory.

CONTENTS

CHAPTER 1

EVENT RELATED POTENTIALS

1.1 DEFINITION AND METHODOLOGY

1.1.1 Introduction

The basic process underlying brain function is the communication which takes place between the vast numbers of neurons of which it is composed. This communication takes the form of electro-chemical signals. When neurotransmitter chemicals emitted from the axon of a neuron bond onto the dendrites or cell body of another they produce a change in the membrane permeability of that cell to certain ions which results in an alteration of the resting potential of the cell. These changes can be inhibitory, called inhibitory post synaptic potentials (IPSP) or excitatory, called excitatory post-synaptic potentials (EPSP), ie. making the cell less or more likely to generate an action potential respectively. If the EPSP rises to a sufficient value, an action potential is generated.

Both post synaptic potentials and action potentials may cause external currents to flow between upper and lower layers of brain tissue and the summed activity of many thousands of such potentials can be recorded on the scalp. This summed activity constitutes the human electroencephalogram (EEG). This reflects the ongoing activity of the brain and changes in the EEG are correlated with changes in brain state. In addition however the EEG activity contains the phasic brain potentials which are elicited by sensory, cognitive and motor events. These "event related potentials" (ERPs) are often indistinguishable from the ongoing EEG activity in a single record. Thus for identification of ERPs to take place the signal-to-noise ratio has to be enhanced, commonly by means of the averaging process (see below, section 1:1:2:2).
The result of this process is called the Averaged Event-Related Potential (AERP).

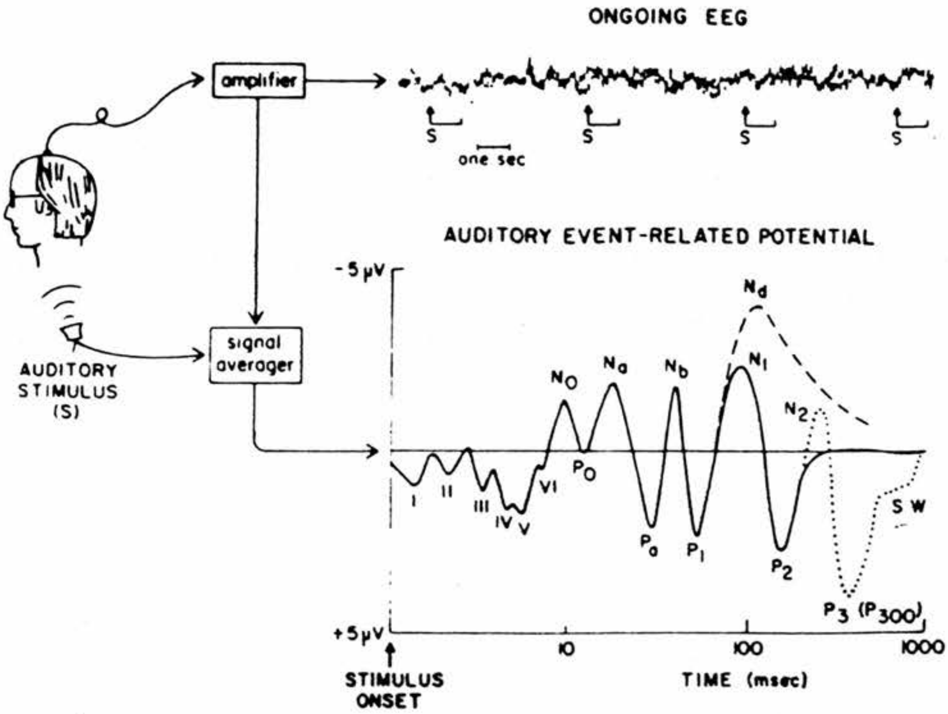

FIGURE 1-1. Idealised waveform of the computer-averaged auditory event-related potential (ERP), to a brief sound, illustrating the sequence of processing described in the text. The logarithmic time display allows visualisation of the early brainstem responses (waves I-IV), the mid-latency components (No, Po, Na, Pa, Nb), the "vertex potential" waves (P1, N1, P2) and the task related, endogenous components (Nd, N2, P300 and Slow Wave). From Hillyard and Kutas 1983, p 35.

Within each averaged waveform it is usually possible to distinguish a number of different positive and negative deflections in voltage (see figure 1:1).

Those deflections which are thought to reflect neural processes are called "components" of the waveform. These components are considered to reflect the neural activity associated with the operation of information processing stages such as sensory registration, identification, encoding, decision making and response preparation. Two kinds of component are sometimes distinguished. One type vary as a function of physical stimulus parameters and are insensitive to changes in information processing demands. They are termed "exogenous" components. The second class of components usually occur later in the waveform and vary as a function of cognitive and perceptual processes carried out on the stimulus. These are termed "endogenous" potentials.

ERP research is concerned with the attempt to correlate changes in the amplitude and latency of these components with changes in experimental variables and thus to identify the sensory and cognitive processes responsible for each one.

1.1.2 Methodology

1.1.2.1 Recording ERPs. -

See figure 1:1. EEG activity is recorded by electrodes affixed to the scalp. The most commonly used form of scalp electrode consists of coils of fine silver wire coated with a layer of silver chloride, encased in a rigid plastic cup. In order to allow the signal to be picked up by the electrode the cup cavity is filled with an electrolytic gel.

The siting of the scalp electrodes depends to a large extent on the psychological process under investigation but in the study of endogenous potentials it is important to record from a number of sites in order to aid component identification (see below, section 1:1:2:3). It is recommended (Donchin et al 1977) that recordings be made from at least three scalp sites; Fz, Cz, and Pz (see figure 1:2) These electrodes are referred to an electrode or electrodes at a neutral site such as the ear lobes or the mastoid bones.

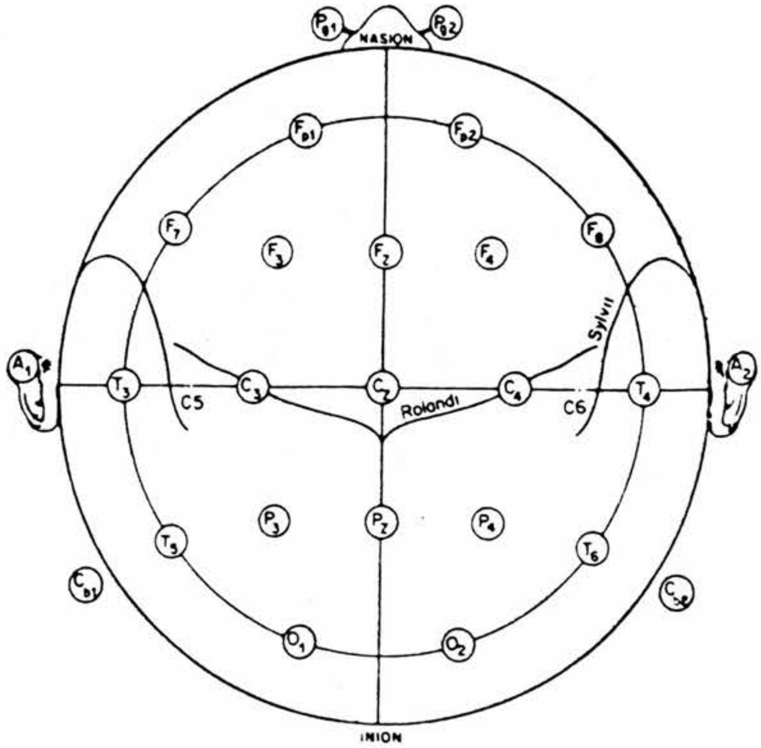

FIGURE 1-2. Figure showing all standard positions of the ten-twenty electrode placement system. The figure represents the head drawn in one plane seen from above. The location of the Rolandic and Sylvian fissures are indicated. The outer circle was drawn to the level of the nasion and inion. The inner circle represents the temporal line of electrodes. From Picton 1978, p 331.

Great care must be taken to ensure that the recorded signal is not contaminated by electrical artefacts such as the activity generated by muscle activity (EMG) and the movement of the eyes (EOG). To avoid these, subjects are required to keep as still as possible and to avoid eye movement, especially blinking, during a trial. In addition the EOG should always be recorded and trials in which EOG activity exceeds a value at which it is liable to be recorded by scalp electrodes should be rejected from the averaging.

The EEG signal must next be amplified so as to be of a sufficient voltage to be evaluated by the "analogue-to-digital" converter of the averaging system (see below, section 1:1:2:2). The activity is also filtered to remove those frequencies in the recording which may unnecessarily increase the variability of the waveform. The amplified and filtered activity may then be input into the computer to be averaged, or stored on tape or computer disc for later averaging and analysis.

One further point should be made here, namely that the EEG is sampled, not recorded continuously ie. the signal is recorded once every few milliseconds. The length of the "recording epoch" is calculated by multiplying the sampling rate by the number of sampling points. For the study of endogenous potentials, the epoch should ideally last for approximately one second or longer (Karis et al 1984).

1.1.2.2 Averaging -

As noted above, in order to distinguish ERPs from the ongoing EEG activity, techniques are required to enhance the signal-to-noise ratio of the ERP. The most common of these techniques is the "averaging" process. (For details see Picton 1980 pp 358-363, Cooper et al 1974 pp 161-162)

The basic requirement for the averaging process is that the stimulus or behaviour evoking the potential is repeated. With each repetition the electrical activity following the event is recorded and the digital values of the waveforms are averaged. The background activity, being random with respect to the event will, on averaging, tend towards a similar mean value at each point in time. As the averaging proceeds it will display less and less deviation from the mean and thus will approach (but will never actually reach) a straight line. If the background activity is a normally distributed random variable its amplitude range decreases by a square root factor of the number of trials. Since the ERP however has a constant relation to the eliciting event, it remains constant during the averaging process and becomes increasingly recognisable in the decreasing EEG noise (figure 1:3)

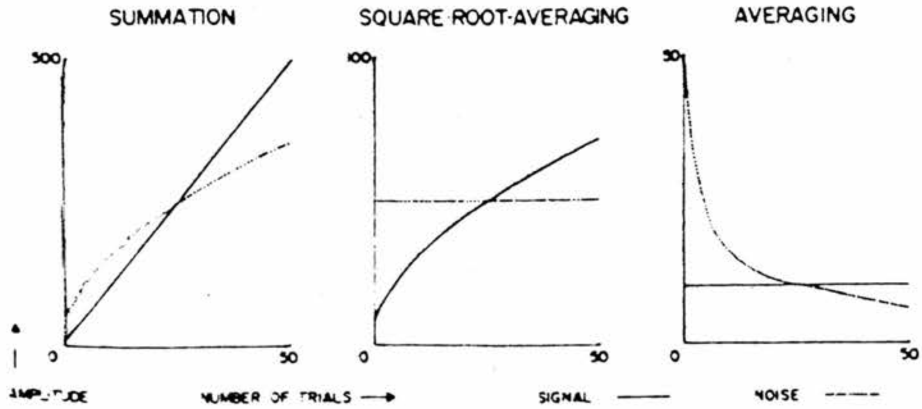

FIGURE 1-3. The theory of signal averaging. Averaging is based upon the fact that whereas the average of a constant waveform ("signal") remains constant, the average of a random variable ("noise") approaches a mean value (a straight line) and its range of deviation from the mean decreases as a function of the square root of the number of trials. An example is shown here. An ERP of 10uV, unrecognisable in a background EEG noise of 50uV, becomes visible through averaging. The ordinate axis represents the amplitude in microvolts and the abscissa represents the number of trials. From Picton 1978, p 359.

It should be noted that the averaging process depends on the assumptions that a) the ERP remains constant and b) that noise is normally distributed. Both of these assumptions may be violated (see Picton 1980 p 362). It also depends on the repetition of stimuli, and where this is not possible use can be made of methods of single trial analysis (Picton 1980 p 363).

1.1.2.3 Identifying Components. -

Six of the most important methods for identifying specific components of the ERP are outlined below;

a) The latency of the component's peak amplitude is often used to identify the component. Thus the N400 component is so-called because it generally occurs at about 400 msec post stimulus. However, in the case of endogenous potentials which are thought to reflect processes which vary in latency, the same component can vary greatly in the latency of its peak amplitude eg. the P300 component was first identified with a peak latency of 300 msec (Sutton et al 1965) but in more complex experimental paradigms it is often recorded at 500-600 msec post stimulus. For this reason, in many studies no attempt is made to identify a component with an already established one but instead a component is simply labelled according to its latency in that particular paradigm, for example if in one particular experimental paradigm the N400 component occurred at 470 msec post stimulus, according to this method it would be named as the "N470". Similarly, in some studies where a late parietal positivity has been found it has been identified as the "Late Positive Component" rather than making assumptions about it which would be implied by calling it the "P300" (Karis et al 1984). However attempts are usually made in such studies to relate these components to others previously identified by using the following methods.

b) A second method which circumvents this problem is the use of sequential numbering eg. the first three positive components are sometimes called P1, P2, and P3. Sometimes however one component might be absent due to the particular experimental design and the next one may be mistaken for it.

c) The third method utilises the morphology of the components. It relies upon the fact that some components have a distinctive form which is almost invariable. Thus the "N1-P2" complex is usually easily identifiable on this basis alone.

d) The above method is usually coupled with the use of differences in morphology or amplitude of a potential between electrode sites. The combination of these two methods provides a very powerful means of identifying endogenous components, eg. the P300 component is usually maximal at the Pz electrode placement.

e) A fifth method is the use of functional characteristics of components. Thus the N400 can be defined as the component elicited by a "semantic mismatch" and the P300 as the component elicited by "task relevant, improbable stimuli". This too is a powerful method but has drawbacks also. One is that two components may share many of the same functional characteristics while latency differences and scalp distribution would indicate that they are separate components. Another is that the experimenter may read into the data what he expects to find. Alternative theories of the psychological bases of certain components might be ignored because one has been adopted as the very means of identifying that component. For these reasons this method is used in conjunction with the others.

f) A sixth approach has been the use of statistical techniques such as Principal Components Analysis (PCA) which assesses the relative contribution of each component to the total variance in the ERP vector matrix (for details see Donchin and Heffley 1978). The main advantage of this method is that components which overlap can be identified. This too has its limitation however since it makes assumptions about components which may not be warranted, eg. that the components are orthogonal (see Norman 1984, Tukey 1978) and there still remains the necessity to associate PCA "components" with ERP "components". In addition, Wood and McCarthy

(1984) have suggested that PCA loses or distorts information leading to what they call a "misallocation of variance", but more recently Mocks and Verleger (1986) have suggested that such "misallocation" derives not from the use of PCA per se but from associated techniques (for example the "Varimax rotation" technique.)

Because the process of component identification is complex, it is usual for studies to employ many or all of the above methods to determine which component is which.

1.1.2.4 Quantifying Components -

The most common measures of ERP components are of their latency and amplitude.

a) Latency: The latency of a component is defined as the time after stimulus onset at which the amplitude of the component is maximal. Latency measures therefore depend upon adequate peak amplitude identification (see below, section (b)). For some ERPs which have no apparent peak amplitude such as the frontal "Slow Wave" or the "Contingent Negative Variation" the latency of the onset of the component is sometimes used.

b) Amplitude: There are two methods used to measure the amplitude of the components of the ERP. (i) The first involves the measurement of the peak voltage amplitude of a component. This has two advantages; firstly that it is a relatively simple operation and secondly that magnitude measures are independent of differences in latencies of components across ERPs. Its major disadvantage is its susceptibility to experimenter bias in identifying the peak voltage of the component because in waveforms composed of relatively few trials the peaks are not clearly delineated. One way to get around this is to use a "window", ie. to measure the largest voltage in a certain latency range regardless of its apparent form. (ii) The second method involves the measurement of the area under selected portions of the ERP curve. This is computed by integrating the voltages relative to a reference baseline, usually the mean of the pre stimulus activity. This method is free of any bias in selecting individual peaks but raises its own problem of determining the latency range to be measured. This can sometimes be arbitrary since components' onset and offset can not always be determined visually. One problem related to this which is common to both methods of amplitude measurement is that components are not always independent of each other eg. the "Slow Wave" has an effect on the measurement of P300 amplitude (N.K. Squires et al 1977). Figure 1:4 shows a theoretical example of such a case.

One way of dealing with this problem of overlap is to use multivariate techniques such as Principal Components Analysis (PCA) or Discriminant Analysis (Donchin and Herning 1975, K.C. Squires and Donchin 1976. See Donchin and Heffley 1978 for details of both). PCA especially has been used with success to dissociate components and measurements and analyses are subsequently carried out upon the factor loading scores of the components. However these techniques too have their limitations (see above, section 1:1:2:3 (f)). Generally speaking they are not necessary for the quantification of ERP components which are thought to be distinct in the waveform, as long as sufficiently objective methods are used in the selection of peaks and area measurement limits.

1.1.3 Application Of ERPs

Before discussing in more detail the present state of knowledge about ERPs it is important to realise that the discipline is not a homogeneous one. People study ERPs for a number of different reasons and the three major approaches taken will be outlined.

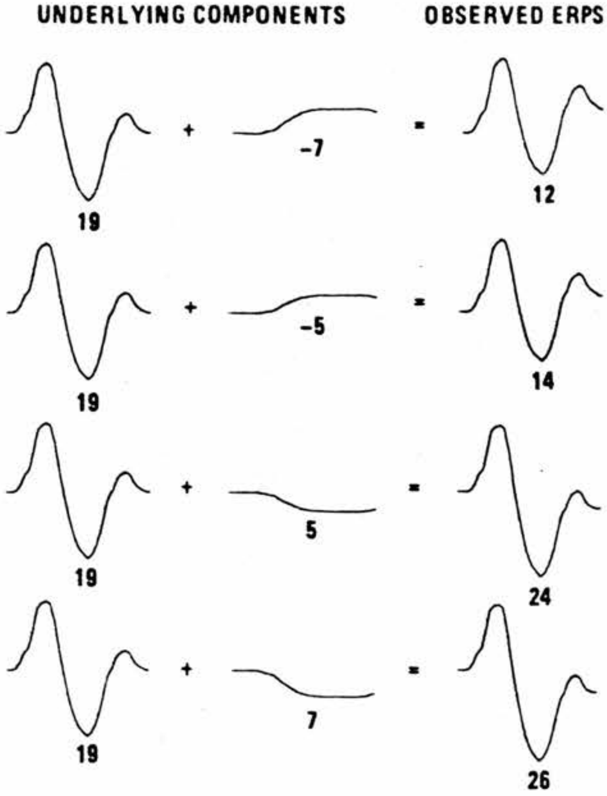

FIGURE 1-4. Baseline-to-peak measurements are made for ERPs composed of two underlying components: a constant biphasic waveform and a varying slow process. The numbers represent peak values relating to the initial baseline (arbitrary units). The measures on the observed ERPs suggest that the sharp positive (downward) component varies across the four ERPs when in fact it is constant. From Donchin and Heffley 1978, p 558.

a) Perhaps the most intuitively appealing application for ERPs is in the area of human physiological psychology or neuropsychology, which seeks to understand the neural basis of human behaviour and cognition. ERPs are particularly useful here for two reasons; (i) Techniques used in animal studies such as ablation and invasive recording cannot be employed on humans. The only times they are, are in cases of brain injury or neurological disorder when the brain may be functioning abnormally anyway. As a non-invasive recording technique the study of ERPs may cast considerable light upon the neural substrates of cognitive processes in the normal brain. (ii) There are some aspects of cognition which have no animal analogues.

Their usefulness here is limited however by the fact that it depends upon the localisation of the generators of the potentials since the primary interest is in which parts of the brain subserve behaviour and in which way. The investigation of generators (reviewed below, section 1:3) is fraught with its own difficulties particularly in the case of endogenous potentials.

b) The second important application of ERP research, possibly the most fruitful to date, is the area of "cognitive psychophysiology" (Donchin et al 1978, Donchin 1984). Proponents of this approach consider the ERP to be an index of the nature and timing of cognitive processes, as are reaction time (RT) and performance measures. It has a considerable advantage over these however, in that while these other, behavioural measures are composites of both stimulus processing <u>and</u> response processes, different ERPs are generated by these two phases of information processing and so it may be possible to dissociate them. By measuring the latency of components thought to reflect stimulus evaluation alone eg. P300, and comparing it with RT data, the length and nature of response processes may become clear. Thus ERPs serve a function as a cognitive tool, as do some brain lesions which have shown a dissociation between cognitive processes.

c) The third approach is to study ERPs as a clinical tool, in cases of neurological impairment. Here there are usually two distinct purposes. One is to try to understand the nature of the cognitive defecit by seeing which of the components of the ERP with known psychological correlates are affected in the patient, and the other is to try to understand the nature of the neurological impairment itself by seeing which ERP components which have known generators are altered, by injury. For introductions see Roth et al 1984 and Teuting et al 1984. It is clear that this application is very dependent upon the findings of the previous two.

1.2 BEHAVIOURAL CORRELATES OF ERPS

1.2.1 Introduction

In this section I shall outline the suggested psychological correlates of the most widely studied endogenous components of the ERP. It is very important to understand the kinds of processes ERPs are thought to reflect, since memory processes may not be independent of others and supposed ERP correlates of "encoding" or "retrieval" may in fact be related to such concepts as "attention" or "stimulus evaluation" which are surely active during learning and retrieval.

This is not an exhaustive review. The aim has been rather to indicate the range of psychological processes ERPs are thought to reflect and also the directions in which ERP research is heading. These issues will be taken up in the conclusion.

1.2.2 The Nd Wave

For reviews see Hillyard and Picton 1979, Naatanen and Michie 1979, Picton et al 1978, Naatanen 1982, Hillyard and Kutas 1983, Hillyard 1984. The "Nd" wave is thought to be an index of early selective attention. It was originally discovered in a paradigm in which auditory stimuli were presented in random order at rapid rates over two or more sensory channels ("channel" refers to the "sensory cue characteristics that distinguish attended from non-attended stimuli eg. ear of entry or tone frequency" Hillyard and Kutas 1983 p 37). Stimuli in the attended channel elicited a broad negative ERP which began at between 60-80 msecs. Further studies showed that this wave was elicited by all stimuli in an attended channel, both targets and non targets (Hink et al 1978, Okita 1981, Donald and Little 1981). See figure 1:5.

This finding was originally understood physiologically as an effect of selective attention upon the amplitude of the exogenous N100 component and interpreted psychologically as a reflection of the operation of an early "stimulus set" attenuation filter (Broadbent 1970, Hillyard et al 1973). This was contrasted with the operation of a later "response set" filter indexed by the late positivity elicited by deviant stimuli.

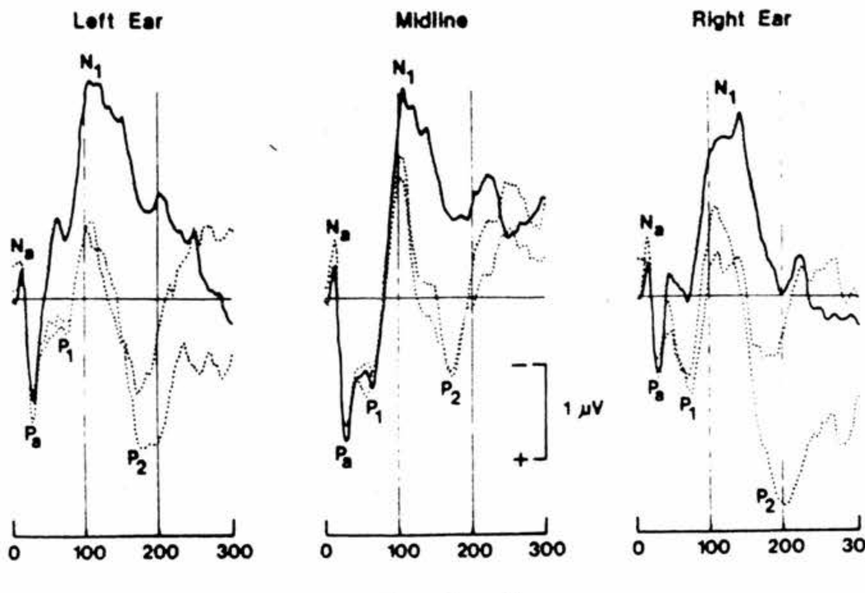

FIGURE 1-5. ERPs triggered by three channels of 60dB clicks, delivered in random order to the left ear, midline (binaural) and right ear, at intervals of 200-400 msec. The subject counted the clicks in one channel at a time and pressed a button after every tenth click. Solid tracings are ERPs to clicks in the channel being attended and the dotted tracings are ERPs to the same stimuli when attention was focused on another channel. ERPs are averaged over 512 clicks. From Hillyard 1984, p 56.

However, Naatanen (Naatanen 1975, Naatanen and Mitchie 1979) suggested that the observed effect was not due to an enhancement of the N100 component but to a negative wave which overlapped the N100 wave in the data reported by Hillyard (1973). He suggested that the latency of this component would depend upon task requirements such that it would continue longer when the channel discrimination was difficult. In Hillyard's experiment (where the 2 channels were distinguished by both pitch and localisation cues) the discrimination was easy and thus the attention-related negativity had occurred early enough to overlap and thus augment the amplitude of the N100 component.

In support of this suggestion Naatanen and his colleagues (Naatanen et al 1978, 1980) conducted two experiments which utilised a longer ISI (800 msec) in a paradigm otherwise similar to Hillyard's and found that there was no attentional effect on the N100 component but that there was a later negative displacement in the ERP to attended stimuli relative to non-attended stimuli. This deflection had an onset of 150 msec post stimulus and persisted approximately until the next stimulus was presented, at least 500 msec. This attention related negative deflection has been termed the "processing negativity" by Naatanen (Naatanen 1982) and described by Hillyard (Hillyard and Kutas 1983 p 38) as "the negative "difference wave" (Nd) between the ERP to stimuli in the attended channel minus the ERP to the same stimulus in the unattended channel". This Nd wave has been further resolved into two distinct sub components; an early, centro-frontal phase followed by a later protracted component having a frontal scalp distribution (Hansen and Hillyard 1980, Naatanen et al 1981a). Although Hansen and Hillyard (1980) suggested that the former component reflected a true enhancement of the exogenous N100 component, in line with their original interpretation, Naatanen suggests (Naatanen et al 1981a) that both are truly endogenous potentials ie. genuine components of the processing negativity, an index of selective attention.

As already noted, Hillyard and his colleagues suggested that this negativity was an index of "stimulus set" filtering, ie. an early form of selective attention which filters out stimuli on the grounds of gross physical features. Further support for their position was given by the finding of Schwent et al (1976b) that this component was affected by channel-selective information in the same way whether pitch cues or localisation cues distinguished the channels. In addition the amplitude of this negativity was increased to all stimuli which shared the simple physical attributes of the attended channel, whether or not they were relevant to the task (Hink and Hillyard 1976, Hink et al 1978) Further support is adduced from the fact that the Nd onset increases when the discrimination of channel cues is made more difficult (Hansen and Hillyard 1980).

Hillyard and Kutas (1983) further suggest however that while being a sign of early stimulus set selective attention, the Nd wave reflects some aspect of stimulus processing that follows the stimulus set selection rather than the process of selection itself (Hillyard and Kutas 1983, Naatanen and Mitchie 1979, Hillyard 1981). What kind of process this might be is not clear. One view is that Nd reflects the further analysis of attended channel stimuli for their task relevant properties. This has received some support; Okita (1981) showed that when "targets" were defined at the end of a tone burst, the Nd build-up took longer than when the "targets" were defined beforehand, indicating that some analysis of target/non target information in the attended channel was reflected by the Nd. It has also been shown that the early phase of the Nd generated by non-target tones was augmented when targets were presented more frequently (Donald and Little 1981) and when the tones were more difficult to distinguish from background noise (Schwent et al 1976a). Contrary evidence however has been found by Parasuraman (1980) who showed that an increase in the difficulty of target/non-target discriminability did not significantly alter the Nd amplitude in a two channel selective attention task.

Another theory is that the Nd wave is associated with the maintainance and rehearsal of the cue characteristics of attended events in short term memory. This is the view taken by Naatanen (1982) for at least one of the components of the Nd wave. Naatanen regards the Nd wave as an index of the matching of a stimulus against the representation of the to-be-attended stimulus held in memory. His view is that subjects establish an "attentional trace" ie. a template of the characteristics of the stimuli to which they have to attend. The trace develops when the subject rehearses the last occurrence of the attended stimulus and this attentional trace lasts only as long as it is rehearsed and corresponding sensory input (ie. a stimulus in the attended channel) is recent. This attentional trace is a form of voluntary orienting towards the stimulus in the relevant channel. While this trace exists all sensory input is automatically processed against it. Thus "the trace serves as a kind of tool by means of which the corresponding stimuli are very rapidly identified when physical differences are large enough." (Naatanen 1982 p 636).

In Naatanen's view, this processing negativity is the neuronal basis of this process of matching stimuli against the template. The earlier, centro-frontal, modality specific component reflects the identification process by which a sensory input is gradually identified as corresponding to the attentional trace. The more similar the stimulus is to the attentional trace, the longer the process continues. When the differences between channels are greatest the process terminates sooner.

The second component, which has a frontal distribution, is more sensitive to the magnitude of the physical differences between attended and unattended stimuli categories than the central component (Hansen and Hillyard 1980) and its onset-latency and duration show a dependence on the inter-stimulus interval (ISI) which the central component does not (Naatanen et al 1981a). This component he believes reflects either further processing of the stimulus after it has been identified as being of the attended channel or the selective rehearsal of the stimulus to be attended in short term memory.

While the nature of this Nd wave seems therefore to be a matter of uncertainty there is some consensus that it reflects the continuing processing of the attributes of an attended stimulus (Naatanen et al 1978, Okita 1981, Hillyard and Kutas 1983) and that the Nd wave terminates when this analysis reveals that the stimulus belongs to an irrelevant class (Naatanen 1982, Hansen and Hillyard 1983). In addition Hansen and Hillyard (1983) have suggested that the attributes of a stimulus are selected in a hierarchical fashion such that when a stimulus is rejected on the basis of an easily discriminable attribute (eg. belonging to the unattended channel) it is not analysed further along other sensory dimensions. Hansen and Hillyard (1984) have found that the onset of the Nd wave is earlier when the stimulus presentation rate is fast which they suggest indicates that the irrelevant tones are being rejected early, before the target/non-target dimension is analysed. Thus they conclude that the Nd wave indexes a hierarchical selection process which increases processing efficiency at high rates of stimulus presentation by rejecting irrelevant information at an early stage of processing. Such a view they suggest, accords with Broadbent's stimulus set mechanism (1970) in line with their original interpretation of the wave (Hillyard et al 1973).

One interesting application of this correlation of the Nd wave with attention processes is that Nd amplitude has been shown to be proportional to the response allocated to a particular channel. When subjects were required to detect targets in two channels simultaneously the amplitude of the auditory Nd to each channel was intermediate between those elicited by the attended and rejected channels when only one had to be attended (Hink et al 1978, Parasuraman 1978, Okita 1979). The total negativity remained constant however which suggests that these ERPs were indexing the allocation of limited processing resources.

1.2.3 Target Selection Negativities

Another ERP component or series of components related to attentional processes, this time in the visual modality, has been reported by Harter and his colleagues (Harter and Previc 1978, Harter and Guido 1980, Harter et al 1982, Aine and Harter 1984 a,b. For review see Hillyard and Kutas 1983 p 41 and Ritter et al 1984). Harter and Salmon (1972) reported an early negative component in occipitally recorded visual evoked potentials (VEPs), in a task requiring subjects to shift attention between two randomly presented visual stimuli which differed from each other in pattern or colour. An enhanced negativity peaking at 235 msec post stimulus (N235a) was elicited by attended stimuli. Other data (Harter and Previc 1978, Harter and Guido 1980) have been interpreted by Harter as indicating that occipital potentials following relevant and irrelevant stimuli reflect not only differential processing of relevant and irrelevant information but also "reflect a progressive change in the specificity of the differential processing - early and late portions of the negative potential reflecting differential processing on the basis of first the general and then the specific characteristics of the relevant stimuli, respectively." (Harter and Guido 1980 p 472). Thus he has suggested (Ritter et al 1984) the following sequence of negativities related to attention to specific features of stimuli; location (100 msec), contours (130 msec), colour or spatial frequency (150 msec) and orientation (200 msec). Even later negativity reflects the selection in neural channels processing the conjunction of these features (eg. colour and word, Aine and Harter 1984a) and then of the word or target itself, as a whole. The selection of conjunctions begins at about 250 msec and the selection of simple words at about 300 msec.

Hillyard and Kutas (1983) suggest that since these different potentials differ in scalp distribution as well as latency, they can be exploited to analyse the time course of the extraction of specific cue information from complex visual stimuli, although Hillyard and Munte (1984) have recently shown that rather than being an unvarying sequential series of selections, the processes manifested by the Nd wave are employed only when such selection is necessary before further selection can take place.

1.2.4 The Na Wave

Ritter and his colleagues (Ritter et al 1982, 1983a,b, Simson et al 1985) have described a negative potential with an onset latency of approximately 150 msec post stimulus which they believe to be associated with a pattern recognition process. The component was obtained by subtracting the ERPs elicited by a stimulus in a simple RT task (in which subjects had to respond as quickly as possible to a stimulus that occurred on 100% of trials) from ERPs elicited by the same stimulus when presented on 80% of the trials of a choice RT task.

Ritter et al (1983a) have reported that in a task where subjects were required to perform physical and semantic classification tasks, the Na peak latency increased as the stimulus complexity increased. The N200 component began after the onset of Na but before the Na peak. Increases in peak latency of Na were associated with delays of N200 and RT. Ritter et al (1982) have also manipulated the latencies of Na and N200 waves independently. The difficulty of a classification task was held constant while the difficulty of perceiving the stimulus was changed by masking the stimulus. While the onset latency remained constant for masked and not-masked stimuli the peak latency of Na was increased by 70 msec in the mask condition (figure 1:6).

The peak to peak latency difference between Na and N200 did not change with the introduction of a mask but did increase when the difficulty of the classification task increased.

Ritter has interpreted these data to indicate that the pattern recognition processes reflected by the Na component are enhanced in discrimination tasks where the stimulus changes unpredictably and its indentity must be ascertained in order to perform the task, compared with a simple RT task where one stimulus is repeatedly presented and the subject expects the same stimulus on each trial.

Recently (Simson et al 1985) this suggestion has been tested and Na shown to increase in a condition where subjects were led to believe (falsely) that the stimulus would change.

Ritter et al (1982) suggested that the N200 component reflects a stimulus classification process which depends upon the pattern recognition process reflected by Na.

1.2.5 <u>The N200 Component</u>

The N200 component of the ERP is characteristically elicited by low probability deviant items occurring in a train of otherwise homogeneous

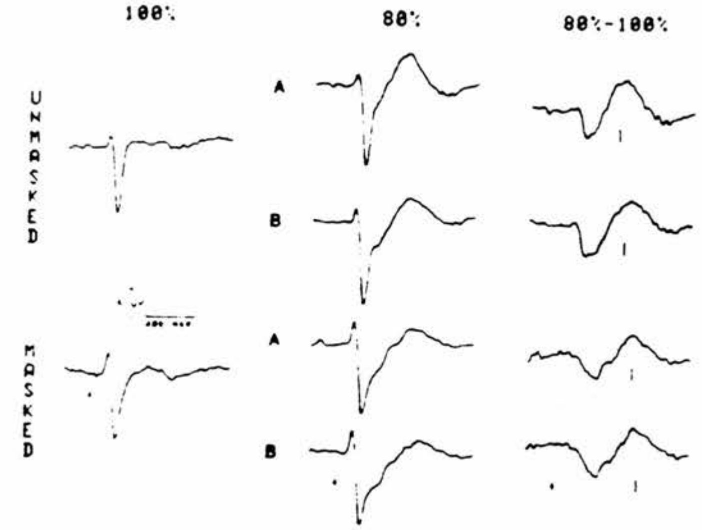

FIGURE 1-6. Fgure showing the change in NA peak latency with the introduction of a mask. Grand mean ERPs averaged across subjects at T5. In the case of the data in the upper half of the figure the stimuli were unmasked and in the case of the data in the bottom half the stimuli were masked. The left column: the letter F presented on all (100%) the trials of a simple RT task. Middle column: ERPs associated with stimuli that occurred on 80% of the trials in a choice RT task. Task A: Subjects respond one way for letters (80% of trials) and another way for digits (20% of trials). Task B: subjects respond one way for four letters (20% of the trials) and another way for all other letters of the alphabet (80% of trials). Right column: difference waveforms obtained by subtracting the waveforms in the left column from the waveforms in the middle column, separately for the unmasked and masked stimuli. Note that the onset of the negative wave in the difference waveforms, NA, is constant across conditions, whereas the peak latency of NA is affected by whether the stimuli are masked or unmasked. Arrow: stimulus onset. Vertical bar: RT averaged across subjects for the stimuli which occurred on 80% of the trials. From Ritter et al 1984, p 28.

stimuli. Several studies have found both N200 and "P3a" components elicited by such stimuli (N.K. Squires et al 1975, Ford et al 1976, Snyder and Hillyard 1976, K.C Squires et al 1977a). Snyder and Hillyard (1976) proposed that this N200-"P3a" complex reflected the functioning of a mismatch detector which automatically detects any change in ongoing background stimuli.

The N200 has been shown to be modality specific, being largest over pre-occipital areas for visual stimuli and over the vertex (Cz) for auditory stimuli (Simson et al 1977a). It is closely associated with stimulus evaluation, as indicated by its early onset and its close relation to RT. Ritter et al (1979) found that when the difficulty of target detections was increased the increase in N200 was closely correlated with the increase in RT latency.

However there is evidence that the N200 may not be a unitary phenomenon. Naatanen has suggested (Naatanen et al 1982, Naatanen et al 1981b; for review see Naatanen and Gaillard 1983) that there are two dissociable negativities occurring at this latency; the "mismatch negativity" (MMN) and the later "N2b".

Naatanen et al (1978, 1980) reported that an N200 component could be recorded to deviant stimuli in an unattended input without a corresponding "P3a". This N200 they named the "mismatch negativity" and emphasised its independence from attention and stimulus significance. They described this potential as a reflection of the brain's automatic, passive response to physical stimulus deviance. Naatanen and Gaillard (1983) pointed out similarities between the characteristics of this component and those of the neural mismatch generator proposed by Sokolov (1975). As evidence for such a correspondence Naatanen and his colleagues (Sams et al 1984) have shown that the MMN exhibits strong short term habituation as does the "orienting response" (OR). On the basis of such a correspondence Naatanen (Naatanen 1984) suggested that these data provide an indication of the nature of short term auditory memory (the sensory register). Each auditory stimulus leaves a trace which is a fairly exact representation of the physical characteristics of the stimulus. The comparison of the incoming stimulus with this trace elicits the MMN generator process if the two are different.

The second subcomponent, the "N2b", is modality non-specific, occurs only when the stimulus sequence is attended (Naatanen et al 1981b) and is always accompanied by a "P3a" component. Naatanen suggests that this potential is an index of the matching of a stimulus to the template of the stimulus the subject is voluntarily holding in memory, the "mental image" of the stimulus. This component, he tentatively suggests, may be an index or concomitant of the orienting reflex.

A similar dichotomy has been drawn by Renault and his colleagues (Renault 1983; Renault et al 1982). They too (Renault et al 1982) have described a modality specific N200 whose latency and duration correlate with perceptual processing and RT, and a modality non-specific N200 which is constant in duration. For Renault these data support the idea that orienting (indexed by the later, non-modality specific subcomponent) is dependent on stimulus identity and related to template matching (indexed by the first, modality specific subcomponent).

Other investigators have cast doubt upon the description of "N2b" as an index of some kind of OR. Fitzgerald and Picton (1983) have reported data which they interpret as suggesting that it reflects rather some kind of controlled processing stage, "We propose that the N2b component reflects the allocation of effort to the evaluation of those stimuli that an initial mismatch process determines as possible targets." (p 270). Neither is it certain that the MMN reflects involuntary mismatch detection, as Naatanen has suggested. Ritter et al (1983a) have shown that the N200 can sometimes come under voluntary control.

The only conclusion which it is possible to draw at present is that there do seem to be two N200 sub-components one of which (MMN or "N2a") is related to the detection of infrequent stimuli, perhaps indexing a mismatch mechanism, while the other occurs in the presence of a late frontal positivity which may index some process subsequent to mismatch detection.

One interesting question is the relationship of the N200 to the processing negativity (Nd). Ford and Hillyard (1981) have recorded a negative peak (Ne) which occurs at 130 msec post stimulus and is sensitive to mismatches and to attention. This peak may therefore reflect some combination of the two negativities. This further complicates the question of the relationship of these negative potentials to one another and while further research may well fractionate off further negativities the question remains whether there are a whole series of processing negativities or whether they are rather all facets of the same process.

1.2.6 The N400 Component

The "N400" deflection, was originally reported by Kutas and Hillyard (1980a,b) to be elicited by semantically anomalous words occurring at the end of otherwise meaningful sentences. The now-famous example of such an anomaly is the sentence "he spread the warm bread with socks". The word "socks" in this sentence elicited a large negativity with a peak latency of about 400 msec. No such wave was elicited by physically anomalous words (see figure 1:7).

They have also reported that this component seems to be relatively insensitive to the probability of occurrence of semantic deviations and that it has a slight right hemisphere predominance in amplitude (Kutas and Hillyard 1982b). These data originally led Kutas and Hillyard to conclude that the N400 was an electrophysiological index of the interruption of sentence processing by a semantically anomalous word and the reinterpretation of that information. In support of this conclusion, Kutas and Hillyard have reported data indicating that the N400 is primarily related to semantic anomaly. No N400 is elicited by physically anomalous words or by violations of grammatical structure (Kutas and Hillyard 1982a). During prose reading, semantic anomalies elicit N400s and grammatical errors do not (Kutas and Hillyard 1983). The amplitude of N400 is directly proportional to the "Cloze" probability of a word ie. the degree to which a subject expects a particular word. They found that the lower the expectancy, the greater was the N400 amplitude (Kutas and Hillyard 1984). From these last data Kutas and Hillyard have reinterpreted their original theory concerning N400 and suggest it reflects the violation of a semantic "prime" set up by the preceding words (Kutas and Hillyard 1984). These findings have been replicated in other semantic paradigms (Boddy and Weinberg 1981; Sanquist et al 1980; Novick et al 1985)

Other studies have reported similar late negativities occurring at about 400 msec post stimulus and these have raised the question of whether the N400 reflects purely semantic processes. Polich et al (1981), found that that the violation of a category expectancy elicited a negative component occurring at 300 msec. This component was elicited by words occurring at the end of a seven item list if they belonged to a different category to the others. This component was very similar to a negative wave elicited by a semantically anomalous word occurring at the end of a seven word sentence. These data suggest that semantic anomaly may not be crucial in eliciting an N400 but that some kind of "categorical expectancy" may be. Polich et al's results may accord with Kutas and Hillyard's recent reinterpretation of the N400 effect. Three other research groups have however reported data that are difficult to reconcile with Kutas and Hillyard's model.

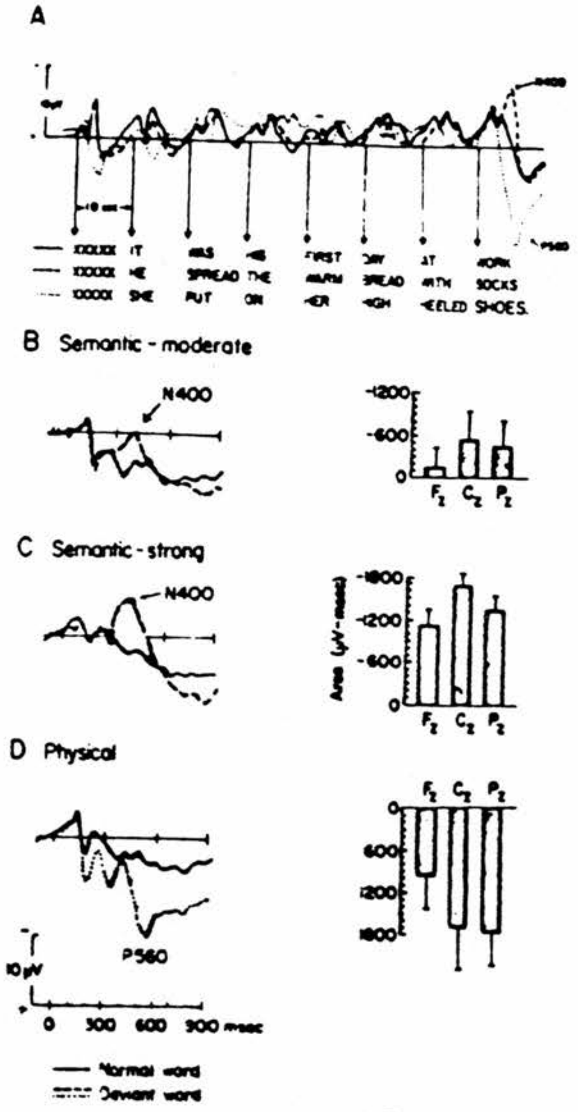

FIGURE 1-7. (A) The timing of word presentations for three sample sentences and typical ERP waveforms recorded over the entire seven word sentence, averaged over three subjects. (B-D) Data showing the apparent dependence of the N400 on semantic anomaly. In each comparison the grand average ERPs (over all subjects) from Pz for the normal (solid line) and deviant (semantic, dashed line: physical, dotted line) seventh words are superimposed. From Kutas and Hillyard 1980, p 203.

Stuss et al (1983, 1984a) have reported a late negativity elicited by non semantic stimuli. In one study (Stuss et al 1984a) a biphasic late negative wave was elicited by visual stimuli which either had to be named or their name read. In another study (1983) they reported that both the earlier "Nx" component (occurring at 250 msec) and the later "Ny" component (occurring at 420 msec), were elicited by stimuli which had to be named and by stimuli which had to be mentally rotated. This has led them to postulate that their "Ny" component, which they associate with the N400 component, may not be specifically related to semantic processes but rather the further evaluation of a complex stimulus.

Fischler et al (1983, 1985) have recorded N400-like negativities to final words in self referential statements which made the statement false. The amplitude of this component was greater for falsifying words in familiar statements than in unfamiliar ones.

Rugg (1984a,b) has reported a late negative potential elicited during tasks which required the sequential matching of words, either on the basis of orthographic (ie. upper or lower type-case) or of phonological similarity (ie whether they rhymed or not). The ERPs generated by non rhyming words were marked by an increased negativity at about 450 msec post stimulus (Rugg 1984a). This negativity is also elicited by non rhyming non-words (Rugg 1984b). Rugg has suggested that this is evidence against the suggestion that the N400 component reflects purely semantic processes.

Other studies have reported late negativities occurring in the same latency range as the N400 but which have not been equated with the N400. Neville et al (1982) have recorded an "N410" component elicited by the visual presentation of words which was larger in amplitude over the left hemisphere than over the right. Bentin et al (1985) have recorded an N400-like negativity elicited by stimuli in a semantic priming paradigm. They found that potentials generated by words which had been semantically primed (targets) were more negative at 400 msec than those elicited either by the primes or by non-related "filler" items. However they reserve judgement on whether this negativity is identifiable with the N400 of Kutas and Hillyard, pointing out that it could equally well be the result of an increased positivity in the waveforms generated by non-target words. Rugg (1985) has reported a similar negativity generated by attended words.

The resolution of the question of what exactly the N400 component reflects is to a large extent dependent upon the relationship of the N400 to these other negativities and indeed whether the N400 is a manifestation of the N200 component (cf. the late N200 recorded by Ritter et al 1983a). Polich has recently suggested (1985) that the N400 is a late manifestation of the N200 component. In a study in which subjects underwent a series of semantic matching tasks, the presence of N400 negativities was seen to correspond to increased response latency and Polich suggests that the greater difficulty of making certain semantic judgements about words leads to a delayed N200 negativity. Thus he concludes that the N400 is one manifestation of a single system involved in comprehending similarities and relationships among stimulus items, also reflected by the N200 component.

Such attempts to relate potentials to one another will hopefully allow some degree of synthesis of the many disparate findings with respect to these late negativities (see Ritter et al 1984 for discussion).

1.2.7 P300 Component

The P300 component of the ERP has probably been the most extensively studied and in terms of its correlates the best understood, of all endogenous components. Research has centred upon 2 aspects of this component, its amplitude and its latency and the determinants of these will be discussed in turn.

1.2.7.1 The Amplitude Of P300 -

According to Donchin, et al (1978) the two major determinants of P300 amplitude are probability and task relevance.

In the study by Sutton et al 1965 in which P300 was first reported the subjects were required to predict prior to each trial which of two events would occur on the trial. ERPs generated when subjects knew the outcome and when they did not, were compared. When subjects were uncertain as to the outcome, stimuli elicited a large positivity at approximately 300 msec post stimulus. The important difference between conditions was that in the "uncertain" condition, the a priori probability of a particular stimulus was lower than in the "certain" condition. Further studies showed more clearly how the a priori probability influenced the P300 component. Teuting et al (1970) manipulated the a priori probability of the stimulus, the sequential dependencies between successive stimuli and the probabilty that the subjects' guess (of what the next stimulus would be) would be confirmed. They found that the P300 amplitude was greater, the less probable the event. Teuting and Sutton (1973) reported that P300 amplitude depended on the "risk" incurred by the subject making a prediction. Donchin et al (1973) varied the sequence-generating rule in different series of stimuli and found that the more predictable the stimulus (ie. the less complex the rule) the smaller the P300 elicited.

Another paradigm in which a relationship between P300 amplitude and probability has been found to exist is the "oddball" paradigm, in which the subject is presented with a random sequence of two or more stimuli and is required to count one of them. Studies in which the relative probabilities of the various stimuli have been varied have shown that P300 amplitude is an inverse function of the a priori probability of the eliciting stimuli (Courchesne et al 1975, Hillyard et al 1973, Roth et al 1976, K.C. Squires et al 1977a, N.K. Squires et al 1975, 1977). Duncan Johnson and Donchin (1977) showed that the P300 amplitude varies monotonically with the probability of the stimulus (See figure 1:8).

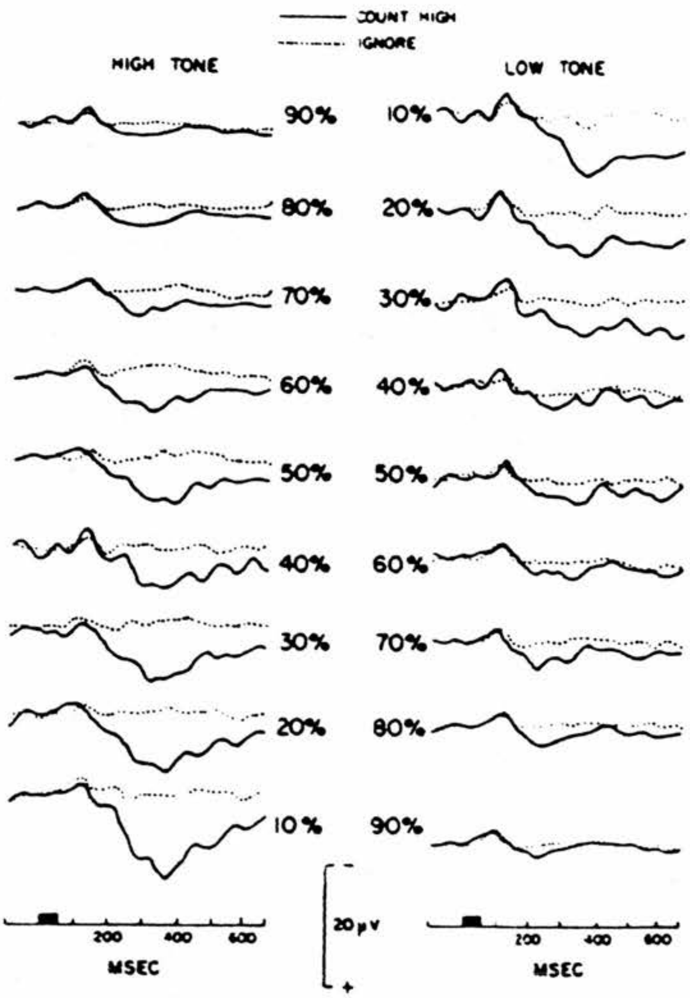

FIGURE 1-8. The ERPs elicited by high and low tones presented in a Bernouli series with their respective probabilities. Data are shown for experimental conditions in which subjects counted the high tones in each series (solid lines) and from a series in which the subject was instructed to solve a word puzzle while the tones were presented (dotted lines). From Begleiter 1978, p 49.

It has also become clear however that the P300 amplitude depends more upon the subjective probability of the stimuli than upon the a priori probability (K.C. Squires et al 1976). It was noted that some high probability stimuli in a Bernoulli sequence elicited large P300s and some low probability items failed to elicit a P300. This trial-to-trial variation in P300 amplitude is due to trial-to-trial fluctuations in the subjective probabilities of the events. K.C. Squires et al (1976) averaged trials in a Bernoulli sequence on the basis of the patterns of stimuli presented on the preceding trials and found that the amplitude of P300 elicited in any one trial was directly related to the pattern of stimuli presented on the preceding trials. An example of this kind of analysis can be seen in figure 1:9.

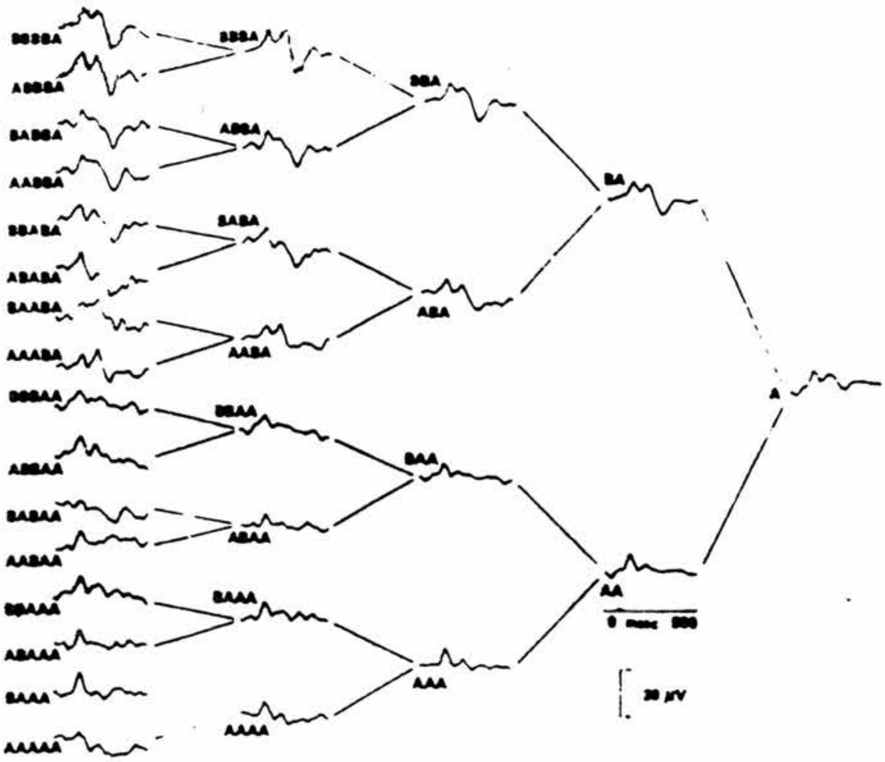

FIGURE 1-9. Average ERP waveforms of one subject for different stimulus sequences. "A" and "B" represent occurrences of high and low pitched tones respectively. ERPs in each case are elicited by the final high-pitched tones in the designated sequence. From K Squires et al 1978, p216.

A number of other studies have further demonstrated this finding (Duncan-Johnson 1978, Duncan-Johnson and Donchin 1977, 1982, Horst et al 1980, Johnson 1980, Johnson and Donchin 1980, 1982, K.C. Squires et al 1977b, 1978.)

The second major determinant of P300 amplitude is task relevance. It was found that the same low probability stimuli which elicited large P300s in the condition where subjects attended to the stimuli (ie. counting them) failed to elicit P300s when the subjects did not attend to the stimuli. (Courchesne et al 1975, Duncan-Johnson and Donchin 1977, Ford et al 1976, Hillyard et al 1971, K.C. Squires et al 1973, 1977a, N.K. Squires et al 1975). Thus low probability is a necessary but not a sufficient condition to elicit P300. Whether the stimuli are relevant to the subject is also important.

This also has been reported in studies of selective attention. Duncan-Johnson et al 1978, presented stimuli in both auditory and visual modalities and required subjects to count rare stimuli in either one or both modalities. Rare auditory and visual stimuli elicited similar P300s when stimuli were counted in both modalities but failed to elicit a P300 when their modality was not counted. Many other attention studies have reported similar results (see Donchin et al 1978 p 384).

Some data however have been inconsistent with the above results (for example Ritter et al 1968, Roth et al 1976, Roth and Koppell 1973, Vaughan and Ritter 1970) who have suggested that P300s which are elicited by rare stimuli in an "ignore" condition have amplitudes of equal values to those elicited by rare stimuli in a counting condition. Donchin et al 1978, suggest that this may be due to the fact that subjects in the studies were required to passively ignore the stimuli. In such conditions, they argue, subjects will always attend to important (ie. rare stimuli) even when told not to. In studies which found that rare stimuli in an "ignore" condition elicited no P300 (see above) another task was always used eg. reading. Other studies have reported that deviant stimuli occurring on an "irrelevant" channel can elicit P300 waves if they are highly intrusive (N.K. Squires et al 1977), that these P300s to "irrelevant" stimuli habituate quickly (Courchesne et al 1978) and correlate with behavioural measures of interference from the "irrelevant" stimuli (N.K. Squires et al 1977) suggesting that these P300s "index the extent to which attention is actively drawn to events outside the attended channel" (Hillyard and Kutas 1983 p 44).

The P300 amplitude appears to reflect the allocation of processing resources to a task. Wickens et al (1977) reported a reduction in the amplitude of P300 elicited by low probability stimuli in a Bernoulli sequence with the introduction of a secondary task. Israel et al 1980a, found that the amplitude did not vary as a function of the difficulty of the secondary task, when that task is not related to stimulus evaluation (eg. tracking difficulty) but that it does when the secondary task is perceptual.

A third important determinant of P300 amplitude is the success of target recognition and the confidence with which such a recognition is made. Early studies showed that a large P300 component could be elicited by correctly detected signals in a threshold signal detection task (Hillyard 1971, Hillyard et al 1971). Its amplitude was found to increase as the hit rate increased and the P300 was absent on miss, false alarm and correct rejection trials. P300 amplitude increased when the decisions were made with greater accuracy ot with a stricter decision criteria (Paul and Sutton 1972, K.C. Squires et al 1973). K.C. Squires et al (1975) reported that P300s could be elicited by false alarms (mistaken reports of signal presence) if the subjects' confidence in their report of signal presence was high, and by correct rejections, if the subject's confidence was high and the signal probability low. Parasuraman (Parasuraman and Beatty 1980, Parasuraman et al 1982) has reported that P300 amplitude increases in relation to successful recognition of targets and to the subjects' confidence in their decision (figure 1:10).

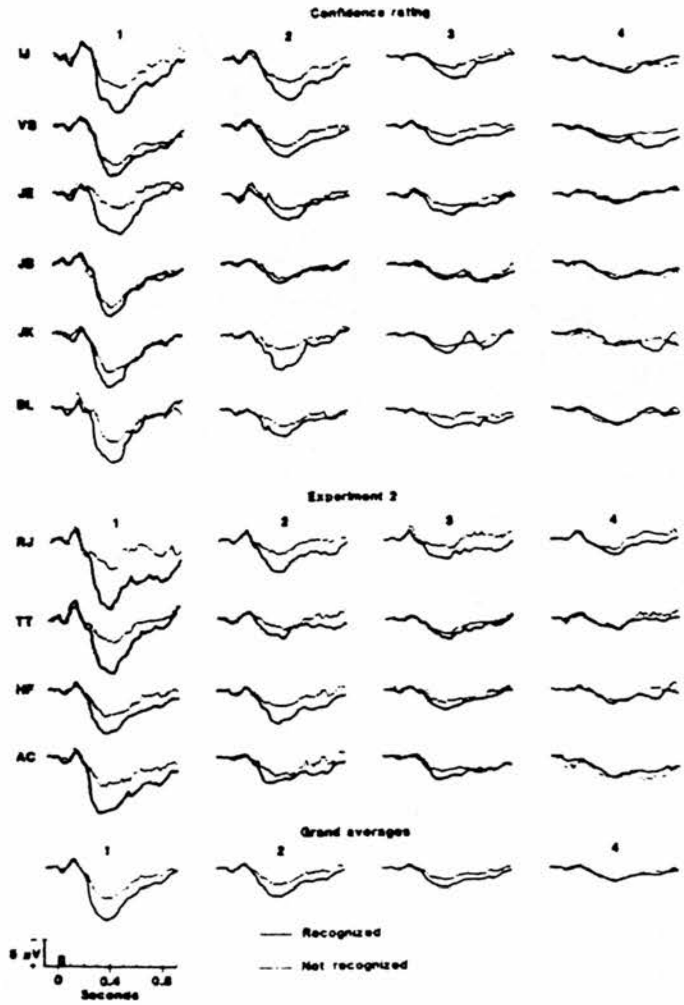

FIGURE 1-10. Event related potentials averaged separately for correctly and incorrectly recognised targets at each of the four ratings of detection confidence (1 yes-sure; 2 yes-unsure; 3 no-unsure; 4 no-sure). The ERPs were recorded from Cz and are shown for each of the six subjects in experiment 1 (in which subjects had to detect and recognise one of two stimuli) and for each of the four subjects in experiment 2 (in which subjects had to detect and recognise one of four stimuli). ERPs averaged across subjects are also shown. From Parasuraman and Beatty 1980, p 81.

Thus three psychological constructs seen primarily to influence the amplitude of P300; subjective probability, task relevance and confidence.

1.2.7.2 P300 Latency -

P300 latency is presently understood to be an index of the time taken to evaluate a stimulus. Kutas et al (1977) were the first to co-vary and dissociate P300 latency and reaction time (RT). They required subjects to perform simple or complex semantic categorisations in order to detect target stimuli under conditions where either accuracy or speed were stressed. They found that in the "speed" condition trials, the correlation between P300 and RT was low while in the "accuracy" condition, the correlation was high. They suggested that while RT reflects all the processes leading to a response, the P300 component latency reflects only the time taken by "stimulus evaluation" processes (encoding, recognition, classification) independent of response processes. This hypothesis was tested by McCarthy and Donchin (1981). They manipulated stimulus evaluation difficulty (and therefore time) by embedding target words in matrices of either ".." signs or letters and manipulated response selection by changing the compatibility between the target word ("right" or "left") and the responding hand. They found that RT was increased by both difficult stimulus evaluation and stimulus-response incompatibility but that only stimulus evaluation effected the P300 latency. It was thus proposed that P300 latency could serve as a "metric" in the study of mental chronometry.

More recently Magliero et al 1984 have reported that P300 latency increased systematically only with increased stimulus evaluation time, produced by graded changes in noise level, whereas RT increased both with noise and with response incompatibility. They suggest too, that in view of recent unpublished studies in Donchin's laboratory (Gratton et al 1984, Coles et al 1983) showing that the latency of P300s elicited by errors is some 100 msec greater that the P300 latency associated with correct responses, P300 latency reflects "situation evaluation" rather that stimulus evaluation. The error, together with the stimulus is part of a "situation" which needs to be evaluated.

1.2.7.3 Functional Explanation Of P300 -

The explanations of functional significance of P300 have been couched mainly in terms of the observed correlates of the component eg. that it has something to do with the evaluation of task relevant, rare stimuli. Such terms are descriptive rather than explanatory. Two explanatory theories of P300 function have been very influential in the past decade. The first of these is the explanation adopted by Sutton and his colleagues (Ruchkin and Sutton 1978a,b, Ruchkin et al 1981, 1982, Munson et al 1984) who have proposed that the amplitude of P300 is related to the amount of prior uncertainty "resolved" by a stimulus. In terms of communication theory (Shannon and Weaver 1949) P300 amplitude increases as the equivocation (ie. information loss in the message) is reduced. "In addition to the influence of a priori uncertainty with respect to an event in determining the amplitude of P300 there is an influence of the degree of a posteriori uncertainty, termed equivocation, of having perceived the event." (Ruchkin and Sutton 1978a p 274). Improbable stimuli reduce a lot of uncertainty and therefore elicit large P300s.

This theory rests on two principal experimental findings. In one study (Ruchkin and Sutton 1979) subjects were presented with trials on some of which the stimuli were present and on others of which stimuli were absent. The latter condition elicits the "emitted" P300. They found that the amplitude of the P300 evoked by the presence of stimuli was greater than that of the emitted P300. This was considered consistent with the notion of equivocation in that temporal uncertainty is considerably greater in the emitted potential condition than in the evoked potential situation since the subject relies on the sense of time judgement to determine that the interval is over and that the stimulus has not occurred. This finding was replicated in another study (Ruchkin and Sutton 1978a) which also reported that the difference in P300 amplitude between emitted and evoked potentials was greatest in a long ISI condition ie. when temporal uncertainty was increased. It is suggested (Sutton 1979) that the data of Kutas et al 1977, showing the dependence of P300 latency on stimulus evaluation, is in accord with an equivocation account of P300 since in that account P300 would occur only when the equivocation had been resolved (ie. when the stimulus evaluation has been completed).

This theory has two main drawbacks. Firstly, the term "uncertainty reduction" is general enough for it to fit much of the data but fitting a general concept to experimental data does not prove the theory. Secondly there have been no experiments which have directly tested this hypothesis in such a way that the other accounts cannot explain the data. Sutton has more recently suggested (Sutton and Ruchkin 1984) a revised form of the theory in which he says that the P300 reflects the "value" a stimulus holds for a subject. Thus a task relevant event holds more "value" than a task-irrelevant one, as does a rare event or one that reduces uncertainty. This latter explanation however seems to be a vague concept that says little more than that P300 amplitude is determined by task relevance!

The other major theory of P300 significance is that put forward by Donchin and his colleagues. Originally K.C. Squires et al 1976, suggested that the P300 component reflected the activity a neural system which noted the violation of subjects' "expectancy". They proposed that expectancy is determined by three factors; a) the memory of event frequency within the prior stimulus sequence, b) "alternation", the structure of the prior sequence ie. how many stimuli of one class precede stimulus of another (it is assumed that subjects expect stimuli to repeat), c) the a priori probability of the event. Like the concept of uncertainty reduction, the concept of "expectancy" fits much of the published data well but little place was given in the model to the relevance of the stimuli, which has been shown to be an important determinant of P300 amplitude.

Donchin himself (Donchin 1975, 1979) has proposed that the P300 is a manifestation of a process which is invoked whenever "context updating" occurs ie. whenever data provided by a stimulus demands that the hypotheses or models of the environment held by the subject be revised. Donchin has more recently (1981) outlined in more detail his theory. He compares the attributes of the P300 with those of the orienting reflex (OR). Events which elicit P300s tend to elicit the OR. The OR is thought to result from a mismatch between external events and the "schema" or "neuronal model" of the environment held in memory (Sokolov 1975). Once a mismatch has been detected the importance attributed to the mismatch determines whether the OR will be elicited. As a relevant stimulus is repeated a few times the neuronal model is altered such that these stimuli need no longer be responded to ie. the OR habituates. Pribram and McGuinnis (1975) referred to this as "context updating". The P300, Donchin suggests, reflects the neuronal mechanism of updating the schema. This schema can be conceived of as "a large and complex map representing all available data about the environment....When there is need the model is revised by building novel representations through the incorporation of incoming data into schema based on long term memory data. It is likely that it is this updating process that we see manifested by the P300" (Donchin 1981 p 32).

Donchin predicts on the basis of these suggestions that P300 amplitude should correlate well with memory performance (since surprising events are assumed to be memorable). This has been experimentally tested in a Von Restorff paradigm (Karis et al 1984) and the amplitude of P300s elicited by oddball stimuli which were later retrieved was found to be greater than that elicited by oddballs not later retrieved. This study is discussed in greater detail in chapter 3 but with respect to Donchin's theory it should be noted that these data do not prove his theory, since "surprising" events may be memorable for reasons other than that they cause an updating of mental schema. In general however, Donchin's model is probably the most testable and clearly articulated of any functional theory of P300 and is thus important.

1.2.7.4 Conclusion -

In conclusion the P300 is a highly robust, endogenous ERP component whose determinants are fairly well understood. In particular its amplitude appears to be primarily responsive to surprising, relevant events and its latency appears to be dependent upon stimulus evaluation processes. Thus P300 can serve as a "metric of information processing" without the functional role of the neural circuits it indexes necessarily being understood. The determination of these will require more that the delineation of more antecedent influences (such as probabilty, task relevance etc.). As Donchin has pointed out (Donchin 1981) it will require specification of a potential cognitive function or process and the consequences of the enactment of such a process. One attempt to do this (Karis et al 1984) has not been successful since other processes concurrent with those manifested by P300 could have produced the same consequences.

The determination of the functions of the process manifested by P300 will probably be the next major step forward in ERP research and the theory propounded will serve as a model for theories of other components. It is thus one of the major research goals of ERP research.

1.2.8 Other Late Positive Components

In addition to the P300 component a number of other late positive endogenous components have been reported (Roth 1978, Teuting 1978, Ruchkin and Sutton 1983, Sutton and Ruchkin 1984).

N.K. Squires et al 1975 reported the existence of a positive deflection in the ERP which preceded the P300 component, which they called "P3a". It was elicited by low probabilty, auditory stimuli presented while subjects were engaging in another task and "ignoring" the stimuli. It had relatively early latency, relatively small amplitude and a fronto-central scalp distribution (see also Renault 1983). Courchesne et al 1975 have reported a P300 to novel visual stimuli that were not task relevant. This component was maximal frontally, had a relatively long latency and habituated quickly as novelty decreased. Ruchkin et al 1981 have reported an early P300 (P300E) which is elicited in a condition where feedback was given to the subjects as to whether their estimate of time interval was correct or not. Stuss and Picton (1978) have reported a later positivity called "P4" which Picton et al 1980 have related to the utilisation of information in conceptual learning.

1.2.9 Slow Wave

N.K. Squires et al 1975 reported finding, in addition to "P3a" and "P3b" components, a long duration slowly varying wave that overlapped with and followed "P3a" and "P3b". This wave, designated the "Slow Wave" was maximally negative over the frontal scalp. The amplitudes of both the "P3b" and the slow wave were largest when elicited by low probability events. It was confirmed in a series of experiments (McCarthy and Donchin 1976, K.C. Squires et al 1977b, Duncan-Johnson and Donchin 1977) that the slow wave amplitude was influenced by most of the same behavioural variables that influenced "P3b". Thus in their 1978 review of ERP literature Donchin et al 1978 stated that "as slow wave is so closely associated with P300 it wil not be further discussed....." (p 356).

Since then however, a number of studies have demonstrated a functional dissociation between P300 and Slow wave (Roth et al 1978a, Ruchkin et al 1980a,b) Results from other studies have in addition suggested that the slow wave may not be a unitary component (Fitzgerald and Picton 1981, Friedman et al 1984, Friedman, in press, Naatanen et al 1982). These have shown that the frontal (negative) slow wave and the parietal (positive) slow wave do not consistently relate in the same fashion to the experimental variables. For discussion of the inter-relationships between these separate portions of the slow wave and other postulated late slow wave components see Ritter et al 1984 and Sutton and Ruchkin 1984.

The functional importance of this slow wave is as yet unclear except that its amplitude is influenced by many of the same variables as effect P300. Ruchkin and Sutton (1983) suggest that it reflects "further processing" but what is meant by this is unclear and Friedman et al 1984 have reported data inconsistent with this claim.

1.2.10 Contingent Negative Variation

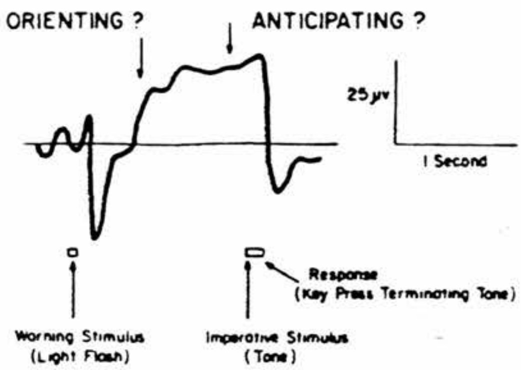

FIGURE 1-11. Prototypical CNV waveform and depiction of a typical eliciting situation; S1 and S2 (separated by a short foreperiod) followed by an RT response. Negativity is indicated by an upward deflection. From Rohrbaugh and Gaillard 1983, p 270.

A brief mention should be given to one of the most widely studied event-related potentials, the contingent negative variation (CNV). A typical CNV is shown in figure 11.

The CNV here is associated with the forewarned reaction time task. Using this paradigm, Walter et al 1964 found a slow ERP wave whose duration extended beyond the foreperiod. This was a broad negative wave that developed over the foreperiod between the warning (S1) and the imperative (S2) stimuli. Hillyard (1973) has classified the paradigms in which the CNV has been recorded into four general types: a) holding a motor response in readiness; b) preparing for a perceptual judgement; c) anticipation of a reinforcer, positive or negative and d) preparing for a cognitive decision. Several studies (Loveless and Sandford 1973 1974a,b, Weerts and Lang 1973) have shown that there are two distinct phases to the CNV. The first occurs in relation to the warning stimulus and is possibly related to an orienting response. The second phase occurs prior to and in anticipation of the second stimulus and is related to some preparatory activity.

Rohrbaugh and Gaillard (1983) have similarly suggested that the CNV is composed of two separate wave complexes. When the foreperiod is extended from the traditional short foreperiod of 1 or 1.5 sec to 3 sec or more, two distinct waves become apparent (see figure 1:12).

The first of these they called the "O" wave (after its supposed relation to orienting proposed by Loveless and Sandford 1973) which they suggest can further be divided into three negative waves: the slow negative wave 1 (SNW 1), the first slow negative wave which peaks frontally at 500-700 msec; the slow positive wave (SPW), the slow positive wave which peaks parietally at about the same latency; the slow negative wave 2 (SNW 2), a late broadly distributed slow negative wave. They suggest that the SNW 1 and the SPW are sometimes jointly identified as the "slow wave" component described by N.K. Squires et al 1975. Gaillard suggests (in

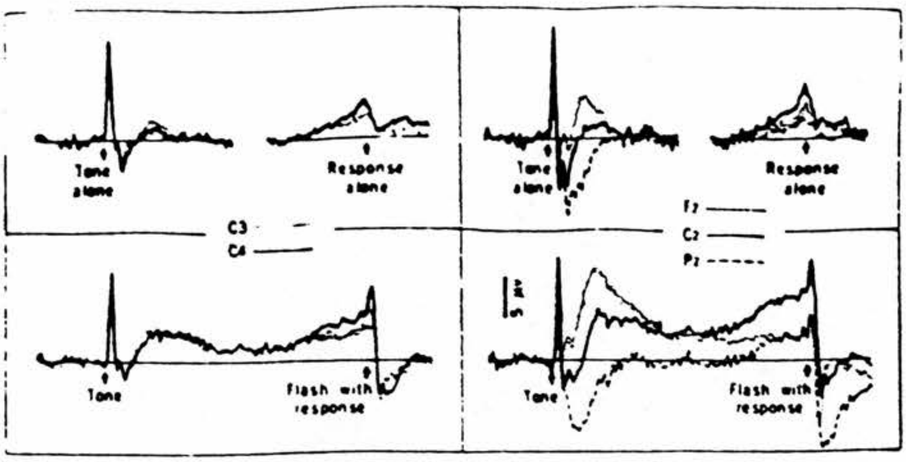

FIGURE 1-12. Event-related potentials elicited in an RT task with a 4 sec. foreperiod (bottom panels), and individually by non-paired tones and uncued key presses (top panels). Records from midline frontal (Fz), Central (Cz) and parietal (Pz) electrode sites are shown in the right panels, and for lateral left (C3) and right (C4) motor sites in the left panels. From Rohrbaugh and Gaillard 1983, p272.

Ritter et al 1984) that the SPW reflects the last stage of stimulus processing and that SNW 1 and 2 reflect processing more related to responding.

The second part of the CNV they claim is a manifestation of the "readiness potential" (Kornhuber and Deecke 1965) and is related to preparation for motor response.

1.2.11 Conclusion

In the preceding section a brief overview has been given of the most significant ERP components and their proposed behavioural correlates. In particular, two trends seem to characterise the research of the last 10 years.

The first is that there has been a proliferation of components. The Nd, the N200 and the CNV components have each been subdivided into two sub-components and several positivities have been recorded in addition to the P300 component. Even the Slow Wave may have a number of subcomponents (not to mention the possibility of there being several different late slow waves). While well established components have thus been subdivided, numerous other positivities and negativities have been "discovered".

It is not clear whether such proliferation is a sign of progress or not. It could be argued that all that such studies have done is to make the field more complicated than it already was without resolving any of the questions that were being asked of the well established components such as the P300. It is tempting at first sight to concur with Sutton when he says, after reviewing the available evidence on the late positive complex, that "It seems as if what we have been saying is that we are in a hell of a mess." (Sutton and Ruchkin 1984 p 9). Recent discussions about the inter-relations between components (Sutton and Ruchkin 1984, Ritter et al 1984) have arrived at no consensus either on possible inter-relations or even on the appropriate methods for arriving at them.

What will be needed in the next ten years then, are studies which attempt to manipulate the psychological correlates of two or more closely related components to describe more precisely how they differ functionally, topographically and in latency. For example if the N400 is merely a facet of the N200 component such knowledge may shed light upon whether N400 indexes some kind of purely semantic process or a more general mismatch process.

On the other hand, for a number of reasons the proliferation of components is a sign of progress. Firstly it could be argued that research restricted to previously well established components (eg. P300) has not advanced our understanding of their functional roles, and progress will thus involve describing other ERP correlates of cognitive processes which may be more easily understood. Secondly, fractionation can resolve differences between empirical findings since it can be demonstrated that different studies were recording different subcomponents of the component in question. Thirdly it can present a more complete picture of the way in which the brain processes stimuli, possibly giving rise to a comprehensive functional theory of what ERP components represent.

The principal reason why it represents progress is that it is a reflection of the fact that the main motivation of much ERP research seems to have altered. Previously research concentrated on discovering the behavioural and cognitive correlates of a particular neural phenomenon. To do so researchers utilised a number of psychological concepts, some of which were poorly defined and were really descriptive rather than explanatory. A different approach has motivated a number of recent studies which have identified "new" components. Such studies have utilised well established psychological paradigms and theories and have studied ERPs either to cast light upon the psychological theories or to index aspects of psychological processes "invisible" to behavioural measures. Good examples of such work are recent experiments recording ERPs during "priming" tasks (Bentin et al 1985, Rugg 1984 a,b). Other psychologically reliable theories ought to be capable of being studied by similar methods.

The second major trend has been the use of broadly similar concepts to explain the functional roles of components. In particular, several components have been designated as signs of "mismatch processes", especially the endogenous negativities. The picture that has emerged is of a sequence of processes which are applied to stimuli, each of which respond selectively to increasingly complex features of the stimulus. The late positivities, such as the P300 and Slow Wave may also be involved in such a system. Whether or not these findings form a basis for an overall unifying theory of what the ERP reflects along the lines of some mismatch system, it seems clear that ERPs are related closely to memory systems and access to them since this is crucial in matching processes. This is especially evident in Donchin's discussion of the possible functional role the P300 (Donchin 1981) where he implicates the process manifested by P300 in the updating of a subject's schema of the environment, upon the detection of a surprising event. Thus the recent findings seem to indicate that ERPs are well suited to be utilised in the study of the nature and timing of mnemistic processes.

1.3 LOCALISATION OF ERP GENERATORS

1.3.1 Introduction

The fact that to some extent the relevance of ERP research to human neuropsychology depends upon the localisation of the neural generators of the ERPs was mentioned above in consideration of their application. In this section I will outline briefly the most important methods used in such investigation and then describe the current findings concerning the neural origin of the endogenous potentials.

1.3.2 Methods Of Determining Generator Sources

There are three principal methods of investigating the neural generators of ERP components (see Vaughan et al 1983 and Wood and Allison 1981).

1.3.2.1 Generator Modelling -

It was noted above that the different scalp distributions of different components was a useful tool in identifying components. It is also of value in determining their generator sources. If certain assumptions are made about the probable nature and geometric configerations of the generators and about the characteristics of the brain as a conductor of electrical activity, then it is possible to use the scalp distribution data to mathematically estimate the intracranial generators (Vaughan 1974). There are two ways of doing this. a) In the "forward" method, hypothetical potential fields are calculated from assumed generators with specified electrical and geometric characteristics, and are compared with the observed topography of the potential. b) In the "inverse" method the intracranial generator configerations are directly computed from the scalp potential distribution.

1.3.2.2 Lesion Studies -

The study of patients with well defined intracranial lesions may provide valuable information on the sources of ERP components. The presence or absence of a particular component following brain damage can be informative. If the site of the lesion had been postulated as a sole generator of that component, then the component's continued presence would argue against that site as its only source. Conversely, if a component cannot be recorded after a lesion then the site of the lesion may contribute to that component. Obviously the use of lesion data is fraught with the same problems as in the use of such data to localise cognitive functions (Shallice 1981). It is however useful as a guide in an area where there are few other methods available.

1.3.2.3 Intracranial Recording -

An increasingly important method of determining ERP sources is that of recording both intracranially and from the scalp simultaneously while the subjects undergo experimental manipulations expected to generate specific components. If a potential from an intracranial structure exhibits the same response to the experimental manipulations as the scalp recorded potential then it is possible that that structure is the source of that component. Clearly however the scalp activity may merely be correlated with the intracranial activity. Both could have a common source. In addition recordings in humans are undertaken only as part of neurological assessment (eg. to determine epileptic foci) and so firstly, recording sites are limited to the neurological needs of the examination and secondly, structures may be functioning abnormally anyway.

1.3.2.4 Magnetoencephalography -

This involves the measurement of magnetic fields generated by brain potentials. One major advantage of this approach is that the field is thought not to be distorted by the skull or other intervening tissue, and thus the scalp topography of magnetic fluxes implies with less ambiguity the location and orientation of the intracranial current flow. For review and assessment see Kaufman et al 1984 and Wood et al 1984 p 716.

1.3.2.5 Conclusion -

Each of these approaches has its own limitations and problems, but nevertheless each has made a contribution to the specification of component sources. In particular the use of generator modelling has proved valuable in the study of the sources of exogenous potentials where components are clearly defined and rarely overlap (Vaughan et al 1983). In the study of endogenous potentials the last two methods, lesion studies and recordings in humans have proved valuable.

1.3.3 Putative Generators Of Late Potentials

By use of the modelling method described above, one group of investigators have postulated that the scalp distribution of the P300 component suggests that the component has a common site of origin for all modalities in which it is recorded and may arise from bilateral sources in or centro-parietal cortex (Simson et al 1976, 1977a,b, Goff et al 1978). They suggest too that the frontal negativity found in the oddball paradigm may arise from sources in the frontal cortex. since they receive well defined projections from secondary modality-specific cortical regions and since they could be expected to contribute strongly to scalp recordings because of their surface locations and large extent (Wood et al 1984).

Some support for a cortical origin of endogenous potentials has come from intracranial recordings made by the Burden group (Cooper et al 1977, McCallum 1980, McCallum and Pocock 1981, Curry and McCallum, Curry, unpublished results reported in Wood et al 1984). Cooper et al 1977 recorded from both scalp and cortex while patients participated in a paradigm known to produce a potential similar in distribution to the P300 which was elicited by the detection of a visual target. They found at both anterior and posterior cortical electrodes a triphasic positive-negative-positive complex, of which the negativity was the closest in time to the peak of the scalp positivity. Using the oddball paradigm, Curry and McCallum (Wood et al 1984) have found two consistent ERP patterns in cortical recording in patients.

The first is a P300 activity which can be recorded from posterior cortical electrodes during an auditory target detection task. At cortical site C13 (see figure 1:13) there seems to be a clear P300 component which is similar to that recorded from the Pz electrode.

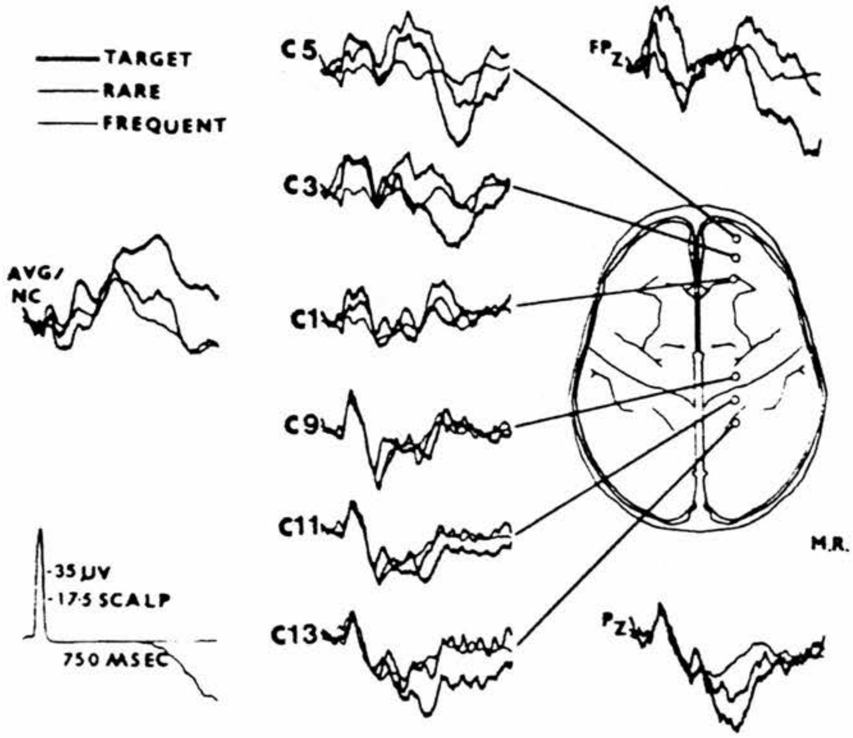

FIGURE 1-13. Averaged cortical responses to auditory stimuli in a target detection task. Positivity is downwards. From Wood et al 1984, p705.

The second finding was that the activity recorded by electrodes deep in the frontal cortex was negative with respect to the extracranial reference. This activity was found to be modality non specific. McCallum and Pocock (1981) too have found cortical potentials that correlate well with scalp recorded potentials.

Two other groups however, using intracranial recording, have found evidence implicating Limbic System structures in the generation of P300 and Slow Wave potentials (Halgren et al 1980, 1983, N.K. Squires et al 1983, Wood et al 1980). Halgren and his colleagues have recorded from electrodes which were stereotaxically placed bilaterally in the hippocampus, hippocampal gyrus and the amygdala. In two studies (Halgren et al 1980, N.K. Squires et al 1983), scalp recorded potentials in an auditory and visual oddball paradigm showed an enhanced P300 component, while at the limbic sites ERPs elicited by oddball stimuli were associated with large late potentials whose polarities varied with recording site. At the hippocampal gyrus the potential was positive, and at the amygdala and hippocampus it was negative (see figure 1:14).

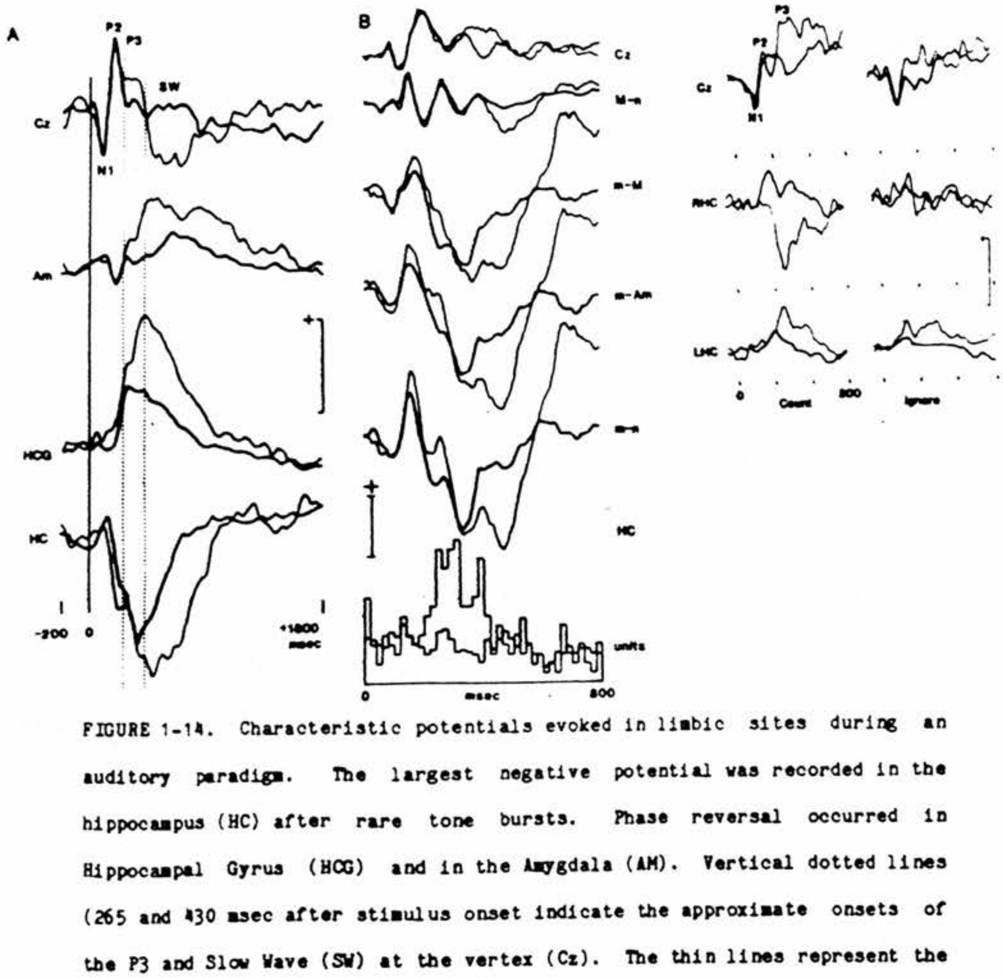

FIGURE 1-14. Characteristic potentials evoked in limbic sites during an auditory paradigm. The largest negative potential was recorded in the hippocampus (HC) after rare tone bursts. Phase reversal occurred in Hippocampal Gyrus (HCG) and in the Amygdala (AM). Vertical dotted lines (265 and 430 msec after stimulus onset indicate the approximate onsets of the P3 and Slow Wave (SW) at the vertex (Cz). The thin lines represent the average of 35 to 45 responses evoked by rare stimuli and the thick lines the averages to 155 to 165 frequent stimuli. Scale 100uV. From Halgren et al 1980, p804.

These "endogenous limbic potentials" (ELPs) had similar latencies and similar functional correlates to the endogenous scalp potentials; they were larger to unexpected than to expected stimuli, they were larger when the subject actively attended to the stimuli than when the subject was reading, and they were evoked by unexpected stimuli in either the auditory or visual modalities. These potentials were also sensitive to the subjective rather than the a priori probability of the stimuli. Halgren et al further suggested that these ELPs were generated in the limbic system and that the activity seen at the scalp was volume conducted from there. The principal evidence cited for this assertion (Halgren et al 1983) is that no patients showed scalp recorded endogenous potentials in the absence of limbic ones.

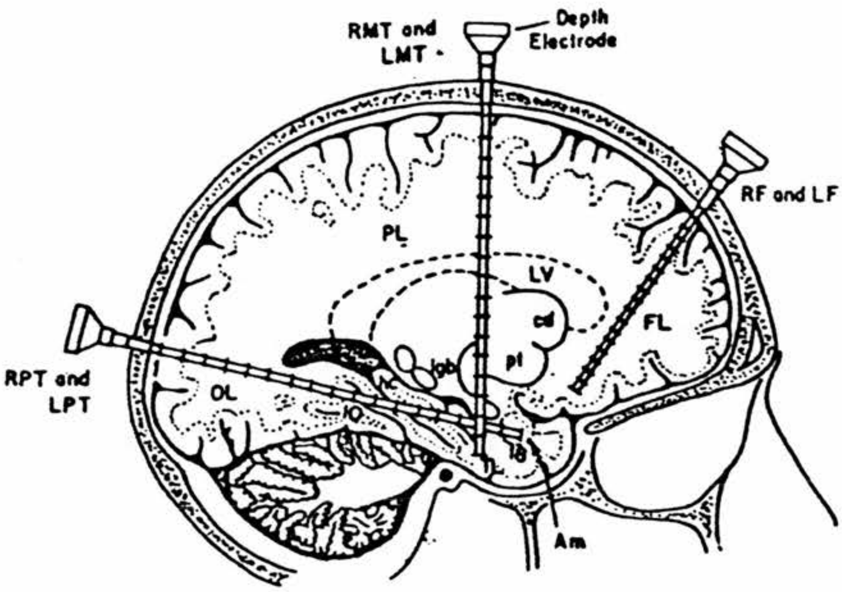

FIGURE 1-15. A schematic representation of probe placements used by Wood, McCarthy and their colleagues. Each probe has 18 recording contacts with contact 1 being the most superficial. The posterior-temporal (RPT and LPT) probes enter at the parieto-occipital border, course through the medial temporal lobe and terminate in the anterior temporal lobe. The mid-temporal (RPT and LPT) probes enter anterior to motor cortex and terminate in the anterior temporal lobe. The frontal (RF and LF) probes sample widely from the frontal lobe. From Wood et al 1984, p707.

The data from the other group who have used depth recording electrodes partially confirm this suggestion (Wood et al 1980, McCarthy, unpublished observations, reported in Wood et al 1984). Wood and his colleagues (1980) using a series of depth probes (see figure 1:15) and employing an oddball paradigm found "P300-like activity" at sub cortical sites, and they suggest that "these results cast doubt upon but do not conclusively eliminate a purely cortical origin for P300 activity."

However they add that their data are also consistent with there being multiple generators, particularly the fact that P300-like activity has an early onset at middle probe locations and later onset at both scalp and deep locations. However the evidence from this group does not prove that the depth recorded potentials were generated in the limbic system. However in more recently run patients Wood and his collaborators (Wood et al 1984) have shown polarity reversals at different recording points on the electrodes which would be expected if limbic structures were involved in the generation of these depth potentials and which had in fact been recorded by Halgren's group (figure 1:16).

According to Wood et al (1984) "Taken together, the data from the UCLA (Halgren et al) and WHVA-Yale (Wood et al) groups provide tantalising evidence that such deep temporal lobe structures as the hippocampus and amygdala generate endogenous ERPs which share many of the functional characteristics ascribed to the scalp-recorded P300." (Wood et al 1984, p 716).

However, as Halgren has pointed out, these data from recording studies "do not rule out a small contribution from a distributed cortical generator which sums with the hippocampal potential to generate a scalp P300. They also do not rule out a possible contribution from a more medial generator, for example the thalamus." (Halgren et al 1983, p 555). Yingling and Hosobuchi (1984) have reported recording a negative endogenous component from the thalamus, which covaries in latency with the scalp recorded P300 component, suggesting a thalamic origin for the P300. Lesion data may

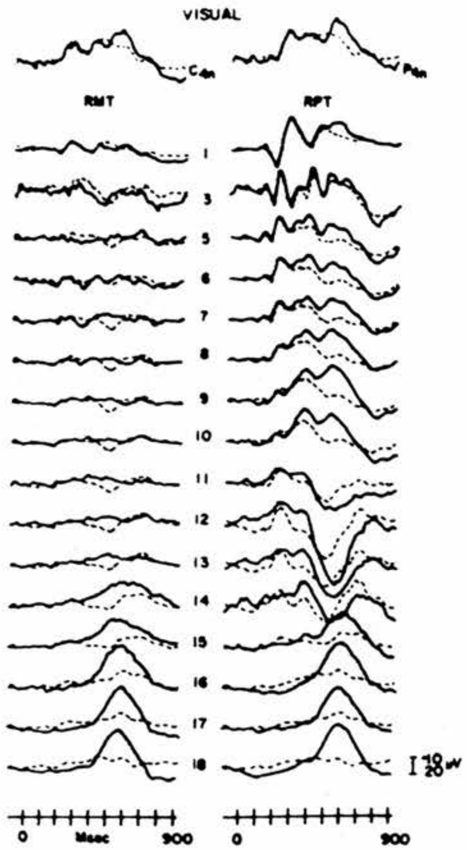

FIGURE 1-16. ERPs elicited in a visual oddball task from contacts on the right mid-temporal (RMT) and posterio-temporal (RPT) probes (see figure 1-15), as well as by cranial pins inserted into the outer table of the skull at approximate locations C4 and P4. Solid lines indicate ERPs elicited by counted rare (p=0.2) male names, while dashed lines indicate ERPs elicited by frequent female names. Calibration is 20uV for depth recordings and 10uV for the two cranial pin recordings. From Wood et al 1984, p711.

prove to be crucial in resolving this issue but as yet data are inconclusive. Some support for the hippocampal contribution has come from McCarthy et al. (unpublished data), who have found lateral asymmetries in the scalp recorded P300 component in a subject with an atrophic left hemisphere. In contrast however, Johnson and Fedio (1986) have found no such asymmetry in patients with either left or right temporal lobectomies.

1.3.4 Conclusion

In conclusion, the neural origin of the endogenous potentials of the human scalp recorded ERP have not been determined conclusively, but some fascinating evidence exists for some contribution, although not necessarily an exclusive one, from the limbic structures such as the hippocampus. In view of recent theories implicating the hippocampus in memory (e.g., O'Keefe and Nadel 1978) and recent findings of the relation of late ERP positivities to memory, such a suggestion is very attractive since it would tie these areas of research together. Localisation of endogenous potential generators is however at a relatively early stage and no firm conclusions can be reached at present.

1.4 CONCLUSION

To draw conclusions about ERP research as a whole is not easy since it is such a disparate discipline, made up of neurophysiologists, psychologists and psychophysiologists. However, three general conclusions can be drawn from what has been said above.

1) The discipline has a set of methods and procedures which clearly mark it off from other disciplines in the "behavioural neurosciences". This set of procedures is widely accepted and thus a common basis exists for comparison of results between laboratories and for general agreement in the identification and analysis of components. Thus the necessary conditions exist for the advancement of the field.

2) Great advances have been made in the last ten years with respect to identifying different endogenous components and attempting to describe their psychological and behavioural correlates. While discovering "new" components presents its own problems, it marks an advance both in terms of

providing a fuller description of the neural correlates of cognition and in terms of the development of the "cognitive" approach to ERPs, in which ERPs are interpreted in the light of well substantiated cognitive theories.

3) Both the behavioural correlates of the ERP components and the localisation of their generators indicate that the ERP may be a useful tool in the study of human memory, both in cognitive and neural aspects. Particularly interesting is the postulated relation between late positive components and memory, and the suggestion that their generators can be localised in the limbic system. Thus evidence is accruing that one might expect to find memory related changes in the ERP component amplitude and latency and in particular effects upon members of the late positive complex.

CHAPTER 2

ENCODING AND RETRIEVAL PROCESSES IN HUMAN MEMORY

2.1 INTRODUCTION

This chapter consists of a review of the current state of research concerning encoding and retrieval processes in human verbal memory. The aim has been to review those findings and theories which are commonly referred to in ERP research and for this reason the review will be selective. With reference to encoding, attention will mainly be focused upon those theories which have addressed the problem of the type of encoding processes performed upon stimuli at presentation. With reference to retrieval this review will concentrate upon recognition rather than recall since the nature of event-related potentials determines that each retrieval process must be initiated by an event (ie the recognition cue).

2.2 TYPES OF MEMORY

Firstly it is important to note that theorists often distinguish between different kinds of memory, the most important of these distinctions being that made by Tulving (1972) between semantic and episodic memories. Semantic memory is thought to contain general knowledge about the world and about language whereas episodic memory is believed to be autobiographical in nature and to store information about events in terms of the time and place of occurrence. Despite some evidence supporting the distinction (eg. studies by Shoben et al 1978, and Hermann and Harwood 1980), and a widespread acceptance of it among memory researchers, such a distinction has been criticised by a number of theorists (Baddeley 1984, Hintzman 1984, McKoon et al 1986, Roediger 1984), and a number of experimental findings have cast doubt upon whether episodic and semantic memories are indeed independent systems by showing apparent interdependence between the "systems" (McKoon and Ratcliff 1979, Anderson and Ross 1980, McKoon et al 1985, McClosky and Santee 1981).

In view of these criticisms Tulving has revised his original theory (Tulving 1983, 1984) and has suggested that episodic memory is a part of semantic memory rather than being a separate system. He has also suggested that "procedural" and "lexical" memories are further independent memory systems separate from either semantic or episodic memory.

While it is not possible within the scope of this chapter to attempt to resolve this issue, it does seem to be the case that different types of memorial experience can be distinguished, in particular there seems to be a difference between memories which carry with them the memory of the encoding context in which that information was attained, and memories which lack such contextual information. To some extent such a distinction mirrors some of the features of the episodic/semantic distinction but has the advantage of not making any assumptions about the nature of the underlying systems. Such a functional distinction has been given different names by different researchers, eg a distinction between "explicit" and "implicit" memories (Schacter and Graf 1986) or between memory with and without "awareness" (Jacoby and Witherspoon 1982)_ Such distinctions are closely related to the "two process" models of encoding and retrieval which are discussed below.

Although most of the experimental effects discussed in this chapter consist of the acquisition and retrieval of lists of words in laboratory settings, ie tasks normally thought of as specifically "episodic" tasks, it is important to note that semantic/lexical memory may play an important part in these tasks. One area where this is highlighted is the commonly observed "repetition effect". This refers to the facilitatory effect of a single presentation of an item on a subsequent test of that same item. Such a facilitation has been shown for a variety of tests, eg studies have shown that the probability of correct identification of a briefly presented word is much higher for words which have been previously presented (Carroll and Kirsner 1982, Jacoby 1983, Jacoby and Dallas 1981, Jacoby and Witherspoon 1982, Morton 1979b, Murrell and Morton 1974). Similarly, in paradigms employing the lexical decision task, in which subjects are required to discriminate between words and non-words, repeated words are positively identified as words with shorter latencies than non-repeated words (Scarborough et al 1977, Scarborough et al 1979).

There has been much discussion recently as to whether these repetition effects are functions of semantic/lexical memory or episodic memory. The effect has commonly been attributed to the former, eg according to Morton (1969, 1979b), when a word's representation in lexical memory (a logogen) is activated by presentation of the word, that logogen's threshold for activation is lowered and thus when the word is repeated, the logogen is more easily activated. On the other hand two studies have attempted to show that repetition effects are episodic memory phenomena (Feustel et al 1983, Salasoo et al 1985). They have reported that the recognition thresholds for non-words, which are not thought to possess representations in semantic memory, can be facilitated by repetition as much as words. They conclude that both effects depend on episodic factors. Recently Rugg (1985, 1987) has utilised ERPs to study this question and he has provided evidence in favour of a lexical contribution to the repetition effects. He has reported (Rugg and Nagy, in press) that repetition-produced ERP modulation was greater for non-words which possessed word-like orthographic characteristics (and which therefore gain access to semantic memory representation of similar words), than for orthographically illegal letter strings (which presumably did not gain such access). He suggests that these data indicate that repetition effects cannot be understood entirely in terms of episodic memory.

Thus, although this chapter bears chiefly upon theories and data arising tasks which are commonly thought to be episodic, it should be bourne in mind that this distinction may not necessarily imply a structural distinction between them and that some forms of "memory" due to prior performance may depend at least in part upon semantic or implicit memory.

2.3 ENCODING PROCESSES

The most influential approach to the study of encoding processes over the last decade has been the "levels-of-processing" approach. In this approach, the type of processing performed upon the item to be remembered is considered to influence how well the item is laid down in memory. This was an attempt to replace the previously accepted approach which conceived of memory as a series of independent stores between which information was passed automatically (eg. from short term store to long term store) by means of operations such as rehearsal.

Craik and Lockhart (1972) proposed that events are analysed to different levels or depths by hierarchically organised cognitive processes and that memory encoding depends on these processes. Preliminary "shallow" analyses are concerned with physical aspects of the stimulus and subsequent "deeper" analyses, with meaning and associative relationships between the stimulus and other stimuli. They proposed that the "depth" of encoding is determined by such factors as meaningfulness of the stimulus, the attention devoted to its analysis, and the nature of the task being performed.

Such a framework was used to explain data from studies employing the incidental judgement paradigm developed by Hyde and Jenkins (Hyde 1973, Hyde and Jenkins 1969, 1973) in which subjects were required to perform one of a number of orienting tasks on a list of words but were not told that they would subsequently have to recall the words. The orienting tasks varied in terms of their processing requirements. The most important determinant of the level of subsequent recall was whether the orienting task required that the subjects considered the meaning of the word (ie. a semantic task) and in particular it was found that semantic orienting tasks led to greater recall than did phonemic or structural orienting (Hyde and Jenkins 1973, Schulman 1974).

In 1973 Craik proposed that deeper analyses required more processing time than shallower analyses and that therefore processing time might serve as an independent index of depth of processing. In a series of experiments designed to test this possibility (Craik and Tulving 1975) the original observed relationship between depth of processing and retention was replicated. However in their experiment 5 they reported that a difficult shallow task took longer to perform than an easier semantic task thus invalidating processing time as an independent index of the level of processing. These experiments generated several other problems for the formulation too. Firstly the concept of a continuum of levels of processing was not supported by the data. As the authors put it "structural analyses do not shade into semantic analyses" (Craik and Tulving 1975 p 290). Positive decisions in the orienting task were associated with higher memory performance, while if the process formed a continuum positive and negative decisions should be processed to a similar depth before a decision is made. To account for this Lockhart et al (1976) reformulated the theory in terms of "domains" of encoding. They suggested that while some structural analysis must precede semantic analysis, a full structural analysis is not usually carried out. Secondly, large differences in retention were found when the complexity of the encoding context was manipulated ie. elaborate sentence frames led to higher recall than did simple sentence frames. Thirdly, intentional learning instructions led to higher recall than incidental instructions even though processing time was the same for both.

To account for these discrepant findings, Craik and Tulving (1975) and Lockhart et al (1976) proposed that as well as the depth of encoding the spread of encoding (elaboration) is an important determinant of memory performance. By this they meant that the more attributes of a word that are encoded at input, especially those at deep levels, the more elaborate will be the memory trace. Craik and Tulving (1975) conclude "greater degrees of integration (or alternatively greater degrees of elaboration of the target word) may support higher retention in the subsequent test. Effective elaboration of an encoding requires further descriptive attributes which are a) salient or applicable to the event and b) specify the event more (sic) uniquely." (Craik and Tulving 1975, p 282)

A modification of this spread of encoding view has been put forward by Lockhart et al (1976) who distinguished between two models of retrieval; reconstruction and scanning. The former involved the attempt to construct an encoding corresponding to the encoding produced at time of learning whereas scanning involved the search of recent traces for a salient feature. They proposed that the depth of processing is an important determinant of successful reconstruction but is less relevant to scanning. This distinction appears to be supported by the findings of Craik and Jacoby (1975) who reported that no difference in recognition test performance between depth conditions was found when the delay between presentation and test was short but significant differences in performance between orienting tasks were found with longer delays. It was proposed that the scanning method was only employed with short delays and the reconstruction method with long delays.

The initial formulation of the levels of processing theory has had to be considerably reformulated in view of experimental data. While the general concept that items which are processed at a semantic level are better remembered than those processed at a physical or phonemic level has been substantiated in many studies, the concept of "depth" was not adequate as an explanation for this.

Both Baddeley (1978) and Eysenck (1977) have criticised the original account principally on the basis of the circularity of the argument. "Depth" is assumed to influence retention, but it is also measured by retention. Therefore the theory was saying the equivalent of "whatever is recalled is processed at a deep level". Another related criticism levelled at the theory was that the concepts are extremely vague eg. "deep", "shallow", "complex processing".

In order to explain the disconsonant experimental data and to arrive at better defined explanatory concepts, more recent research has been focused on the contributory process underlying the "depth" and "spread" of encoding.

Probably the most important of these is the concept of "elaboration". Three studies have dealt with the elaboration of sentences. As noted above, Craik and Tulving (1975) and Lockhart et al (1976) have employed the concept, and more recently Anderson and Reder (1979) have suggested that "manipulations designed to affect what has been referred to as the "depth" of processing are having their effect by changing the number and type of elaborations stored." (Anderson and Reder 1979, p 386). They assume that long term memory is composed of a network of interconnected propositions and that the to-be-remembered information and any elaborations are encoded into this network. Any particular coded proposition is "fragile" ie. there is a significant chance that the subject will not br able to activate that proposition at test. However if the subject generated a memory episode which encoded a set of multiple propositions that were partially reduntant with the to-be-remembered information they would have a better chance of recalling it at the time of the test. (See also Battig 1979, Ross 1981).

This theory has been tested by Bradshaw and Anderson (1982) and by Stevenson (1981) both of which showed that the elaboration of sentences in terms of cause or effect resulted in substantially improved memory performance when compared to elaborations that were neutral or unrelated to the target sentences. Stein and Bransford (1979) further showed that elaborations only facilitate performance when they clarify the precise significance of a target word contained in each sentence presented for study, for example if the sentence "the fat man read the sign" was elaborated by the sentence "the fat man read the sign warning of thin ice" then recall of "fat" was facilitated.

Fisher and Craik (1980) have reported an effect of elaboration at encoding in the recognition of target concepts from input sentences. They found that both the complexity of the sentences and whether or not the sentences contained words which were strong associates of the target item affected recognition performance. Fisher and Craik suggested that this was because their elaboration enhanced the reconstruction of the original encoding enviroment.

Some studies however have found negative effects of elaboration on recall performance (Bransford et al 1977, Reder 1982). Bransford et al (1977) conducted an experiment in which a large number of elaborations resulted in poorer recall than did a smaller number of elaborations. In view of these limitations upon the degree to which elaborations influence recall, Eich (1985) has concluded that "the construct of elaboration is inadequate as an explanation of levels effects. Consequences of elaboration vary, it appears that some explanation is required for the effects of elaboration." (Eich 1985, p 24).

The second concept that has been postulated as the source of the levels-of-processing effect is "distinctiveness". It is suggested by some researchers (Bransford et al 1979, Craik and Jacoby 1979, Jacoby and Craik 1979, Nelson 1979, Eysenck 1979) that semantically processed traces are more distinct from one another than are the traces processed with respect to surface properties, and they predict that more distinctive traces will be better recalled.

This theory has been tested directly in a series of experiments by Jacoby et al (1979). In these studies the difficulty of semantic judgements was varied and it was found that more difficult decisions led to better retention. The authors conclude that more difficult initial processing implies more extensive or elaborate analysis and that this more extensive analysis is reflected in a more distinctive memory record of the event. This distinctive trace is in turn more discriminable from other memory traces and is retrieved with greater ease.

Anderson has argued against the distinctiveness account on the basis of evidence from Bradshaw and Anderson (1982). He claims that the distinctiveness view could not predict their finding of superiority in terms of percent recall of information which had benn encoded with related information over information encoded alone.

Whether or not it can conclusively be shown that processing difficulty is related to distinctiveness it seems that another construct, the "effort" involved in processing has a large effect on retention. In one study (Johnson-Laird et al 1978) subjects had to classify objects as belonging or not, to the class of objects that are consumable, solid and natural. The list contained words with all three, two, one or none of the components and it was found that recall was a linear function of the number of the components a word possessed. The authors concluded that the greater the amount of semantic processing, the greater the retention.

The effect of "effort" has also been used to explain the "generation effect" (Jacoby 1979, Slamecka and Graf 1978). In Slamecka and Graf's experiment subjects were given related word pairs that were either complete (eg. rapid-fast, ruby-diamond) or in which the second word of the pair was represented by its initial letter (eg. rapid-f, ruby-d). Subjects read the complete pairs and generated the response members of the incomplete pairs. Response members of word pairs which were generated were better recognised and recalled than non-generated words. Jacoby (1978) suggests "the idea is that the necessity of construction involves consciousness and engenders arousal in a way that effortless remembering does not; it is this involvement of consciousness and heightened arousal that is responsible for differences in subsequent levels of retention." (Jacoby 1978 p 663).

Tyler et al (1979) have similarly argued that the amount of cognitive effort (defined as the engaged proportion of limited capacity central processing) during encoding is an important determinant of later memory performance. They found a large effect upon retention independent of a levels of processing effect. Eysenck and Eysenck (1979) using the concept of "expended processing capacity" have also investigated the role of effort in retention. They found that semantic processing requires more expended processing capacity and leads to better memory performance than non-semantic processing. They found too that greater elaboration at encoding also takes longer to perform and requires more expended processing capacity but only leads to better memory performance following semantic processing.

However Craik (1981) points out that in some difficult "shallow" processing tasks the effort is not related to retention (Craik and Tulving 1975, experiment 5) and concludes that "difficulty" and "effort" typically signal "deep", "elaborative" or "extensive" processing but do not in themselves give rise to high levels of retention" (Craik 1981, p 387).

A fourth explanation of the levels of the levels of processing results is that advanced by Bransford et al (1979) and Tulving (1979) who have suggested that information extracted in the semantic processing condition is more consistent with the retrieval requirements of the surprise recall test than information extracted in other conditions. Bradshaw and Anderson (1982) have criticised this for being merely descriptive.

In conclusion there seems to be no clear consensus concerning the explanation for the observed effect that stimuli given "deeper", "more extensive" or "more elaborative" processing are generally better recalled and recognised. Jacoby and Dallas (1981) have concluded that "although there are currently a large number of experiments showing effects of manipulating an orienting task, there is no generally accepted framework that incorporates the results of those experiments." (Jacoby and Dallas 1981, p 309).

Whether or not a satisfactory explanation for the levels of processing effects is forthcoming, the levels-of-processing model has proved immensely valuable in highlighting the importance for retention of the type of processing carried out on the stimuli, and some of the concepts discussed within the level of processing context have been taken up and pursued elsewhere.

Mandler (1979) has suggested a distinction between intra-item and inter-item processing. Intra-item processing integrates the stimuli by rendering them more discriminable from other encoded events. The variables which contribute to the integration of items are repetition and reinforcement. The actual process which is thought to constitute integration is an analysis of the perceptual characteristics of the stimulus. Mandler suggests that it is the same process that has been described as the incrementing of "familiarity" or "occurrence information". This kind of processing he suggests is particularly effective in aiding recognition memory. Inter-item processing on the other hand is an elaborative process which produces associative interconnections between the target item and other information. Such processing is elicited when subjects are instructed to find a rhyme or a category for a word, to remember a sentence or to precis a story. This type of processing is particularly important for recall. This framework is illustrated in figure 2:1. Mandler further identifies these two processes with two types of rehearsal postulated by Woodward et al (1973) and by Craik and Watkins (1973), namely intra-item organisation with maintainance (or primary) rehearsal and inter-item organisation with elaborative (or secondary) rehearsal. This theory will be dealt with again in the section on studies of retrieval processes.

It is possible to conclude that memory is to a large extent a by-product of the kind of processing performed upon stimuli. Which aspects of stimulus processing are most related to memory is not clear but there is considerable evidence that a form of processing in which the semantic content of the stimuli is extracted and the item related and associated to other items leads to better retention than processing in which the structural features of stimuli only are extracted. The former has been termed "deep", "extensive" or "elaborative" processing and the latter

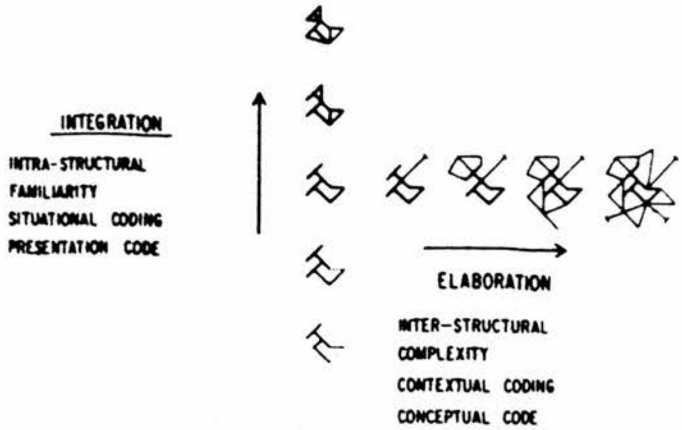

FIGURE 2.1. A diagramatic analogy of the two processes postulated by Mandler. For the elaboration process, a single structure is related increasingly to other external structures and becomes part of a more extended structural system. For the integration process the nine nodes are at first weakly connected and become more strongly connected. The verbal descriptions for the two processes show four sets of previously used distinctions that map into integration and elaboration. From Mandler, 1979, p296.

"shallow", "structural" or "integrative". To some extent these formulations are vague and intuitive. However more recent work by theorists such as Mandler (1980), Jacoby (Jacoby and Dallas 1981) and Geiselman (Geiselman and Bjork 1980) are beginning to specify more exactly the nature of such processes as "elaboration".

2.4 RETRIEVAL PROCESSES

The distinction outlined above proposed by Mandler is an integral part of his theory of recognition memory (Mandler 1979, 1980, 1981). In line with earlier suggestions (Atkinson and Juola 1974, Juola et al 1971) he proposes a dual model of recognition based on two processes; a test for familiarity and a separate retrieval process. The test for familiarity (which is the product of intra-item integration) is relatively automatic and depends on the similarity of the test item to the encoded item.

Retrieval (whilst the product of inter-item integration) is a more optional, controlled process and is conceived of as retrieval of the item's presentation context. These processes are thought to work in parallel but since retrieval is a slower process, the familiarity component is the initial factor in recognition. Familiarity is independent of the context of the encoding situation, (when familiarity is incremented), as long as the item being incremented remains unchanged in sensory perceptual terms. Changes in presentation modality from study to test (Jacoby and Dallas 1981) or the voice of the speaker (Geiselman and Bjork 1980) may reduce the effect of prior occurrence.

A very similar model has been put forward by Jacoby and his colleagues (Jacoby and Dallas 1981). He also postulates two bases for recognition memory. The first he terms "perceptual fluency" which is effected or incremented by prior presentations and in particular upon intra-item encoding. The second is termed "retrieval of study context". Jacoby suggests that recognition depends on both "perceptual fluency" and "retrieval of study context", and recall upon the latter only.

Important evidence for Jacoby's model was reported by Jacoby and Dallas (1981). In one of their experiments the authors showed a dissociation of the effects of encoding upon perceptual identification and recognition. Levels of processing manipulation affected recognition memory but not perceptual identification while varying the number of repetitions affected both perceptual identification and recognition. Jacoby has gone on (Jacoby 1983a) to postulate that "perceptual fluency" might underlie all the examples of a prior occurrence of an item having an advantage upon a subsequent presentation of an item ie. word-fragment completion (Tulving et al 1982), making lexical decisions (Scarborough et al 1977), solving anagrams (Jacoby and Dallas 1981), and reading inverted text (Kolers 1976). Thus perceptual fluency is thought to be the basis for the repetition effects discussed above (p 2-1).

He has also shown (Jacoby 1983b) that a greater reliance on data driven encoding processes, such as having a subject read a word out of context facilitates later perceptual identification of the word while a greater degree of conceptually driven processing of a word such as having the subject generate the word from a conceptual clue results in better recognition memory performance and less facilitation of perceptual identification. More recently Jacoby and his colleagues (Johnson et al 1985) have provided further evidence for his theory. They hypothesised that if perceptual fluency were the basis of recognition memory then words which were fluently perceived (quickly identified) would tend to be judged "old" regardless of their actual old/new status. In the test phase of a recognition task each item was gradually clarified until it was identified, at which time subjects made an old/new judgement. In their first experiment they found that words were more likely to be judged "old" if they were quickly identified and, in addition, if they actually were old. In their second experiment using non-words, recognition judgments for non-words were more dependent on speed of identification than on their actual old/new status. The authors conclude that they have shown that "perceptual fluency" is the basis for feelings of familiarity and have shown that the second factor in recognition memory, the retrieval of context, can be separated from "perceptual fluency". Additional evidence has been provided by Carroll and Kirsner (1982), who also report the importance of relative perceptual fluency in a comparison of a lexical decision task and a recognition memory task. They concluded that the relative perceptual fluency was the main factor in lexical decision performance. Other studies have provided evidence that inter-item elaboration is important in recognition memory (Donaldson 1981, McGee 1980).

In view of such theories, recent work on repetition effects (ie the facilitation of response to words shown previously, in such tasks as word identification and lexical decision) may cast some light upon the underlying nature of the processes thought to underlie the feeling of familiarity. Jacoby's concept of perceptual fluency is thought to depend on episodic memory. Processing the physical characteristics of stimulus items is thought to establish or enhance an episodic trace of the item. Mandler's account however seems to imply that familiarity depends upon the "updating/incrementing" of an already established representation of the item, presumably in semantic memory. Although some recent findings have been interpreted as supporting an episodic basis for repetition effects there have been recent findings that suggest that a purely episodic explanation is inadequate (Rugg 1985, 1987; see above, section 2.1). These data suggest that repetition effects depend both on the activation of representations in semantic memory and also upon the creation of episodic representations. The first of these contributes both to semantic priming effects and repetition effects (when words are involved), the latter distinguishes the two, possibly explaining the greater durability of repetition effects. If indeed the same processes underlie the feeling of familiarity and repetition effects, then it implies that putative processes such as intra-item processing and enhancement of perceptual fluency are themselves composed of two separate contributory processes, one depending upon semantic representations, and the other upon episodic traces.

The dual process model has been utilised by both of its proponents (Mandler 1980, Jacoby and Dallas 1981) to investigate the nature of the cognitive deficit in amnesia. Mandler, Graf and more recently Squire (Graf and Mandler 1984, Graf and Schacter 1985, Graf et al 1982, 1984, 1985, Squire et al 1985) have reported studies based on the finding that while amnesics could not recall or recognise previously presented words, they could give these words as responses to partial cues when instructed to complete them to form a word. This advantage for partial cuing has been shown in normals also (Graf and Mandler 1984, Graf et al 1982, Tulving et al 1982, Jacoby and Dallas 1981). Graf et al (1982) proposed that this is due to the fact that the process of familiarity updating or perceptual fluency is intact in amnesia while their inability to retrieve the encoding context (or to encode it) disrupts their performance on recognition memory tests. Similarly Jacoby and Witherspoon (1982) have suggested that the amnesic deficit lies in the lack of the amnesics' "awareness" of having previously seen an item ie. retrieving the context, whereas their "perceptual fluency" remains intact. They showed that a dissociation between the memory for an event and the awareness of that event exists in normals.

The dual process model has also been used to explain other memory phenomena. Mandler (Mandler 1980, Mandler et al 1982) has suggested that the model provides an explanation for the word frequency paradox in recognition ie. the fact that high frequency words are recalled better than are low frequency words but low frequency words produce higher hit rates in tests of recognition than do high frequency words. Mandler suggests that the advantage of low frequency words in recognition is due to a greater incremental integration resulting from prior exposure ie. there is a relative increase in familiarity for low frequency words over high frequency words.

Jacoby and his colleagues (Johnson et al 1985) have related the dual process model to other theories of memory retrieval, in particular the SAM (Search of Associative Memory) model (Gillund and Shiffrin 1981, Raaijmakers and Shiffrin 1980, 1981) and its recent application to recognition memory (Gillund and Shiffrin 1984). They suggest that perceptual fluency and retrieval of context are identifiable with two of the parameters ("c" and "b", respectively) posited in the Gillund and Shiffrin (1984) model. Increases in parameter "b", which is the strength of association stored between two different items, improves both recognition performance and the recall performance. Increases in the parameter "c", which is the value of unit strength stored between an item when used as a cue and its own memory image, improves recognition only. Presumably Johnson et al (1985) equate parameter "b" with inter-item processing which aids the retrieval of context and parameter "c" with intra-item processing.

However, Gillund and Shiffrin reject any such identification between their model and that of the dual process models. They propose that recognition is determined by a direct access familiarity process. In a recognition test the subject probes memory with two cues; the context cue and the tested item. The total activation of long term memory store in response to this probe set is taken to be the value of familiarity on which a response is based. They admit that search processes are sometimes used in recognition but deny that this is common. Their model is a familiarity-only model.

Gillund and Shiffrin liken their model to that of Ratcliff (1978) in which recognition memory is conceived as the activation of a large portion of memory. Ratcliff uses the metaphor of resonance to describe memory structure and recognition of items in it. A probe item can be thought of as a tuning fork vibrating at a certain frequency. Other items of the same frequency will begin to vibrate too. Items are then compared and if a feature match counter exceeds a criterion value the items are identified as matching. The yes/no decision process is thought to be self terminating on a "match" so that if enough evidence is accumulated in just one comparison process, a "yes" response is produced. By contrast it is exhaustive on non-match comparisons so that a "no" response is produced only when all comparison processes terminate in nonmatches.

The Gillund and Shiffrin model also has similarities to the model of memory retrieval recently proposed by Tulving (Tulving 1982a, 1983). His GAPS theory (General Abstract Processing System) encompasses both recognition and recall and is based upon the assumption that there is no qualitative difference between them (Tulving 1976, Tulving and Watkins 1973). In this model retrieval cues interact with the stored information, the "engram", through the process of "ecphory". The product of a successful act of ecphory ie. the conjunction of information from the cue and memory trace is referred to as ecphoric information. Ecphory is a synergistic process and ecphoric information reflects the synergy of encoding and retrieval components. Ecphoric information is thought of as consisting of elementary components or features. The particular features of ecphoric information determine the qualitative properties of what the individual remembers ie. the individual's recollective experience. This recollective experience, the subject's awareness of the "pastness" of an event has to be translated into performance in a memory test by means of the conversion process. He equates the recollective experience with "familiarity". Figure 2:2 shows an outline of the model.

In this model recall and recognition only differ in the respect that the retrieval cues differ in the two cases and thus the ecphoric information differs. Different kinds or different amounts of ecphoric information are required for the judgement that a test item is "old" than for the production of the name of a previously encountered study list item.

The model seems to depend largely upon the principle of encoding specificity. Tulving proposed in 1973 (Tulving and Thomson 1973) that reinstating the encoding context at the time of retrieval was crucial for memory retrieval to take place, thus shifting the emphasis from the nature

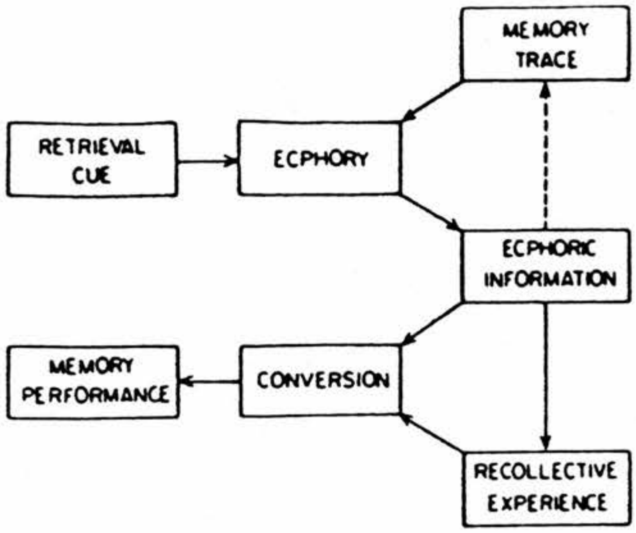

FIGURE 2.2. Elements of the GAPS retrieval process. From Tulving, 1982, p133.

of the stored trace to the nature of the retrieval cues. Evidence for this has been provided in a number of studies by Tulving and his colleagues (Thomson 1972, Thomson and Tulving 1970, Tulving and Osler 1968, Tulving and Thomson 1971, 1973, Tulving and Watkins 1973, Watkins and Tulving 1975, Wiseman and Tulving 1975). Tulving and Wiseman (1975) expressed the principle as follows; "A retrieval cue is effective if its informational content matches and compliments the information contained in the trace of the to-be-remembered event" (p 371). Thus they proposed that the initial presentation of to-be-remembered stimuli leads to a specific encoding and that the subsequent presentation of a retrieval cue on the retention test also leads to a specific encoding. Irrespective of whether a recall or a recognition test is used, memory performance depends upon the overlap or similarity of encoding processes at presentation and at test. The principal evidence for this is the finding of the superiority of recall over recognition. In spite of the fact that a to-be-remembered item is identical with its nominal copy in the recognition test, it is possible for the specifically encoded trace of that item to differ significantly from the copy cue, to preclude recognition while permitting recall. Wiseman and Tulving (1975) presented a series of to-be-remembered words accompanied by weakly associated contextual words followed by a cued recall test using the weak associates as cues. Overall recall was superior to recognition. Thus only a specific set of retrieval cues can provide access to the trace, namely "The cues that on pre-experimental grounds can be thought to be closely related to and associated with the words to-be-remembered such as strong semantic associates (Thomson and Tulving 1970) or nominal copies of to-be-remembered words (Tulving and Thomson 1973, Tulving 1974)" (Wiseman and Tulving 1975 p 128).

This principle has come to be widely accepted in the field of human memory although as Eysenck (1979) points out it is not clear that Tulving has as yet demonstrated the existence of recall superiority over recognition. In particular Santa and Lamwers (1974, 1976) have pointed to a number of alternative explanations for the effects observed in the studies by Tulving and his associates. In addition Reder et al (1974) and Salzberg (1976) have reported that recall superiority over recognition is higher only for certain kinds of words, limiting its applicability.

Tulving (1982a) has noted a point of similarity between his theory and that of the dual process theorists. In particular he suggests they share in common the view that recognition can occur on the basis of just an experienced feeling of familiarity under conditions where more detailed information about the to-be-retrieved event is not accessible. In addition, he points out that "recall requires more and richer ecphoric information". While this, in his view, derives partly from an increased richness of the retrieval cues it might presumably derive also from a more richly encoded engram. In general the model is an important attempt to provide a coherent general theory which can account for all the available data on encoding and retrieval in human memory.

2.5 CONCLUSION

A) Encoding: Research and theory on the encoding processes performed upon stimuli has been dominated over the last ten years by concentration upon assessing retention as a function of the type of processing performed. The levels-of-processing approach has attempted to describe such processes by postulating such concepts as "depth" and "breadth" of encoding and suggesting that within each "level" or "depth" items can be more or less "elaborated". These concepts are not well defined and attempts to find the processes which underlie such general descriptions have not been successful. Other theorists have similarly postulated concepts such as elaborative and non-elaborative processing to describe encoding processes. These theories have the advantage that they attempt to specify what "elaboration" is, vis. the relating of one item to another.

Thus there appears to be a growing consensus among many leading theorists that the kind of process engaged in, largely determines retention and some attempt has been made to specify what these kinds of processes may be. Different processes may give rise to different scalp recorded brain potentials and, as will be seen in the next chapter, studies have specifically attempted to find such neural correlates of different levels-of-processing. In addition, the concepts of "elaboration" and "depth" have been widely used to explain differences between ERPs recorded at encoding between remembered and not remembered words. Thus it appears to be a fruitful framework within which to address the study of the ERP correlates of encoding.

B) Recognition: Here too it is noticeable that a consensus is emerging among many theorists, particularly with respect to the distinction between "familiarity" or "perceptual fluency" and "recall" or "retrieval of context". This approach has the advantage of being consistent with the appropriate models of encoding such as the distinction between inter- and intra-item processing. In addition several of the "global" theories of retrieval which address both recognition and recall have employed similar concepts, such as "familiarity" and have stressed the importance of the nature of the encoded information for retrieval.

In conclusion the following model will be adopted within which to examine ERP correlates of mnemistic processes. Performance on a memory test is thought to depend partly on the nature of the encoding process performed upon the stimulus, and partly too upon the success of retrieval processes performed at the time of test. At initial presentation items are thought to be processed in one of two ways depending upon the task requirements. Firstly, the physical characteristics of the item only may be encoded, resulting in an enhanced response to the same physical characteristics when the item is re-presented. The processes involved are referred to in the account of Mandler (1980) as "familiarity incrementing" (or intra-item processing) and "familiarity checking" respectively. Jacoby has interpreted these processes in terms of the degree of "perceptual fluency" a word possesses. Secondly, the semantic content of a word and its relation to other items may be processed, resulting in the ability at test to retrieve an item's encoding context. The encoding process is referred to as "elaborative" (or inter-item) encoding. The different encoding processes have different implications for performance on subsequent tests for stimulus items. Familiarity incrementing will allow a word to be facilitated in a tests of "implicit" memory eg lexical decision tasks or word completion tasks. Elaborative processing will allow a word to be facilitated in tests of "explicit" memory such as recall tests. Both processes will facilitate response to words in recognition memory tests. One way of possibly distinguishing between the responses on such a test on the basis of the underlying processes, is to look at the level of confidence with which a word is recognised, assuming that low confidence implies a feeling of familiarity and high confidence implies the retrieval of the encoding context.

CHAPTER 3

ERP STUDIES OF ENCODING AND RETRIEVAL PROCESSES IN HUMAN MEMORY.

ERP STUDIES OF ENCODING AND RETRIEVAL PROCESSES IN HUMAN MEMORY.

3.1 INTRODUCTION

The purpose of the present thesis is to identify ERP correlates of encoding and retrieval processes in human memory. This chapter consists of a review of studies which have attempted to do this.

It is necessary first to try to describe in general terms the experimental design which it is proposed might successfully do this. It is not sufficient to record ERPs during the acquisition and retrieval of information without taking into account whether such processes are successful or not, since there is no way of knowing whether such ERPs reflect memory-related processes or the stimulus evaluation performed upon all stimuli irrespective of the memory processes performed upon them. It is necessary for studies therefore to compare ERPs elicited by stimuli which are successfully encoded or retrieved with ERPs generated by words that are not. Any resulting ERP difference must necessarily reflect cognitive processes which are important in determining whether a stimulus is remembered or not. This is not to say such processes are purely "memory" processes as distinct say from processes such as attention since it is probable that storage and retrieval of items depends upon a number of contributory processes, eg attention, resource allocation and stimulus discriminability. However such a design does allow the identification of ERP correlates of the working of such processes in the storage and retrieval of stimuli.

For this reason, not all the studies which have recorded ERPs during tasks with a mnemistic component fall within the scope of this chapter. Studies of acquisition in which ERPs are recorded over a series of trials during associative learning (see Donald 1980 for review) have not recorded ERP correlates of "successful" as distinct from "non-successful" acquisition. Similarly, in the study of retrieval, a large number of studies have recorded and compared latencies of ERPs generated by probes in a Sternberg Task under different memory loads. It is proposed however that ERP differences observed in these studies between different memory load conditions need have little to do with the mechanisms specifically of search and retrieval (see Brockhuis et al 1981, 1983 and Roth et al 1977, 1978b for discussion of possible interpretations).

The kind of study therefore, which will provide evidence of encoding related ERP effects will consist of the comparison of ERPs recorded during the initial presentation of stimuli and averaged on the basis of whether the words which elicited the ERPs are subsequently retrieved from memory or not. Similarly, evidence of retrieval related effects will be provided by studies in which ERPs generated during testing are compared on the basis of whether the words eliciting them are retrieved from memory or not. In view of the theoretical account of encoding and retrieval processes outlined in chapter 2, where it was suggested that at both encoding and retrieval two separate processes may occur, it is possible that ERPs may reflect any of four processes. To determine whether the modulation in ERPs is the result of any of these processes, however, it is necessary to identify what kind of processing the words generating those ERPs have received. Since it was suggested that different encoding processes facilitate performance on different tests ("familiarity updating" on tests of implicit memory, and "elaboration" on tests of explicit memory), and that different retrieval processes are active in each kind of test, it might be expected that ERPs generated by words averaged on the basis of performance on different tests of retrieval might exhibit differences related to the operation of separate encoding operations. It will be noted in the review below that some studies have utilised such a design.

3.2 ENCODING PROCESSES

One laboratory which has employed the approach outlined above to study encoding-related ERP effects is that of Chapman who has postulated the existence of what he terms a "storage" component occurring at 250 msec post stimulus. The basic design he and his colleagues have employed is as follows: on each trial each subject was presented with four stimuli consisting of two digits and two letters. On half the trials the subject was required to determine which of the two numbers was the greater in which case the letters were irrelevant, and in the other half to determine which of the letters occurred earlier in the alphabet, in which case the numbers were irrelevant. The order of presentation of these four stimuli was random. They were presented tachistoscopically for 10 msec with an ISI of 750 msec. Each trial began and ended with a light flash, and the subjects indicated their response by moving a switch to one side or the other during a one and a half second response window following the last blank flash.

ERPs were recorded to each of the 4 stimuli, usually from one site, CPz, using linked earlobes as reference. Sampling started 20 msec before stimulus onset and lasted for about 500 msec. Separate averages were made for ERPs generated by stimuli at each of the four serial positions, referred to as "programs" G, H, J and K.

Chapman claimed that he was thus able to look at the ERP correlates of separate cognitive processes since the processes performed upon the stimuli differed according to the serial position of each stimulus. Subjects were thought to have performed "storage" operations upon items 1 and 2 (ie programs G and H) and "memory comparison" operations upon stimuli in positions 3 and 4 (ie "programs" I and J). In order to ensure that each "program" reflected specific processes certain data were excluded from each average; for program H, the ERPs elicited by a stimulus occurring at the second position when it was the second stimulus of its type, for program J when the stimulus occurring at the third position was the first occurrence of a stimulus type and in the case of program K, when the first instance of a stimulus type had occurred at position one. In addition separate averages were compiled for relevant and irrelevant stimuli for each serial position so that eight averages were eventually generated.

Two experiments have been conducted by Chapman and his associates using the above design. In the first (Chapman 1973, Chapman et al 1978), 12 subjects were tested in a procedure identical to that described above. Two forms of analysis were carried out. The first consisted of the measurement and comparison of the mean area under the ERPs generated by each "program", relative to a pre-stimulus baseline, and of the amplitude measures taken at specific latencies (not dependent on observed peaks and troughs) namely at 105 msec and 225 msec after each stimulus. Secondly, Chapman conducted PCA on these ERP area and amplitude data (Chapman et al 1978) which yielded eight components which together accounted for 96.4% of the variance in the data. Of interest here is Chapman's component 3, which Chapman describes as having a rapidly rising time course reaching a positive peak at about 250 msec post stimulus. Its factor score was highest for the conditions in which the information was being stored for future comparison, ie program G, irrelevant of whether the stimulus was a number or letter or whether it was relevant or irrelevant to the task. For the other storage condition, program H, the factor scores were high only for relevant stimuli regardless of the type of stimulus. It seems strange that the factor scores should be highest at the first stimulus position regardless of whether it was important that the stimuli be stored or not (ie the scores were equal for relevant and irrelevant stimuli). Chapman suggests that "it seems reasonable that even the irrelevant information may be stored in memory when the first intra-trial stimulus is presented (program G) since at that point in the trial there is no previous memory load taxing the capacity of short term memory" (Chapman et al 1978, p 97).

Chapman's group replicated this finding using one subject (Chapman 1977, Chapman et al 1981) in an experiment in which they varied the light intensity of the stimuli. In this study, 9 components were found to account for 95% of the variance. Again a component which peaked in amplitude at 250 msec was found whose amplitude was greater when evoked by stimuli occurring at positions one and two, than when evoked by stimuli occurring at positions three and four. As in the first experiment, this component's amplitude was greater for all stimuli occurring at position 1, regardless of whether it was relevant to the task or not, but was greater only for relevant stimuli at position two. This component appeared not to vary with light intensities.

Chapman concludes from this series of experiments (Chapman et al 1981) that he has identified a component of the ERP which indexes the storing of information in short term memory for later use in a comparison task. This component is a positivity with a latency of 250 msec post stimulus and is distinct from P300. He explains the lack of similar findings by other groups as due to the fact that in most of these, only peaks in ERPs were examined whereas the "storage" component was only discovered by use of PCA. This component, he claims, "may be used to assess storage per se, uncontaminated by retrieval mechanisms" and "provides an entry to understanding the neural process related to memory" (Chapman et al 1978, p 78).

However, there are several criticisms of this work which cast doubt upon the reliability of these findings. Firstly, the statistical analysis of the electrophysiological data was inadequate. In neither experiment was any statistical analysis carried out upon the reported PCA components and in the second experiment no statistical analysis at all was reported on the ERP data. The latter was probably due to the fact that only one subject was involved. Since in neither electrophysiological experiment were there observed any significant ERP effects and in neither was there any statistical testing of apparent PCA component differences, it is impossible to rule out the possibility that the reported effects could be attributable to chance. Further, Karis has suggested (Karis et al 1984), that a "first time effect" (ie that the first item in any series, irrespective of condition, usually elicits a very large response), may be an adequate explanation for Chapman's data. Thus at present Chapman's explanation of his data as reflecting a storage component remains unproved.

One study which has examined ERP correlates of long-term memory from the standpoint of the levels of processing approach is that by Sanquist et al (1980). The intention of Sanquist et al was to specify an independent index of the level of cognitive processing. Nine subjects were required to determine whether two words presented on each trial were the "same" or "different" on the basis of orthographic, phonemic or semantic similarity. Following the judgement task, subjects were given a forced-choice recognition memory test. The recognition presentation list was composed of all the judgement task words randomly intermixed with the same number of new words.

ERPs were recorded from Fz, Cz and Pz and from two lateral sites, C3 and C4. For judgement task ERPs separate averages were formed for each comparison criterion and judgement type ("same", "different"), and also for each subsequent recognition category ("hits", and "misses"). It was found that ERPs elicited by words during the judgement task differed according to whether the word was recognised or not in the subsequent recognition test (figure 3:1).

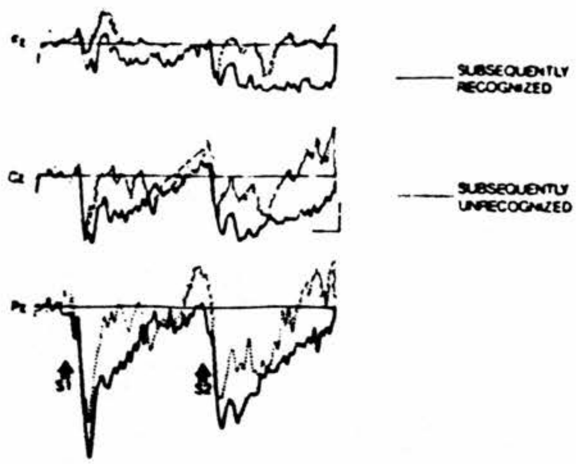

FIGURE 3:1. Midline grand ERPs for the semantic judgment task items that were subsequently recognised and unrecognised in the memory test. Averages are collapsed over "same" and "different" judgment types. Calibrations: 500 msec and 5uV, negativity upwards. From Sanquist et al 1980, p 573.

They found that the Slow Wave which preceded the second stimulus was larger in the ERPs generated by words that were recognised. They suggest that this Slow Wave may represent an index of the type of processing ie "strong" or "weak" encoding. The Late Positive Component varied in the same way as the Slow Wave. This component was larger in the ERPs generated by recognised words. Both effects were observed at all three midline sites in both the phonemic and semantic conditions.

The authors interpret these data as indicating the existence of a "storage" component. However, it is necessary again to qualify these results. Firstly, these averages contain the data from very few subjects, only three in the semantic condition and four in the phonemic condition. Because of this no statistical analysis was carried out on the data. Secondly, their judgement task ERP data reveal that in the phonemic and semantic conditions potentials evoked by the response "same" were of greater amplitude than the potentials evoked by the "different" response. Stimuli to which the response "same" was generated were better recognised and thus the ERPs generated by "hits" were yielded by stimuli which evoked greater amplitude potentials due to their judgement task responses. It is not certain that this could account for the large differences observed between recognition conditions in the waveforms but since only a few subjects' data are included in the averages and these subjects' judgement task performances are not reported, it could well be the case that one or two subjects who showed large differences between "same" and "different" conditions have contributed to the "memory" effect.

Another approach has been that adopted by Karis and his colleagues (Karis et al 1984, Fabiani et al 1986). Karis et al (1984) have recorded ERPs elicited during the Von Restorff memory paradigm (Von Restorff 1933), (for design see figure 3:2), in which subjects are required to memorise lists of words in each of which one or more words are isolated, usually by printing them in a different type-case from the other words.

The common finding in this paradigm is that the "isolates" are better recalled than the other words. In the study of Karis et al ERPs were recorded from both "isolates" and "non-isolates" in 80 word lists and averaged on the basis of word type and whether the word was subsequently retrieved from memory. Retrieval was tested by a free recall test occurring 7 seconds after every 15 word lists, a grand free recall test occurring after all the lists had been shown and a final recognition test. The prediction was that P300 amplitude would be directly related to the "strength" of memory since it was assumed that P300 amplitude reflected the processes involved in updating the subject's schema of the environment held in working memory which takes place when "surprising" events are encountered (such as "isolates"). If P300 is related to the amount of updating done and updating is reflected in better memory performance in subsequent retrieval tests, then P300 amplitude should "predict" later retrieval. It was assumed that performance on each memory test reflected

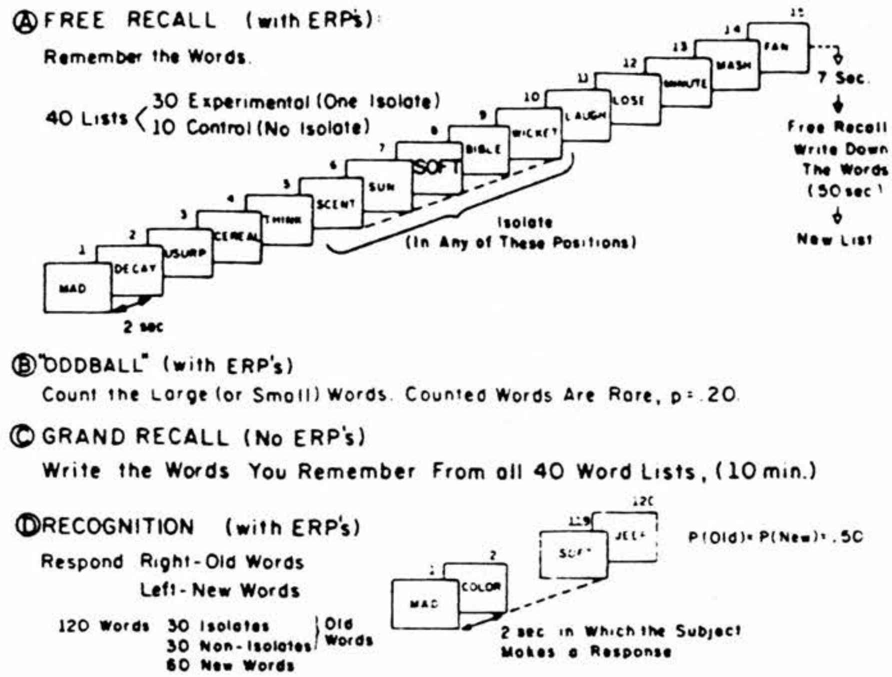

FIGURE 3:2. Experimental design of the study by Karis et al, 1984. From Karis et al 1984, p 182.

varying levels of memory strength, such that retrieval in the grand recall test would indicate that the item retrieved had been better learned than an item retrieved in the free recall tests but not the grand recall, which items in turn would be more strongly held than an item not recalled in either recall tests but successfully recognised. As well as measuring subjects' overall memory performance they also computed a VRI (Von Restorff Index) for each subject which was the number of "isolates" retrieved as a proportion of the total number of words retrieved. A high VRI indicated better recall of "isolates" than of other words.

Behaviourally, the most important finding was that subjects could be divided into three groups on the basis of their memory performance in the free recall test. Group 1 (N=3) showed a high VRI indicating good recall of "isolates" and not very good recall of "non-isolates", group 3 (N=3) subjects obtained a low VRI indicating no difference in retrieval between word types, while group 2 (N=6) took an intermediate position. It should be noted that the recall of "isolates" per se was the same in each group while the recall of "non-isolates" varied. No difference between groups in recognition performance was found. The subjects' self reports of their memory strategies were classified by nine undergraduates who defined the strategies reported by subjects in group 1 as rote learning strategies and those employed by subjects in group 3 as elaborative strategies. Again group 2 took an intermediate position but whether this means that each used an intermediate strategy or half used one and half another is not made clear. A significant correlation was found between VRI score and the rank given to a subject's strategy.

The ERP data revealed that larger P300s were elicited by isolates than by non-isolates. For the ERPs averaged on the basis of word type and on whether the word was recalled in the recall tests PCA was conducted on the ERP data. Four components accounted for 90% of the variance. Significant effects were found between conditions in only two components, identified as the P300 (component 1) and a frontal-positive slow wave (component 2). They found that the amplitude of the P300 components elicited by isolates was larger than the amplitude of P300s elicited by non-isolates. This was expected since the probability of isolates was 10%. They also found that the amplitude of P300 was greater for recalled words of all types. Further, they found that subjects in group one yielded larger P300s to words recalled than to words not recalled, a difference that was smaller for group 2 and absent for group 3. Differences in the second component, occurred mainly in subjects of group 3 and only at Fz, and took the form of greater amplitude generated by recalled words (figure 3:3).

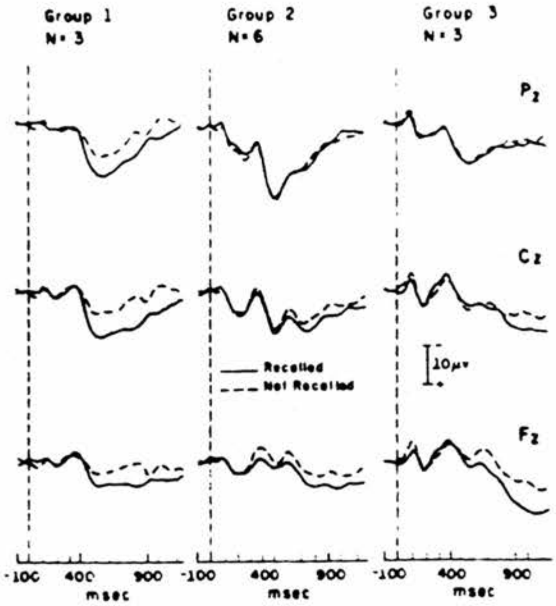

FIGURE 3:3. Group averages for "isolates" at three electrode sites. Each average is divided into recalled vs. not recalled. From Karis et al 1984, p 194.

ERPs were also averaged on the basis of whether the words by which they were evoked were recalled in the grand recall test. Separate averages were compiled for (a) words never recalled, (b) words successfully retrieved in the first recall test and (c) word successfully retrieved in both the free and grand recall tests. An ANOVA performed on component scores revealed a significant main effect of memory for the P300 component. Karis suggests the waveforms reveal that there is a gradation of P300 amplitude correlated with memory strength. However it does not appear that any post hoc statistical test were applied to the data. To further substantiate this claim the ERPs were further re-averaged on the basis of subsequent recognition performance, allowing the comparison of four different levels of memory strength (figure 3:4).

Although no statistical analysis was conducted on these waveforms, Karis suggests that they demonstrate the suggested correlation.

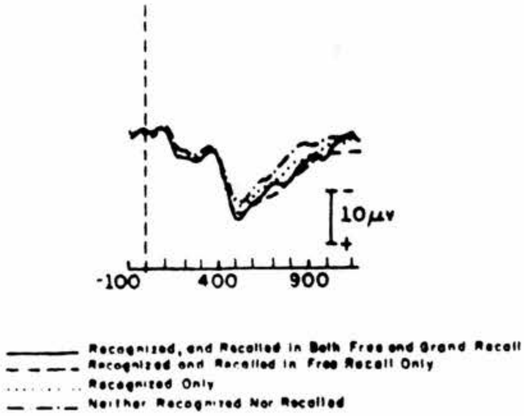

FIGURE 3:4. Grand averages for all subjects for the "isolates" at Pz. This figure depicts further reaveraging on the free recall data on the basis of all three performance measures: free recall, grand recall and recognition. From Karis et al 1984, p 200.

Karis et al conclude from these data that two separate neural events were occurring as the subjects processed the words. The first, reflected by the P300 amplitude, was the process of context updating. The second, reflected by the frontal positive slow wave, was an elaborative encoding process and was only observed in group 1 who used rote memory strategies. In those who used elaborative strategies P300 did not predict recall. The P300 they suggest reflects the initial encoding of surface features of a word whereas recall can be dependant upon subsequently occurring elaborative processing. In subjects who do not use these then the initial surface processing will predict memory performance. In "elaborators" it will not.

Considering that the intent of the study was to test the claim by Donchin (1981) that P300 amplitude reflects the amount of context updating, the main interest of the authors centres on the differences observed in P300 amplitude between conditions. They claim that the observed gradation in P300 amplitude across "memory strength" conditions confirms this hypothesis. However it should be noted that this is not necessarily the case. Firstly there seems to be some confusion concerning the process reflected by P300. The mechanism which P300 is thought to reflect is described as some sort of "automatic" schema updator which is called into operation by surprising events. However, the P300 effects were found in a group of subjects who used the considerable "controlled" processing involved in rote learning. Whether therefore the invoking of P300 and the use of a rote learning strategy are as closely related as Karis et al suggest is open to question.

Secondly it is conceivable that any process which is related to the evaluation of a stimulus will have some influence on the memorability of the stimulus without the need to identify that process with a specific memory function. Whatever process P300 reflects, it is invoked by surprising task events. It is likely that surprising events which are important to the subjects are better remembered than other words. It is interesting in this respect that group 1 subjects remember "isolates" better than other words in the list. It is possible that they were simply those in whom P300 was invoked by the surprising events, ie the "isolates". For "elaborators" in group 3 the "surprise" value of the "isolates" may have been reduced due to the elaborative strategies used to remember the words which tended to ignore the physical difference between the words.

In addition to these conceptual problems the study was subject to a number of methodological ones. Firstly, no attempt was made to control for the frequency or imagability of the words being presented. All words were randomly selected from a word pool on the basis of word length. In view of the fact that word frequency, concreteness and imagability have effects on the memorability of a word, such factors should be taken into account, since any of theses characteristics could be the cause of ERP differences seen in "recognition" ERPs.

Secondly, there is no certainty that the free recall tests were assessing long term memory, since subjects were give no interposing task between the end of each word list and the respective free recall test. In a paradigm in which subjects were told to try and remember the words it is probable that the subjects rehearsed the words they had seen in the 7 second interval between the last word and the test. This also implies that the subsequent memory performance may have depended upon the rehearsal in that period as well as the processing carried out during the period over which ERPs were being recorded, weakening any relationship between memory performance and ERP measures.

Thirdly, the reported "gradation" of P300 amplitude in relation to memory is deduced from visual inspection of the wave forms only. An analysis of variance carried out on the ERPs generated separately by words recalled in the grand recall, those recalled in the free recall and those not recalled at all, respectively, showed a main effect of memory, ie P300 amplitude was greater to words recalled than words not recalled. No post hoc analysis was done to show any differences between the two "recalled" ERPs. In addition, ERPs elicited by words successfully recognised were added to the analysis and the conclusion drawn from visual analysis that a gradation is visible (see figure 3:4). It has yet to be proved that this is the case, since no statistical analysis was done and the differences appear very small.

In view of these differences, conceptual and methodological, it is not clear how to interpret the observed differences in P300 between memory conditions. The later differences seen in group 3 subjects at Fz (see figure 3:3) are possibly therefore the most interesting data from this experiment (although they are somewhat neglected by the authors) principally because the process manifested by the slow wave differences between retrieved and non-retrieved words is unlikely to be dependant upon the relative probabilities of the words and rather more upon the processes carried out upon the word. This is emphasised by the second experiment conducted by this group (Fabiani et al 1986) which employed an incidental learning paradigm. Subjects were asked, unexpectedly, to recall as many items as possible from a list of male and female names in an oddball task. ERPs were averaged on the basis of subsequent recall for each oddball condition ("count rare names" or "count frequent names)" and for each type of stimuli (rare or frequent). The ERPs elicited by names not likely to elicit P300s (ie frequent names) show a frontally maximal large difference between ERPs elicited by recalled and not recalled words (see figure 3:5).

The difference at Pz is much smaller.

It seems likely that the differences at Fz beginning at about 700-800 msec reflect the same differential processing as was seen in Karis et al. In this case however the subjects were not engaging in elaborative processing. Similarly the P300 amplitude differences observed in ERPs elicited by rare names were not due to any "rote learning" process. These data indicate that the memory-related differences in P300 and slow wave amplitudes have less to do with conscious learning strategy than with "automatic" activation of "surprise-related" and "elaborative" processes respectively. In the case of the former the activation of this process may

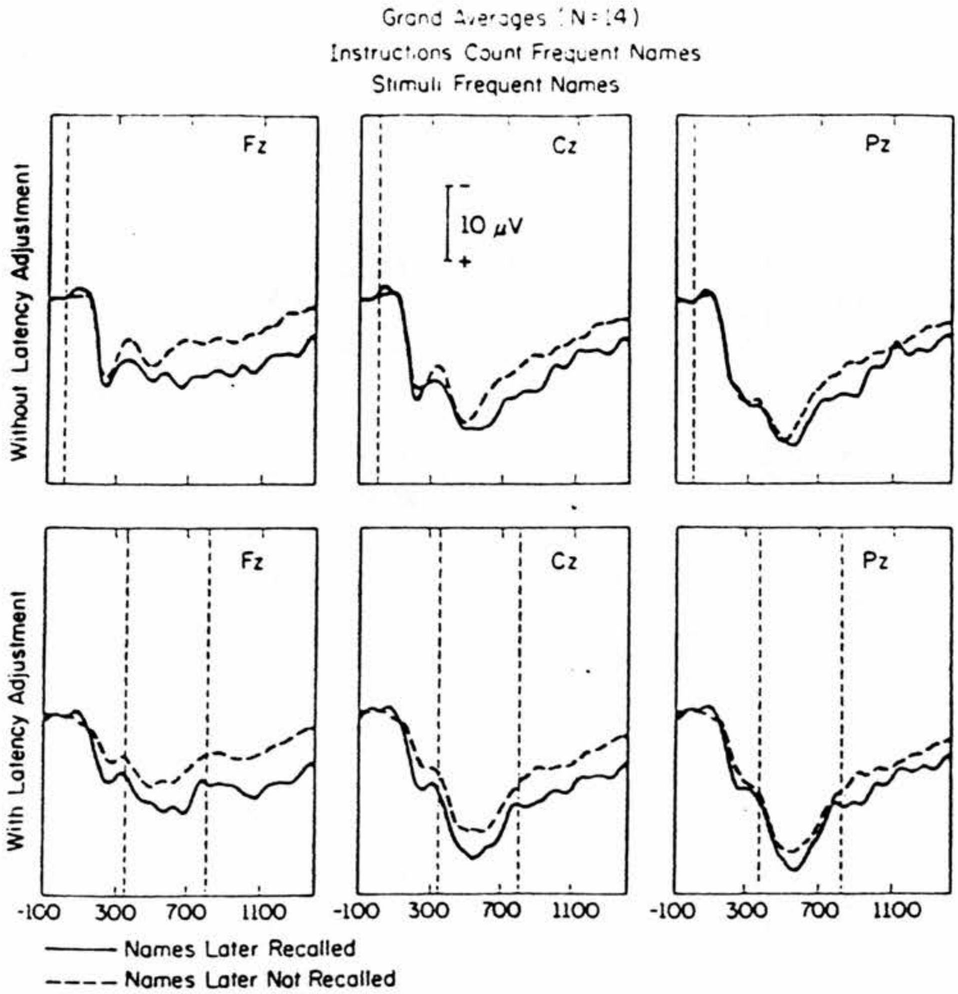

FIGURE 3:5. Grand averages of ERPs elicited by frequent names under the instruction to count frequent names, from three electrode sites. Separate averages for ERPs elicited by recalled and not recalled words are shown. From Fabiani et al, unpublished results, figure 5.

be related to the frequency of a word and in the case of the latter, upon some semantic features of the word.

Neville et al (1986) have utilised a similar design to study both encoding and retrieval ERPs. In their first experiment subjects were presented with 120 four word phrases one word at a time. Each phrase was completed by a fifth word which either fitted ("fit" words) or did not fit ("no-fit" words) with the sense of the preceding phrase. Approximately 2 seconds after the fifth word the subject pressed one of two buttons to indicate whether the word did or did not fit the sense. A recognition test was given to subjects one minute after every forty phrases. Each test list consisted of the 40 "fifth" words they had seen randomly mixed with 40 new words. ERPs were recorded during both the judgement task and the recognition task. They found that in ERPs from the judgement task, averaged on the basis of later recognition, the late positive component (the largest peak in a 400-950 msec window) was 30% larger to words that were subsequently recognised than to those that were not. However this analysis could only be carried out on two subjects due to the lack of a sufficient number of recognition test errors in the other subjects. To examine this effect in more detail a second study was conducted which aimed to increase the recall test error rate.

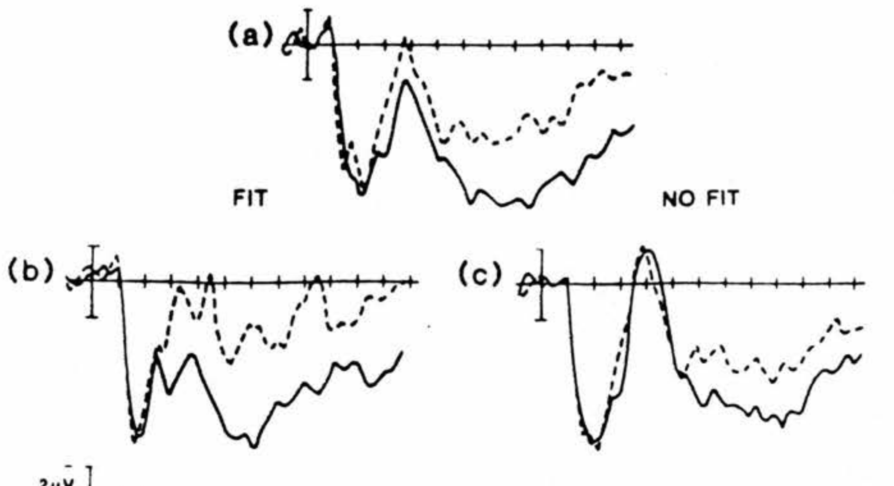

FIGURE 3:6. ERPs recorded from Cz in the judgment task of experiment 2 averaged according to subsequent recognition in the recognition test. a) ERPs averaged across "fit" and "no fit" words. b) ERPs averaged for "fit" words and c) "no fit" words. From Neville et al 1986, figure 8.

Several modifications were made in the design of the experiment, namely one test was administered following all 120 phrases and the memory load of each subject was increased. They found that ERPs to words that were subsequently correctly recognised displayed more positivity than did the ERPs to words that were not subsequently recognised (see figure 3:6a).

This difference onset was at 250 msec and was more pronounced over the left than the right hemisphere (see figure 3:7).

It was further shown that this effect was not due to differences between the number of "fit" words compared to the number of "no-fit" words contained in the two recall categories since the effect was observed for both classes of words (see figure 3:6 b,c). They interpret the enhancement of the late positive component to words later recognised to reflect "processing beyond the initial encoding, namely the elaborative/consolidative procedures engaged for the laying down of distinctive memory traces." (Neville et al 1985, p 33)

A study by Johnson et al (1985) has produced data which are somewhat discrepant with the above findings, in that no late positive component (LPC) amplitude difference between ERPs generated by subsequently recognised and not-recognised words was found. Instead the authors identified a significant LPC latency difference, with LPCs generated by words later recognised occurring on average 22 msec earlier than LPCs generated by non-recognised words (see figure 3:8).

In their study ERPs were recorded to words which subjects were told to memorise. Words were presented sequentially on a TV monitor and subjects were required to passively watch and try to memorise the words. These words were then mixed with the same number of "new" words and presented in a recognition test. The authors interpret the apparent contradiction between their data and those of other studies which have found memory

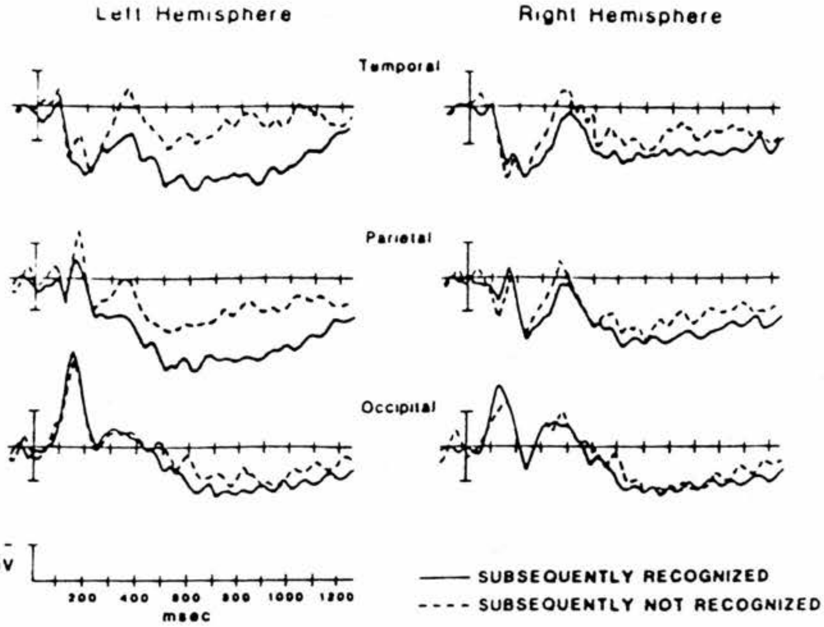

FIGURE 3:7. ERPs in the judgement task of experiment 2 (averaged across "fit" and "no fit" words) averaged according to performance in the recognition test. The experimental effect, ie a larger positivity to words subsequently recognised, is greatest in ERPs recorded from the parietal and temporal regions of the left hemisphere. From Neville et al 1986, figure 9.

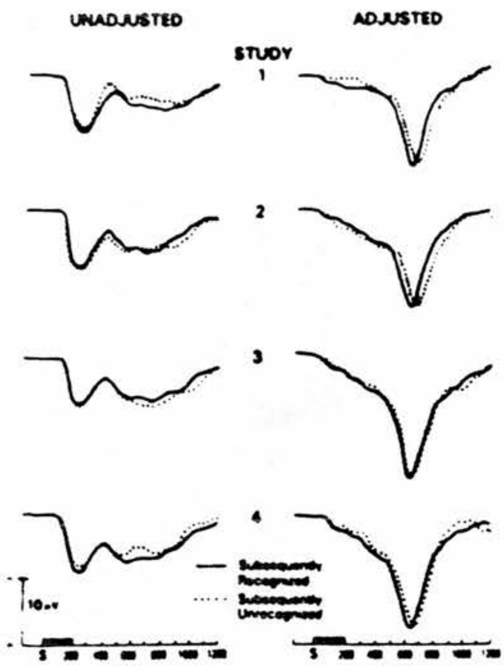

FIGURE 3:8. ERPs recorded from Pz and averaged according to subsequent recognition performance. From Johnson et al 1985, figure 7.

related LPC differences, as being due to the high task demands placed upon subjects due to the requirements of memorising a long list of words (75 words in each study list). P300 amplitude has been shown to be related to task demands (Courchesne et al 1978, Johnson 1984, Poon et al 1974, Teuting and Sutton 1976) and they suggest that since P300 amplitudes were enhanced due to these task related factors, any memory related effect may have been masked. They interpret the observed latency difference in terms of the discriminability of the stimuli. P300 latency is believed to be related to the discriminability of an item (Johnson and Donchin 1985), the more discriminable the word, the shorter the latency. Johnson suggests that the familiarity incrementing process may depend on the discriminability of words and that the more discriminable the word, the more easily it will be recognised. Thus they conclude that their observed P300 latency difference on the basis of subsequent recognition is a neural correlate of the familiarity incrementing process.

Using a slightly different design from the above studies, Friedman and Sutton (1986) have reported the existence of two memory related ERP effects. They employed a continuous recognition paradigm, (Shepherd and Teghtsoonian 1961) in which pictures of common objects (selected from Snodgrass and Vanderwart 1980) were repeated within the same presentation list and subjects were required to identify each picture as either "new" or "old". The authors have reported that pictures which were subsequently recognised generated a larger P300 and were significantly more positive later, between 700-1600 msec post stimulus (see figure 3:9).

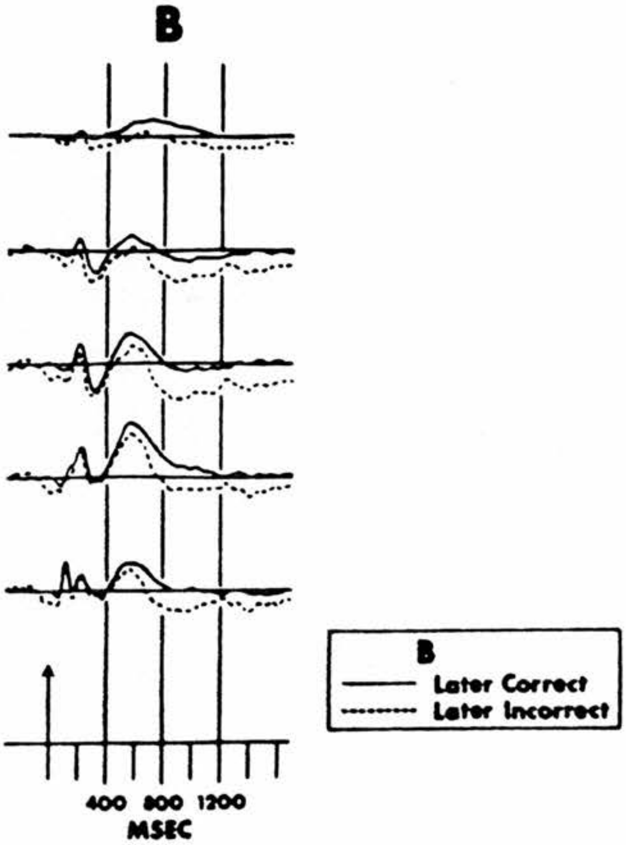

FIGURE 3:9. ERPs recorded during initial presentation and averaged according to recognition category. From Friedman and Sutton 1986, figure 1 (B).

One difficulty with interpreting these data is that the numbers comprising each waveform are not reported. In a continuous recognition paradigm the time between first presentation and repeat is comparatively short and it is likely that many more items were recognised than were not recognised. A second difficulty is that the stimuli used were non-verbal making direct comparison with other studies difficult. It is also of interest that the later positivity did not appear to be especially marked at the frontal recording sites. However it should be pointed out that in such a design, which involves words being grouped together on the basis of recognition over a very short period, it is unlikely that ERPs generated by such words would exhibit any activity associated wtih more elaborative processing and thus it is possible that the late positivity in these data and that seen in the studies of Karis and Fabiani reflect different processes.

The only study to date which has attempted to distinguish between ERP correlates of different encoding processes, is that conducted by Paller et al (1986). Utilising the concept that the type of encoding words received could be distinguished on the basis of performance on different kinds of retrieval test, Paller grouped words on the basis of subsequent performance both on a test of "explicit" memory ie cued recall and on a test of "implicit" memory ie word fragment completion. Subjects were required to assess a series of words with unique stems (ie the first three letters) as either "abstract" or "concrete". In the word completion task, the stems of half of the presentation words were re-presented and subjects required to complete the word. This was followed by a test of cued recall in which the stems of all the words were re-presented and subjects asked to recall the word on the basis of the stem. A further test of free recall for all words followed this. Word fragment completion testing took place one minute after the end of each presentation list (26 items in each). Memory testing occurred following presentation of the final list and associated completion test.

Subjects successfully completed 59% of stems with respect to a baseline of 12% which could have been completed if they had not been presented before. 34% of words were recalled in the cued recall test and 6% in the free recall test. Only ERPs generated by words not included in the completion test were entered into "recall" averages. The ERPs generated by various conditions in the experiment are shown in figure 3:10.

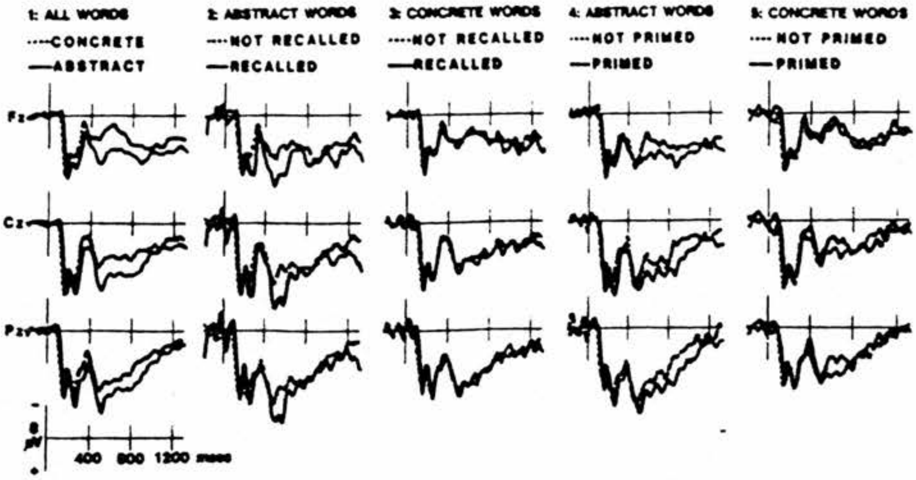

FIGURE 3:10. ERPs recorded during initial presentation and averaged according to type of word and subsequent test performance. From Paller 1986.

ERPs generated by items in the two recall conditions showed differences only for abstract words. In this case, words which were later recalled generated activity that was more positive in the 400-600 msec region, than did words not recalled. ERPs differed as a function of performance on the word completion test in the cases of both abstract and concrete words. Words that were later successfully completed generated more positive activity than words that were not completed. This enhanced positivity occurred from approximately 500 msec post stimulus onwards. However, while the difference was apparent at all three midline sites in the case of abstract words, it was restricted to central and parietal sites and lasted for a shorter period, in the case of concrete words. Because the ERP effects differ between tests, Paller et al conclude from these findings that "the presumably independent processes that mediate good performance in implicit and explicit memory tests are reflected by partially distinct ERPs."

To conclude, studies examining the ERP correlates of encoding processes have utilised three different kinds of retrieval test. According to two-process theories of encoding and retrieval, performance on different retrieval tests depends on different encoding processes. It may be useful, therefore, to divide up the findings according to the retrieval test used.

a) Only one study of processes involved in regulating performance on a test of specifically "implicit" memory has been conducted. Paller et al, (unpublished data) reported that ERPs generated by words later successfully completed in a word fragment completion test generated more positivity than ERPs generated by words not completed. This enhanced positivity began at 400 msec and took the form of a consistent difference extending until virtually the end of the epoch.

b) Several studies have studied ERPs averaged on the basis of subsequent recall, which is assumed to be a test of specifically "explicit" memory. These have reported findings that appear to differ on the basis of the encoding task involved. Karis et al (1984) have shown that during the employment of elaborative encoding techniques words subsequently recalled generate enhanced positivity at the frontal electrode site. Fabiani et al (1986) reported a similar enhanced late frontal positivity generated by words in an incidental learning paradigm. Paller et al, (unpublished data) have reported similarly, that during an incidental learning semantic task, words later recalled generated enhanced positivity, but this seems to take the form of an enhanced late positive component rather than a slow late positivity, and it appears equally present at all three midline sites. In tasks involving non-semantic processing (Karis et al 1984) words later recalled were found to generate larger late positive components than words not recalled. This was interpreted to be a difference in amplitude of the P300 component.

c) Several studies (Sanquist et al 1980, Neville et al 1986, Johnson et al 1985, Friedman and Sutton, unpublished data) have utilised a test of memory (recognition memory test) which is thought to depend on both processes. The majority of these have reported finding enhancement of the late positive component in ERPs generated by words later correctly recognised. In addition both Sanquist et al and Friedman and Sutton have reported finding enhanced late positivity generated by words subsequently recognised.

Thus a number of memory-related ERP effects have been observed. The nature of the processes generating these effects is not yet clear but on the basis of "two-process" theories of encoding and retrieval, it is possible to assume that ERP effects generated on the basis of subsequent tests of "implicit" memory reflect intra-item processing while effects observed between ERPs averaged on the basis of subsequent tests of "explicit" memory reflect inter-item processing. One area needing clarification is the extent to which ERP differences seen in ERPs averaged on the basis of subsequent recognition reflect either process. In view of the two-process model high and low confidence of recognition decision may reflect the outcome of the two processes respectively.

3.3 RETRIEVAL PROCESSES

Of the studies mentioned in the preceding section, Sanquist et al (1980) Karis et al (1984), Neville et al (1986), Johnson et al (1985) and Friedman and Sutton (1986), also recorded ERPs during the recognition tests and averaged them on the basis either of successful or unsuccessful recognition or of whether the words were "new" or "old". The data of Sanquist et al (1980), (see figure 3:11), reveal a large difference in the amplitudes of the LPCs of ERPs elicited by "hits " and "misses".

The ERPs elicited by "hits" were some 10uv more positive than those elicited by "misses". ERPs elicited by "false alarms" and "correct rejections" had intermediate amplitudes although ERPs elicited by both these categories of words are at least 5uv smaller than the amplitude of ERPs elicited by "hits". The authors conclude that "the LPC appears to index processes associated with stimulus recognition in a test of memory" Sanquist et al (1980, p 575).

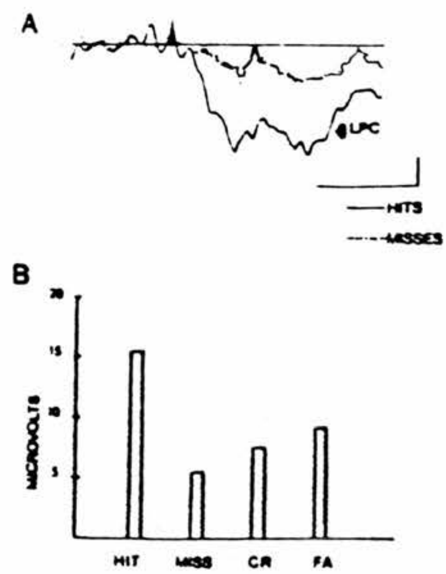

FIGURE 3:11. A. Grand average ERPs elicited by "hits" and "misses" in the recognition memory test. Calibrations: 500 msec and 5uV, negativity upwards. B. Average voltage over 450:750 msec poststimulus interval for "hits", "misses", "correct rejections" (CR) and "false alarms" (FA). From Sanquist et al 1980 p 573, figure 5.

Karis et al (1984) also recorded ERPs during their recognition test, and averaged them according to word type ("isolates" and "non isolates" and "new") and according to whether or not they were recognised. The "new" category contains both "correct rejections" (correctly recognised) and "false alarms" (incorrectly recognised). It can be seen from figure 3:12

that the amplitudes of P300 components in ERPs elicited by successfully recognised words were greater then of those generated by both incorrectly recognised words and new words.

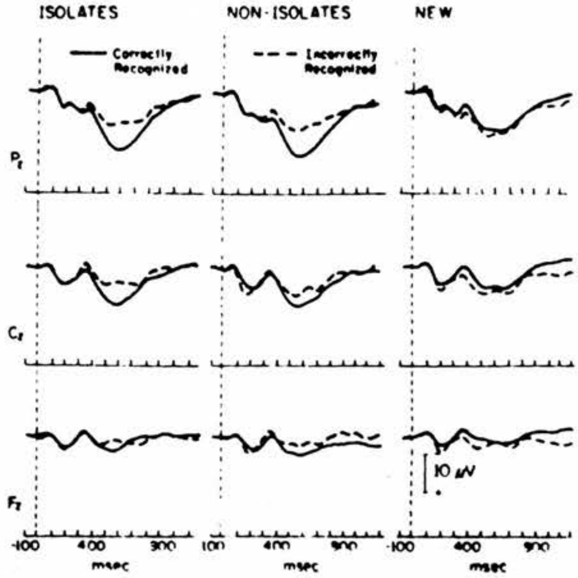

FIGURE 3:12. Grand average waveforms for 12 subjects elicited by words presented during the recognition test. Averages are presented for three classes of words at the three electrode sites, and are divided into those correctly and incorrectly recognised. From Karis et al 1984 p 201, figure 12.

In the study by Neville et al (1986) the data revealed that the LPC amplitudes elicited by successfully recognised "old" words was greater than the amplitude of LPCs elicited by "new" words (see figure 3:13).

The data from incorrectly recognised words are not reported. In addition, in an earlier experiment, Neville et al (1982b) have reported that the amplitude of the P300 component was enhanced in a study of recognition based on pre-experimental memory for items. Subjects were shown a series of slides of people and paintings taken from magazines, books and personal slide collections, and asked to indicate which they

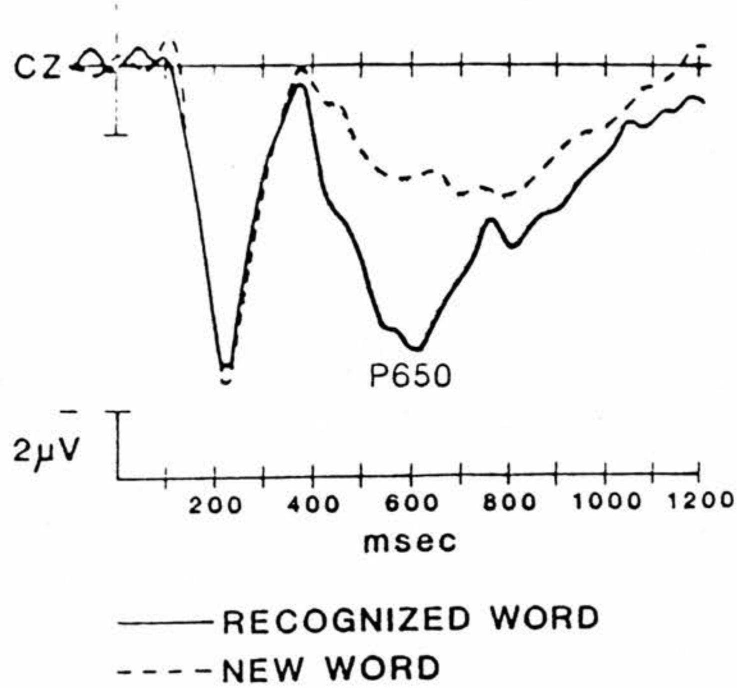

FIGURE 3:13. ERPs to correctly recognised old words (both "fit" and "no fit" words) and to correctly identified new words. From Neville et al 1986, figure 4.

recognised. EPRs elicited by recognised and not recognised slides are shown in figure 3:14.

P300 amplitude at Fz was significantly greater to recognised slides than to not recognised slides. No other component showed significant amplitude or latency changes as a function of recognition. The authors conclude from this that the process of recognition is a major determinant of P300 amplitude and that "whether or not this is so, the enhancement of the P300 response to recognised slides can serve to measure the integrity of the perceptual and memory systems that underlie this complex cognitive activity" (Neville et al 1982b, p 2123). It should be noted however that the number of slides correctly recognised by the subjects was very small (on average 11.3%) and thus the P300 effect may be due to a "probability" effect, ie stimuli which are less probable elicit larger P300s.

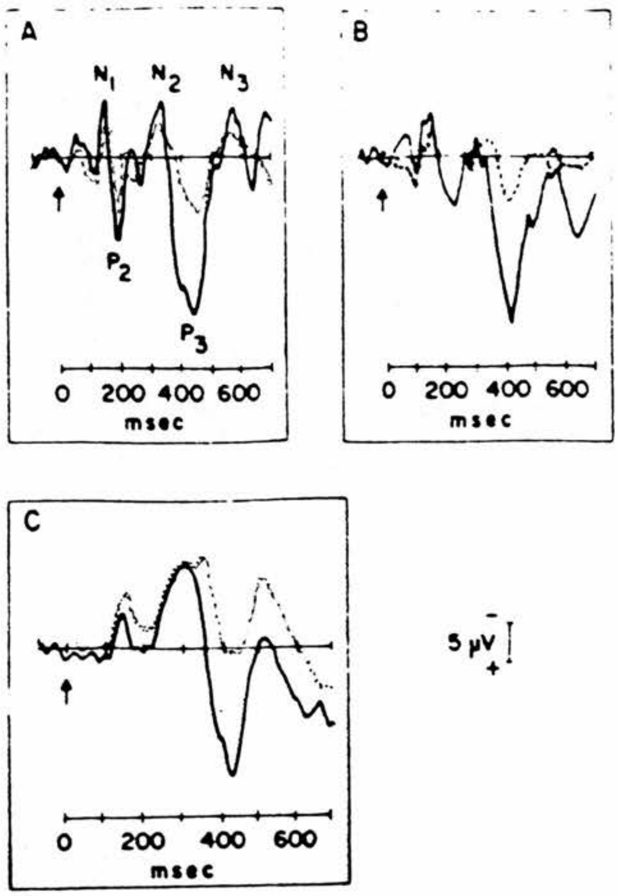

FIGURE 3:14. ERPs from two individual subjects (A and B) and ERPs averaged over all nine subjects (C) (all Pz electrodes) to recognised (__) and to unrecognised (.....) slides. From Neville et al 1972 p 2121, figure 1.

Johnson et al (1985) report a greater amplitude and earlier peak latency of P300s generated by "old" words (whether or not they were recognised) compared to the amplitude and latency of P300s generated by "new" words (figure 3:15). Friedman and Sutton (unpublished data) report a similar finding (see figure 3:16) of enhanced P300 amplitude generated by "old" words.

In addition, they report that a separate late negative component beginning at about 800 msec post stimulus was enhanced in potentials generated by "old" words.

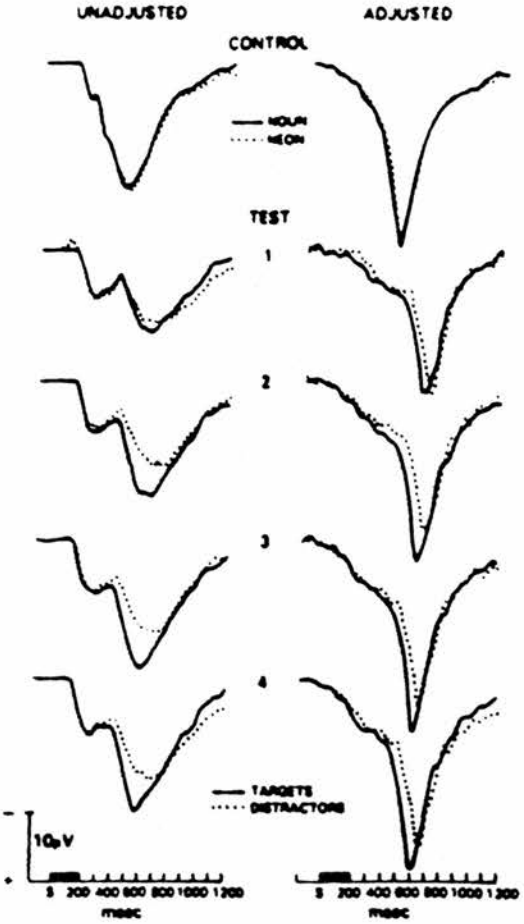

FIGURE 3:15. Unadjusted and latency adjusted ERP waveforms at Pz averaged across all subjects for the correctly identified words from the memory test. From Johnson et al 1985, figure 2.

In addition to these studies Warren (1980) has recorded ERPs during a recognition memory test. Subjects were presented three times with a list of 64 nouns to study at a rate of one word every 5 msec. They were then shown a recognition test list consisting of 30 words they had seen and 30 "new" words and were required to respond according to whether they had seen the word before or not. ERPs were recorded during the presentation of all four lists from two sites (Fz and Pz) and averaged according to whether they were old or new words. In a second experiment the influence of the degree of learning on ERPs elicited by the two classes of words was assessed by giving one group of subjects two study trials for each word and

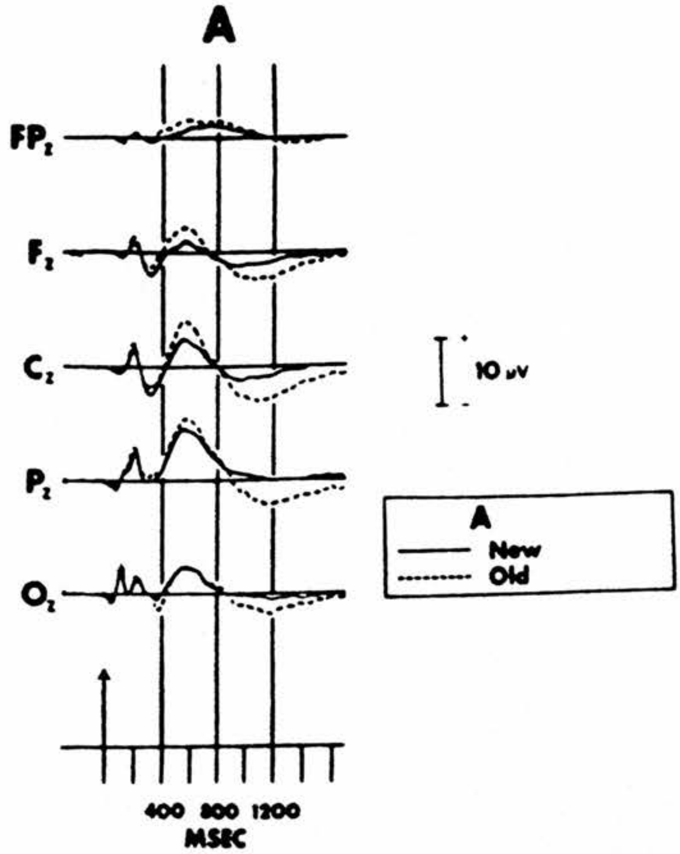

FIGURE 3:16. ERPs generated by correctly identified "old" words and correctly recognised "new" words. From Friedman and Sutton 1986, figure 1 (A).

another group six study trials.

In both experiments she found no changes in ERP component amplitude or latency over the study trials but did find that the latencies of the N200 and P200 components were greater in ERPs elicited by old words than in those elicited by new words. The latency of P300 elicited by old words was decreased relative to those elicited by new words. No differences were observed between ERPs elicited by words presented twice and those presented six times. These results are hard to interpret however in view of the fact that no measurements of the ERPs are reported.

In view of the implications for memory research of repetition effects, data from a series of experiments by Rugg in which ERPs were recorded to both first and second presentations of words in a lexical decision task are of interest. Data from the first experiment (Rugg 1985) which compared the ERP correlates of repetition and semantic priming, are shown in figure 3:17.

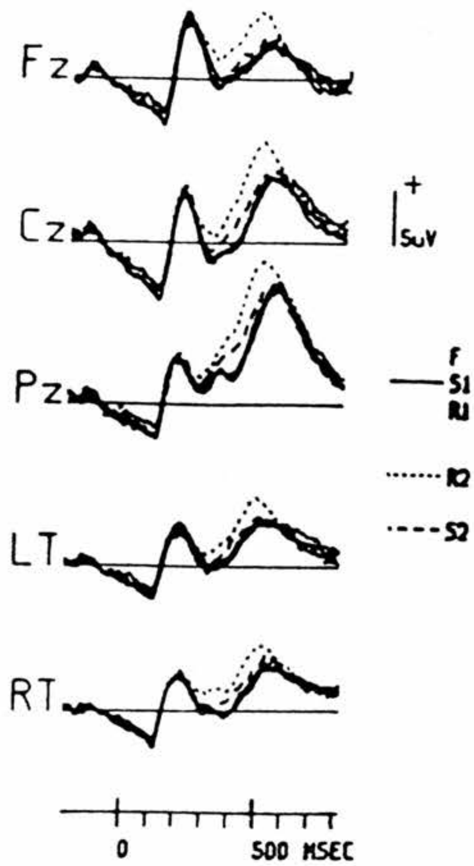

FIGURE 3:17. Grand average waveforms from each site and condition. F = filler words, S1 = semantic primes, S2 = semantic targets, R1 = first presentations and R2 = second presentations of repeated words. From Rugg 1985.

Significant differences in two regions of the waveforms were found between ERPs generated by repeated words and other words. Words which were repeated generated greater positivity than words presented for the first time, between 250-600 msec post stimulus. In two follow-up experiments (Rugg 1987) in which ERP correlates of repetition for words and non-words were compared the data revealed an early repetition effect which was present in both words and non-words, and a later effect (similar to that seen in Rugg 1985) which was greater for words than for non-words. Rugg interprets the earlier of these effects which consisted of a negative deflection at between 200 and 300 msec post stimulus, generated by repeated words, as reflecting an element of the repetition effect which did not depend upon prior lexical representation. The later effect, an enhanced positivity to repeated items in the later part of the waveform, was interpreted as an element of the repetition effect which does depend on prior representation. In a further study (Rugg and Nagy, in press), ERP correlates of repetition were found only for items which possessed some representation in lexical memory (figure 3:18).

Rugg has suggested that the enhanced positivity to repeated items may be due to an attenuation of the N400 component generated by words on their first presentation.

In conclusion, retrieval related ERP effects seem to consist of an enhancement of the late positive component in ERPs generated by successfully recognised "old" items compared with those in ERPs generated by unsuccessfully recognised "old" items (Karis et al 1984, Sanquist et al 1980) and in ERPs generated by "old" items compared with those in ERPs generated by all "new" items. In addition a late negativity has been found to distinguish between retrieval conditions (Friedman and Sutton, unpublished data).

The interpretation of these data is difficult because different studies have used different retrieval tests on which to base ERP comparison and not all the studies have compared successful and unsuccessful

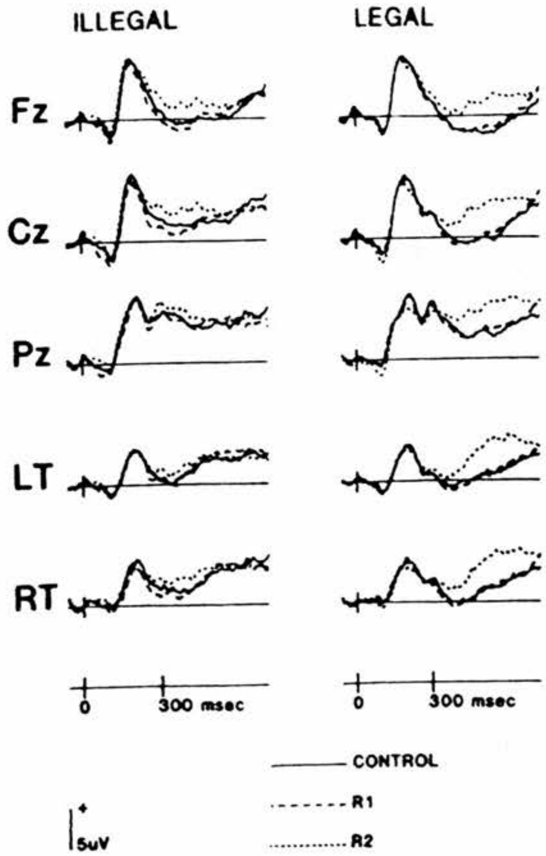

FIGURE 3:18. Grand average waveforms elicited by control, R1 and R2 orthographically illegal and legal non-words. From Rugg and Nagy in press, experiment 1.

retrieval. On the one hand it could be argued that what is seen here is an effect of memory processes per se, ie the neural process of retrieving an item from memory is reflected in the LPC. This is the view adopted by Sanquist et al (1980). On the other hand Karis (Karis et al 1984) has suggested that the effects on the recognition ERPs are merely due to two previously established experimental phenomena, the "target effect" (ie the fact that targets elicit larger P300s than non targets, see Duncan-Johnson and Donchin 1977) and the effect of "confidence" (P300 amplitude increases with the confidence with which a decision is made; see section 1.2.7.1). However as Neville rightly points out (Neville et al 1986, p 28) there is as yet no evidence bearing on the degree of "confidence" involved in correctly recognising or failing to recognise words. The data from repetition studies have some bearing on resolving these different theories. Repeated words generated greater positivity than words at first presentation. Basically the same data are reported in the other studies, where ERP responses to repeated words are compared with responses to "new" items. In view of the similarity between the two sets of data, it is possible that the effects observed in the "memory" related experiments are the same as those in the repetition effect studies.

The nature of the processes involved in repetition are difficult to resolve at present. In the context of the dual process theories, repetition effects are thought to be the product of intra-item processing, or the enhancement of the item's perceptual fluency. Behavioural and ERP studies of the effect have differed over whether the locus of the effects is in episodic or semantic memory. (See Chapter 2 for brief discussion of these issues.) Clearly, the same kind of differentiation between results obtained in different retrieval tests as was employed in studies of encoding, will be needed in the study of retrieval processes. ERP correlates of repetition, recall and possibly different confidence levels of recognition should be utilised to distinguish between ERP correlates of different processes.

3.4 CONCLUSION

Several studies have employed a very powerful experimental design to investigate the degree to which encoding and retrieval processes are indexed by ERP components. Findings from these studies have indicated that ERPs may be able to distinguish between the different processes thought to be involved in encoding and retrieval. The following series of experiments was conducted to further elucidate these processes by utilising the concept that processes may be differentiated on the basis both of retrieval test used and of decision confidence level.

CHAPTER 4

EXPERIMENT ONE

EXPERIMENT ONE

4.1 INTRODUCTION

In the conclusions of chapters 1 and 2 it was suggested that the present state of knowledge concerning both ERP and human verbal memory research indicated that the study of the ERP correlates of human verbal memory might be a fruitful line of research, both from the point of view of determining the neural correlates of learning and memory and of casting light upon cognitive understanding of encoding and retrieval. In chapter 3 several studies were reviewed which have attempted to do this by means of averaging ERPs, recorded at both first and second presentations of words, according to retrieval performance. The data from these studies revealed that components of ERPs recorded during encoding and retrieval may have been sensitive to the kind of processing performed upon the stimulus items. It was pointed out that the retrieval test employed gave some indication of which processes these might be, performance on tests of "explicit" memory being dependent upon elaborative or inter-item processing, and performance on tests of "implicit" memory being dependent upon intra-item processing.

One problem in interpreting much of the data is that they are derived from studies employing recognition memory tests, performance on which is thought to depend upon both types of processing. It was suggested in chapters 2 and 3 that, on the basis of the dual process models of memory, that one way to distinguish between the relative contributions of the various processes would be to assess the confidence with which stimulus items are recognised. The identification of a stimulus item as "familiar", which is thought to depend upon intra-item processing would presumably allow subjects to "feel" that the item was "familiar" whereas the ability to recall encoding context, which is thought to depend on inter-item processing would presumably allow subjects to remember <u>where</u> they had seen the item. It is assumed that the former memorial experience would give rise to low confidence recognition decisions, whereas the latter would give rise to high confidence recognition decisions.

The purpose of the present experiment was to investigate the ERP correlates of words responded to with different levels of confidence in a subsequent test of recognition memory, both at encoding and retrieval.

4.2 METHODS

4.2.1 Design

See figure 4:1. In this experiment, subjects undertook a semantic discrimination task in which they were required to discriminate between animate and inanimate nouns, and 24 hours later a recognition memory test, in which they were shown the items from the discrimination task intermixed with distractor items and required to identify the words previously shown. Each "old"/"new" discrimination decision could be made with one of two confidence levels. ERPs were recorded from every word at both presentation and test. ERPs recorded during the semantic discrimination task were averaged on the basis of word type (animate/inanimate) and of whether the word was later recognised or not and with what level of confidence. ERPs recorded during the recognition test were averaged on the basis of whether the word was correctly or incorrectly identified as "old" or "new" and with what confidence level.

4.2.2 Tasks

Two tasks were employed in the present experiment. The first was an incidental learning task, consisting of the discrimination between nouns which referred to animate objects (eg "CAT", "TREE") and those which referred to inanimate objects (eg "HOUSE", "CAR"). The nouns were presented to the subjects one at a time on a TV monitor and responses were made by pressing one of two microlevers. Each semantic discrimination task

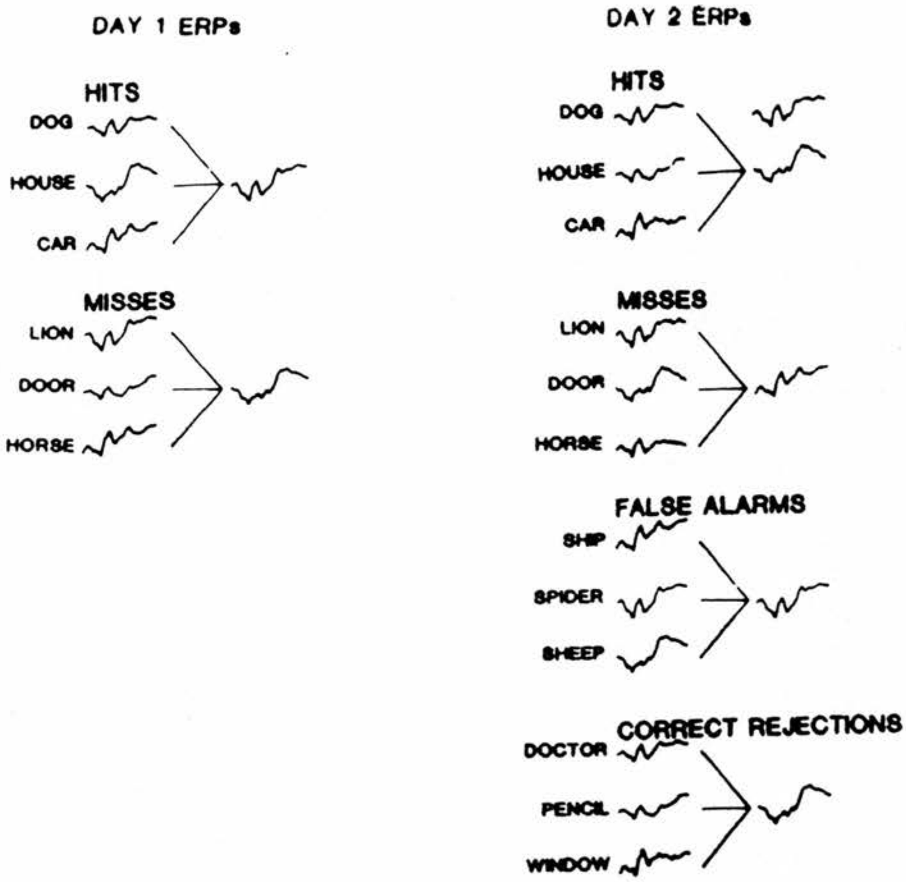

FIGURE 4:1. A simplified representation of the basic rationale of experiment 1. ERPs elicited by verbal stimuli were recorded on two successive days. Words were sorted according to whether they were correctly or incorrectly identified as "old" or "new" during the recognition test on day 2. ERPs generated by words in each category were averaged together. Thus AERPs could be produced for each recognition response category.

session lasted approximately 1 hour.

The second task was a forced choice recognition memory task, conducted 24 hours after the semantic discrimination task. The time lag was to allow for sufficient forgetting to take place to allow equal numbers of words to fall into each response category. If the recognition test had immediately followed the semantic discrimination test most of the words would probably have been recognised. In this recognition test, all the items from the first task were re-presented to the subjects, randomly mixed with the same number of "new" items, and the subjects were required to indicate whether they thought each word was "new" or "old" and whether they were very sure or uncertain about their decision. Subjects did this by pressing one of four microlevers corresponding to each response/confidence category. In the case of recognition, subjects were required to wait after each word before responding, until a response window was indicated. This was to prevent possible interference in the ERPs by motor responses. Each recognition session lasted about 1 hour.

4.2.3 Stimuli

The stimuli consisted of 320 nouns, half of which were animate and half inanimate. The words were selected from the Paivio word norms (Paivio 1968) and were all rated with a value of 5 or more (in a scale of 1 to 7) on the dimensions of imagability and concreteness. They all had a frequency of over 1 in a million (AA or A) on the Thorndike-Lorge word count. Words possessed between 1 and 4 syllables, average syllable length being 2. All words were presented at moderate contrast and brightness on a TV monitor. Words appeared in the middle of the screen and were left justified. All words were presented in upper case.

For the semantic discrimination task, half of each type were randomly selected for inclusion in 4 presentation lists, each of which contained 20 animate and 20 inanimate nouns. The remaining 160 animate and inanimate nouns served as distractors in the 4 recognition test lists. Each recognition test list consisted of the items of one of the presentation lists plus 20 animate and 20 inanimate distractors.

Two practice lists were also generated, the first containing 20 nouns, serving as a "presentation" list for the second 40 noun recognition practice list.

The stimulus parameters were as follows:

(i) Presentation: A fixation star was presented for 500 msec followed 150 msec later by the stimulus which was displayed for 200 msec. The response window which began at stimulus onset lasted for 1600 msec. The Inter-Trial Interval (ITI), ie the time between the end of one trial and the beginning of another, was 5 seconds. The total Inter-Stimulus Interval (ISI) is the time from the onset of one stimulus to the onset of the next was 7.25 seconds.

(ii) Recognition: Fixation star and stimulus display parameters were the same as at presentation. 1 second after stimulus onset a response prompt was displayed which lasted for 2 seconds. The ITI was 5 seconds and the total ISI was 8.65 seconds.

The stimuli were presented across the point at which the fixation star had appeared and at the viewing distance employed, subtended a vertical visual angle of approximately 1.5 degrees.

4.2.4 Subjects

These were 10 right-handed male and female undergraduate students all of whom had normal or corrected to normal vision.

4.2.5 Procedure

4.2.5.1 Semantic Discrimination Task - Following electrode application subjects were seated in front of the TV monitor with their heads supported by a chin rest and the index finger of each hand resting on the levers of microswitches. The nature of the task was explained to the subjects. They were told they were required to respond as fast and as accurately as possible with one hand if the noun was animate and with the other hand if it was inanimate. For each subject the same hands were employed for "animate" and "inanimate" responses throughout the sessions but choice of hand was counterbalanced across subjects.

The subject was given 20 practice trials and then shown the 4 experimental lists with a break of 5 minutes between each list. The order of list presentation was counterbalanced across subjects.

Subjects were informed of the importance of maintaining fixation throughout a trial and of minimising eye and body movements. No indication was given that the session on day 2 would consist of a recognition test.

4.2.5.2 Recognition Task - Following electrode application subjects were seated in front of the TV monitor with the first two fingers of each hand resting on the buttons of the 4 microswitches corresponding to the response categories: "very sure, seen before", "uncertain, seen before", "very sure, not seen before", "uncertain, not seen before". The nature of the task was explained to the subjects. They were required to classify each word according to whether it had been shown on day 1 or not, and to indicate their confidence level, by depressing one of the 4 switches during the signalled 2 second interval. For each subject, one hand was assigned to "seen before" responses and the other to "not seen before" responses across all 4 test lists, but the hand used for each response was counterbalanced across subjects. The index finger was always assigned to non-confident responses.

The practice trials were presented followed by the 4 recognition lists, each separated by a 5 minute break. List order was counterbalanced across subjects and was not related to presentation list order. Again, the subjects were reminded to maintain fixation and to minimise eye and body movements.

Following the recognition tests, subjects were asked if they had suspected that they would be required to remember any of the words shown in the semantic discrimination task.

4.2.6 Behavioural Responses

During presentation in the semantic discrimination task subjects' responses and reaction times were recorded and stored on disk. During the recognition task subjects' responses were recorded and stored.

4.2.7 ERP Recording

EEG was recorded to every word in both sessions. EEG was recorded by means of silver/silver chloride electrodes from Fz, Cz, Pz and left and right temporal sites. The temporal electrodes were situated 75% of the distance between Cz and T3 and T4 respectively. All were referred to linked mastoids. A placement half way between Fz and Cz was employed as a ground. EOG was recorded from a bipolar electrode pair situated on the outer canthus of the left eye and just above the right eyebrow. Inter-electrode impedance was less than 3 Kohm. EEG and EOG were amplified with digitimer D160/150 amplifiers with low pass attenuation of 3 dB at 30 Hz and a time constant of 5 seconds. These were sampled on-line at a rate of 1 point every 4 msecs, starting 100 msec before stimulus onset and continuing for 1024 msec thereafter. EEG and EOG samples were stored on a computer disk for subsequent off-line processing.

4.2.8 ERP Analysis

4.2.8.1 Semantic Discrimination Task ERPs (Day 1) - Separate averaged ERPs were formed for each subject for each category (animate and inanimate) and for each recognition response category (confident hits, confident misses, non-confident hits and non-confident misses).

4.2.8.2 Recognition Memory Task ERPs (Day 2) - Separate averaged ERPs were formed for each subject for each of the eight recognition response categories (confident and non-confident; hits, misses, false alarms and correct rejections).

In both cases only trials in which no eye-movement artifact was detected (ie when EOG amplitude did not exceed a particular value) were entered into the averages.

4.2.9 ERP Measurement

Quantification of ERPs took the form of both a) peak measures and b) measurements of the mean amplitude of selected regions of the waveform, which were made relative to a baseline consisting of the mean amplitude of the 100 msec of activity prior to stimulus onset.

In all the experiments the peak measures and amplitude measures were determined in the following way.

a) Peak measures. The selection of peaks to be measured was determined firstly by visual inspection of the Grand Averages. To measure the peak of a component a latency range for that peak in each experimental condition were assessed and measurements were made from individual subjects' averages of the highest value positivity or negativity (depending on the polarity of the peak to be measured) in that latency range.

b) Amplitude measures. The regions of the waveform from which mean amplitude measures were taken were also primarily determined by visual inspection of the Grand Average waveforms. The regions measured were those in which ERPs generated by different conditions appeared to differ at any point by at least 2 microvolts. The beginning and end of each region were defined as approximately the first and last latencies in that portion at which there was any visually discernable difference between ERPs in the Grand Averages. Measurements of mean amplitude were then made on individual subjects' averages between those latencies.

4.2.10 Statistical Analysis Of ERPs

Statistical evaluation of data was carried out using repeated measures ANOVA with factors of condition and site. All F ratios were were evaluated with degrees of freedom estimated from the Greenhouse-Geisser procedure for controlling Type 1 error in repeated measures designs (Keselman and Rogan 1980). Significant effects were further elucidated where necessary using the Newman Keuls test for pairwise comparisons between means and the Scheffe test for the post hoc testing of differences between pairs of means. Post hoc testing was carried out using the 5 per cent significance level.

4.3 RESULTS

4.3.1 Behavioural Data

4.3.1.1 Semantic Classification Task - Percent-correct classification performance and mean RTs to each type of word are shown in table 4:1. Analysis was carried out using repeated measures ANOVA with one factor of word type (animate and inanimate). Analysis of RT data revealed a significant effect of word type, responses being faster to animate words (F1

TABLE 4:1

Percent Correct Classification Performance and Reaction Times (msec)

		Animate	Inanimate
% Correct	Mean	96.6	93.0
	SD	2.9	6.1
RT	Mean	735.0	823.0
	SD	136.0	182.0

1,9 = 19.57 P < 0.005). Analysis of classification responses revealed no significant differences.

4.3.1.2 Recognition Memory Performance - Percent-correct recognition performance is shown in table 4:2.

TABLE 4:2

Expt 1. Recognition Performance Expressed as percentage of Old and New Words

		% of Old Words		% of New Words	
		Hits	Misses	Correct Rej	False A
Confident	Mean	44.5	9.4	35.6	7.5
	SD	17.5	7.2	16.5	8.8
Non Confident	Mean	26.2	18.9	35.8	18.8
		11.7	13.9	21.8	5.5

It can be seen from these data that subjects' correct recognition rate was high. Subjects tended to be confident when correct and less confident when incorrect.

Subjects' recognition performance analysed separately for animate and inanimate words is shown in table 4:3.

It is apparent from the table, without the need to perform statistical testing, that animate and inanimate words are equally well recognised.

TABLE 4:3

Expt 1. Recognition Performance Expressed as a Percentage of Each Kind of Word

		Con Hit	Con Miss	Non Con Hit	Non Con Miss
Animate	Mean	44.8	9.9	26.3	18.6
	SD	18.4	7.3	13.1	14.4
Inanimate	Mean	42.5	9.1	26.4	19.2
	SD	17.8	7.6	13.2	13.7

4.3.2 Electrophysiological Data

Due to the small number of confident misses and confident false alarms, averages were generated for pooled misses and pooled false alarms. One subject's data was not included in the analysis of the presentation or recognition ERPs due to an insufficient number of responses in any of the confident categories. Another subject had too many semantic discrimination task ERPs rejected because of EOG artifact for their data to be included in the analysis of ERPs recorded during the semantic discrimination task.

4.3.2.1 ERPs Averaged On The Basis Of Semantic Classification Task - ERPs generated during the semantic classification task and averaged according to subjects' classification responses are shown in figure 4:2.

No large differences between waveforms are discernible from the averages. Measurements of mean amplitude were taken for the regions 412-572 msec and 572-684 msec to see if the small differences might be important but ANOVA revealed only a main effect of recording site in both regions ($F(1.8,14.1) = 5.72$ $p < 0.05$; $F(2.3,18.3) = 9.46$ $p < 0.01$). Thus there is no indication of any significant differences between the ERPs generated by animate and inanimate words.

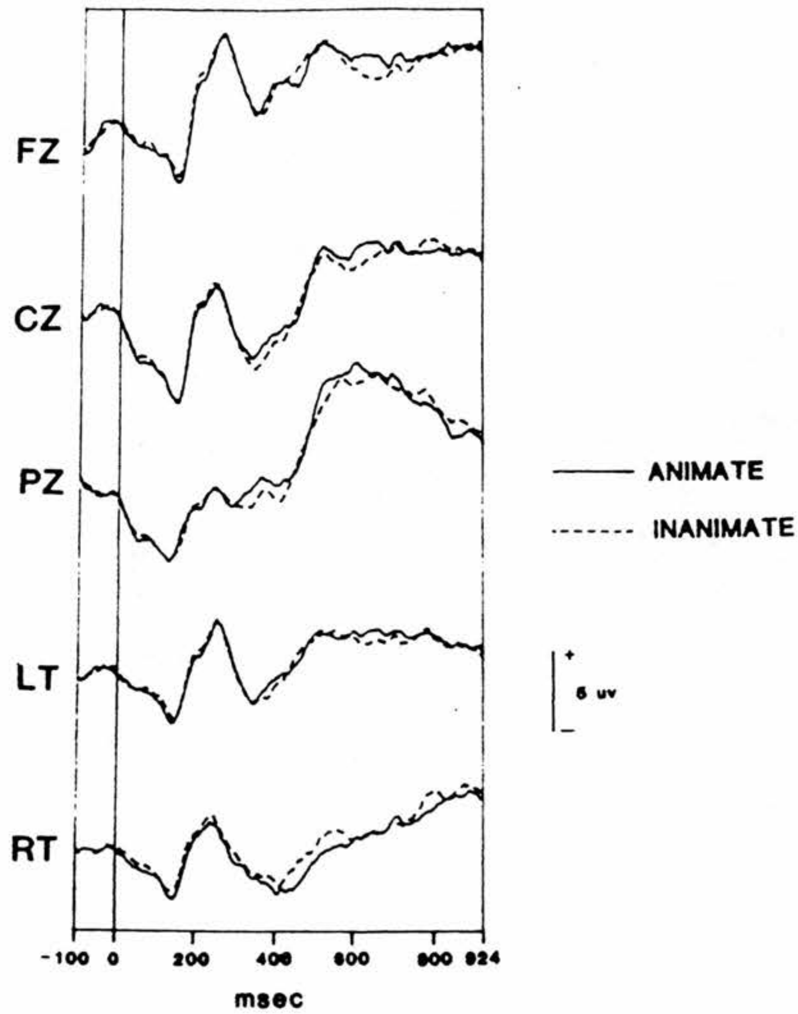

FIGURE 4:2. Grand average waveforms elicited during day 1, averaged according to the semantic class of the words (animate and inanimate) at all five recording sites; FZ = Frontal; CZ = Central; PZ = Parietal; LT = Left Temporal; RT = Right Temporal.

4.3.2.2 <u>ERPs Averaged On The Basis Of Subsequent Recognition Performance</u> - ERPs generated during the semantic classification task and averaged according to the subsequent recognition category are shown in figure 4:3.

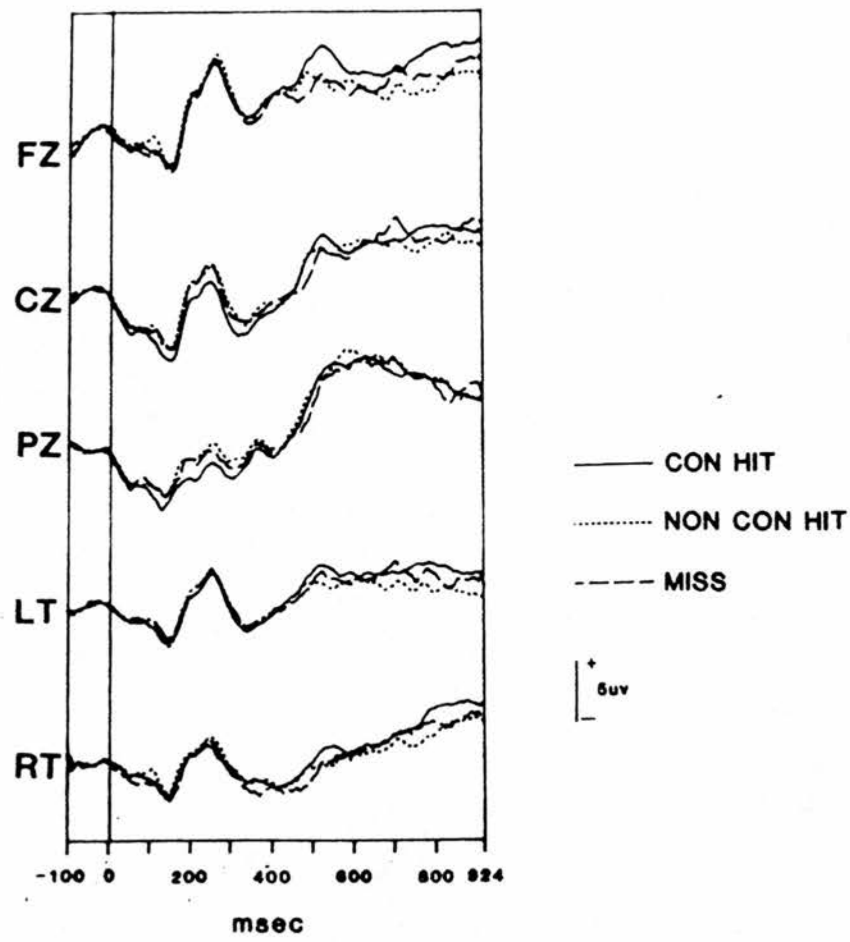

FIGURE 4:3. Grand average waveforms elicited during day 1, averaged according to the subjects' recognition performance on day 2, at all 5 recording sites. CON HIT = Confident Hits; NON CON HIT = Non Confident Hits.

Two differences between waveforms are apparent.

(i) At Cz and Pz the N100-P200 complex in the confident-hit average is of greater amplitude than the complex in the other two conditions.

(ii) Between 500-700 msec at the frontal site, the confident-hit waveform shows a larger positivity than the other two waveforms.

a) Peak Measures: Peak measures were made of N100, P200 and the Late Positive Component peaks and the mean values are shown in table 4:4.

TABLE 4:4

Expt 1. Presentation: Peak Measures (uV)

1. N1 Peak Amplitude

		Fz	Cz	Pz	LT	RT
Con Hits	Mean	-3.6	-4.8	-6.2	-3.6	-3.4
	SD	3.2	5.8	3.5	2.1	1.7
Non Con Hits	Mean	-3.4	-5.8	-4.9	-3.6	-3.2
	SD	3.9	2.9	3.1	2.7	2.3
Misses	Mean	-4.2	-5.8	-5.5	-3.6	-3.8
	SD	3.4	3.3	2.3	2.7	1.8

2. P2 Peak Amplitude

		Fz	Cz	Pz	LT	RT
Con Hit	Mean	6.8	1.8	-0.1	3.3	2.0
	SD	6.0	4.7	3.3	4.0	1.4
Non Con Hit	Mean	7.7	3.2	1.3	3.3	2.6
	SD	6.7	5.6	3.5	4.3	2.9
Misses	Mean	6.9	3.0	1.1	3.5	2.4
	SD	6.7	5.1	4.1	4.7	2.3

3. P300 Peak Amplitude

		Fz	Cz	Pz	LT	RT
Con Hits	Mean	8.6	6.2	8.5	4.3	2.2
	SD	6.7	6.2	3.5	4.0	3.7
Non Con Hits	Mean	6.6	5.7	9.1	3.3	1.5
	SD	7.6	6.6	4.7	4.0	2.9
Misses	Mean	6.0	5.9	8.7	3.7	1.9
	SD	5.2	5.1	2.9	3.5	3.6

Significant effects of recording site were found for all three peaks. ($F_{1.6,11.3} = 6.97$ $p < 0.05$; $F_{2.0,13.7} = 6.68$ $p < 0.05$; $F_{2.1,14.4} = 8.31$ $p < 0.01$ respectively).

b) Mean Amplitude Measures: Mean amplitude measures were made for three regions of the waveform, 100-300 msec, 300-700 msec and 700-924 msec. Amplitude values for these regions of the waveform are presented in table 4:5.

TABLE 4:5

Expt 1. Presentation: Amplitude Measures (uV)

1. Mean Amplitude 100-300 msec Post Stimulus

		Fz	Cz	Pz	LT	RT
Con Hits	Mean	1.8	-2.4	-2.9	-0.1	-0.5
	SD	3.1	2.7	2.3	1.9	0.9
Non Con Hits	Mean	2.4	-0.9	-1.5	0.2	0.1
	SD	4.1	3.2	2.4	2.7	1.8
Misses	Mean	1.6	-1.3	-1.9	0.2	-0.5
	SD	3.2	2.8	2.5	2.5	1.4

2. Mean Amplitude 300-700 msec Post Stimulus

		Fz	Cz	Pz	LT	RT
Con Hits	Mean	4.6	1.4	3.6	1.3	0.0
	SD	5.6	4.6	1.9	3.0	2.5
Non Con Hits	Mean	3.5	1.6	4.2	0.8	-0.5
	SD	6.7	5.5	2.8	3.5	2.8
Misses	Mean	3.2	1.3	3.5	1.0	-0.7
	SD	4.4	3.6	1.8	2.5	2.6

3. Mean Amplitude 700-924 msec Post Stimulus

		Fz	Cz	Pz	LT	RT
Con Hits	Mean	6.9	5.3	5.6	3.2	4.3
	SD	1.7	1.7	2.2	2.7	2.9
Non Con Hits	Mean	4.3	4.2	5.6	1.4	2.7
	SD	4.2	3.9	3.8	3.7	2.7
Misses	Mean	5.3	5.1	5.6	2.5	3.3
	SD	3.2	2.3	2.1	2.1	4.2

Analysis revealed only a main effect of recording site for the 100-300 msec region of the waveform ($F_{1.9,13.2} = 9.02$ $p < 0.01$). An ad hoc analysis of data from Fz only, of peak and amplitude data revealed no significant effects.

4.3.2.3 Recognition Memory Task ERPs -

ERPs generated during the recognition test and averaged according to recognition response category are shown in figure 4:4.
Quantification of data and subsequent analysis was similar to that for ERPs

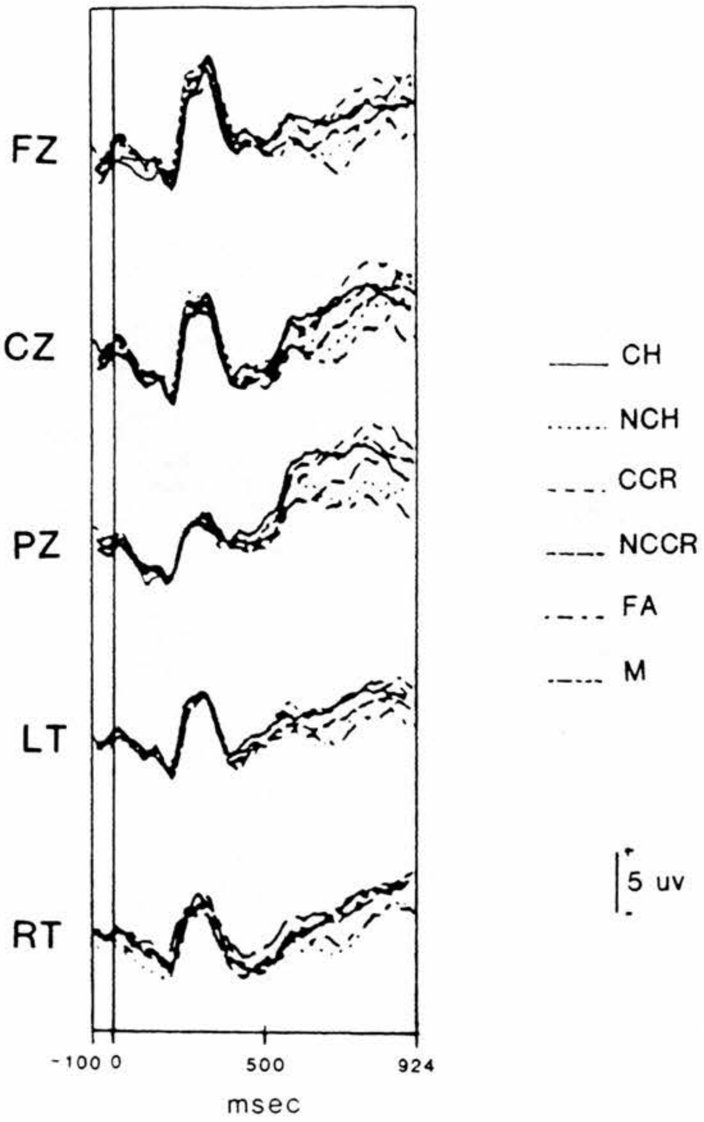

FIGURE 4:4. Grand average waveforms elicited during the recognition test and averaged on the basis of recognition category and confidence. The conditions marked are; CH = Confident Hits; CCR = Confident Correct Rejections; NCH = Non Confident Hits; NCCR = Non Confident Correct Rejections; M = Misses; FA = False Alarms.

recorded during the semantic classification task. Analysis was carried out using repeated measures ANO A with factors of condition (confident hits, non-confident hits, confident correct rejections, non-confident correct rejections, misses and false alarms) and recording site.

a) Peak measures: No single late positive component peak could easily be identified. N100, P200 and N100-P200 values (table 4:6) were entered into analysis. Significant effects of site were found for N100-P200 amplitude ($F_{1.2,9.6} = 6.51$ $p < 0.05$) and for P200 amplitude ($F_{1.7,13.4} = 6.91$ $p < 0.05$).

TABLE 4:6

Expt. 1 Recognition: Peak Measures (uV)

1. N1 Peak Amplitude

		Fz	Cz	Pz
CH	Mean	-2.4	-4.3	-4.0
	SD	2.7	2.6	3.0
NCH	Mean	-2.4	-3.3	-3.3
	SD	2.5	3.0	2.6
CCR	Mean	-3.4	-5.2	-4.1
	SD	3.1	3.3	3.4
NCCR	Mean	-3.6	-5.1	-4.2
	SD	2.7	3.3	3.7
FA	Mean	-2.7	-4.2	-3.9
	SD	2.2	2.7	3.7
MISS	Mean	-2.7	-5.0	-4.3
	SD	1.8	2.4	2.6

2. N1 - P2 Peak Amplitude

		Fz	Cz	Pz
CH	Mean	8.5	9.0	6.9
	SD	2.4	3.3	3.9
NCH	Mean	8.5	9.0	6.4
	SD	3.4	3.2	2.9
CCR	Mean	8.8	8.7	7.0
	SD	3.0	3.2	3.2
NCCR	Mean	8.3	8.4	6.4
	SD	3.0	3.6	3.1
FA	Mean	9.7	8.7	7.1
	SD	3.7	3.6	4.0
M	Mean	9.1	9.0	8.0
	SD	3.7	4.1	6.9

3. P2 Peak Amplitude

		Fz	Cz	Pz
CH	Mean	6.1	4.7	3.0
	SD	2.9	3.7	4.7
NCH	Mean	6.1	5.7	3.1
	SD	2.6	3.4	3.4
CCR	Mean	5.4	3.5	2.9
	SD	2.6	3.6	4.3
NCCR	Mean	4.7	3.2	2.2
	SD	3.5	4.4	5.2
FA	Mean	7.0	4.6	3.2
	SD	4.3	3.9	4.7
M	Mean	6.4	4.0	3.7
	SD	3.3	4.0	7.3

b) Mean amplitude measures: Measurements were taken on two portions of the waveform; 300-500 msec and 500-924 msec post stimulus. The data are summarised in table 4:7.

TABLE 4:7

Expt 1. Recognition: Mean Amplitude Values (uV)

1. Mean Amplitude 300-500 msec Post Stimulus

		Fz	Cz	Pz	LT	RT
CH	Mean	2.3	-0.7	1.6	0.0	-1.4
	SD	7.2	6.3	4.9	4.3	4.3
NCH	Mean	1.8	-1.2	0.7	0.3	-2.0
	SD	6.4	5.4	4.3	3.8	4.1
CCR	Mean	0.4	-2.6	-0.3	-0.9	-2.6
	SD	6.2	5.8	4.6	3.8	3.8
NCCR	Mean	0.5	-2.4	0.0	-1.2	-2.2
	SD	6.7	5.9	4.5	3.8	4.2
FA	Mean	1.2	-1.8	0.4	-0.5	-1.6
	SD	6.8	6.4	5.5	4.2	4.8
MISS	Mean	0.7	-2.1	0.3	-0.3	-2.0
	SD	6.4	5.9	4.7	4.0	4.3

2. Mean Amplitude 500-924 msec Post Stimulus

		Fz	Cz	Pz	LT	RT
CH	Mean	4.0	4.1	7.0	2.7	1.8
	SD	4.6	3.9	2.7	3.3	3.4
NCH	Mean	0.9	1.2	3.7	1.0	0.0
	SD	4.1	3.7	3.4	2.7	3.6
CCR	Mean	2.9	3.4	6.6	2.6	1.7
	SD	4.6	4.3	3.5	3.4	3.7
NCCR	Mean	1.8	2.1	4.8	1.6	1.4
	SD	4.4	4.1	3.6	3.1	3.7
FA	Mean	1.1	0.9	3.4	1.0	0.5
	SD	4.3	3.4	2.9	2.8	3.9
MISSES	Mean	2.7	3.1	6.4	2.9	1.7
	SD	4.9	4.7	3.7	3.4	4.4

There were two significant effects; (i) In the 300-500 msec region of the waveform, a main effect of condition was found ($F_{2.7,21.9} = 3.63$ $p < 0.05$).

Scheffe testing showed that this effect resulted from the fact that the waveforms yielded by hits, confident and non-confident, were significantly greater in amplitude than those yielded by confident and non-confident

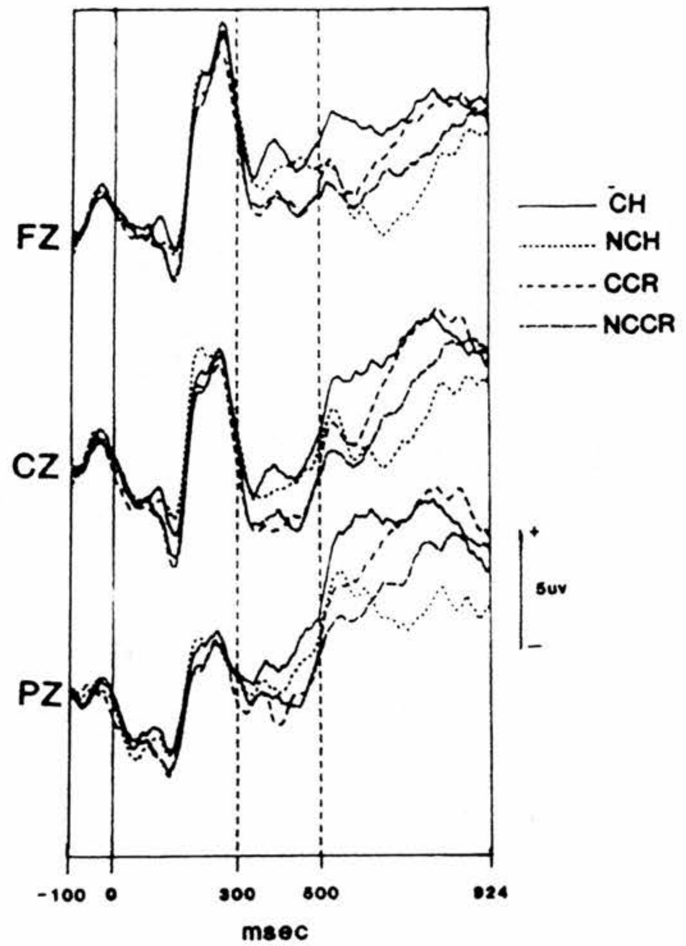

FIGURE 4:5. Grand average waveforms elicited during day 2, averaged according to recognition category, at the three midline sites only. The recognition categories marked are; CH = Confident Hits; NCH = Non Confident Hits; CCR = Confident Correct Rejections; NCCR = Non Confident Correct Rejections. The latency range in which the hits and correct rejections significantly differ is marked by dotted lines.

correct rejections. Waveforms for misses and false alarms have intermediate values. This difference is shown in figures 4:5 and 4:6.

(ii) In the 500-924 msec region of the waveform, analysis of variance revealed a main effect of condition ($F_{2.9,23.3} = 6.68$ $p = 0.005$). Scheffe tests revealed that the waveforms generated by confident hits, confident

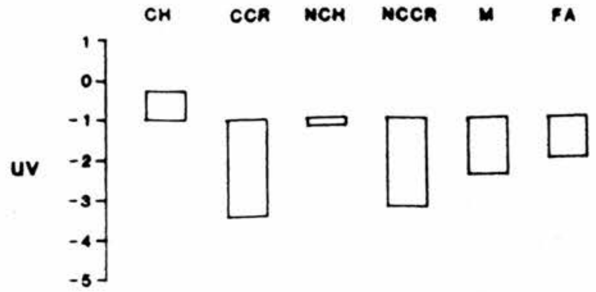

FIGURE 4:6. Histogram showing values of mean amplitude measurements across the range 300-500 msec, collapsed across all 5 recording sites. The conditions marked are; CH = Confident Hits; CCR = Confident Correct Rejections; NCH = Non Confident Hits; NCCR = Non Confident Correct Rejections; M = Misses; FA = False Alarms. ERPs generated by confident and non confident hits differed from those generated by confident and non-confident correct rejections.

correct rejections and misses were significantly more positive than those generated by non-confident hits and false alarms which showed a pronounced negativity around 600 to 700 msec. These differences are shown in figures 4:7 and 4:8.

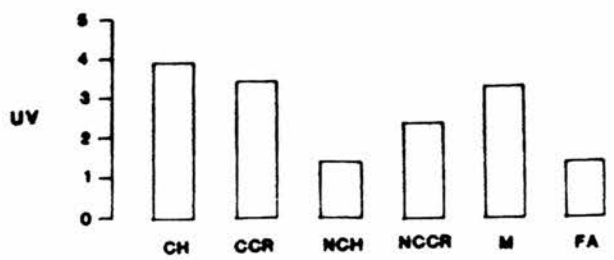

FIGURE 4:8. Histogram showing values of mean amplitude measurements across the range 500-924 msec, collapsed across all 5 recording sites. The conditions marked are; CH = Confident Hits; CCR = Confident Correct Rejections; NCH = Non Confident Hits; NCCR = Non Confident Correct Rejections; M = Misses; FA = False Alarms. ERPs generated by confident hits, confident correct rejections and misses differed from those generated by non confident hits and false alarms.

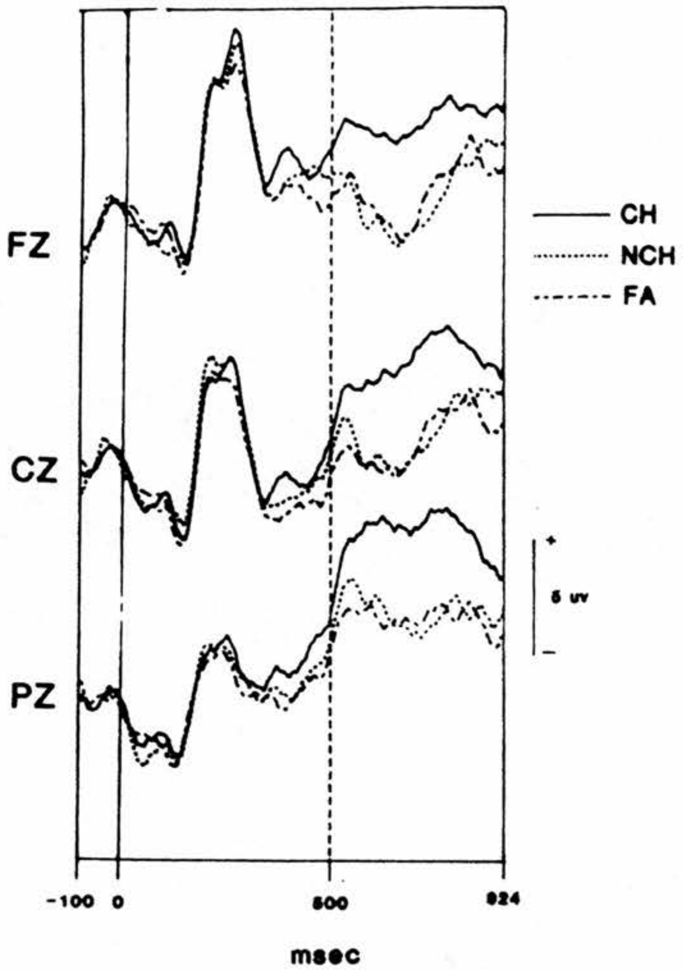

FIGURE 4:7. Grand average waveforms elicited during day 2 and averaged according to recognition category, at the three midline sites only. The recognition categories marked are; CH = Confident Hits; NCH = Non Confident Hits; FA = False Alarms. The latency range in which the conditions shown significantly differ is marked.

4.4 DISCUSSION

4.4.1 Behavioural Data

Animate and inanimate words were equally well identified but not equally quickly.

Despite the faster response to animate nouns, both types of word were equally well remembered with almost equal numbers of each type falling in the 4 response categories.

The recognition data reveal that subjects remembered about twice as many words as they forget and correctly identified as new, twice as many as they wrongly identified as old. They were more confident when correct than when they were wrong.

4.4.2 ERPs Averaged On The Basis Of Semantic Classification Task Performance

The fact that no differences were found between ERPs averaged on the basis of semantic classification task performance despite the fact that latency differences were found, may indicate that the process which resulted in a delay to respond to inanimate words were not those manifested in the ERP averages. This suggests that the reaction time difference may be due to factors other than the time taken to evaluate the stimuli (reflected by P300) and result rather from response factors. Further support for this notion arise from the finding that equal numbers of animate and inanimate words were successfully recognised which seems to imply that the delay in responding to inanimate words was not due to any difference in the degree or nature of the stimulus processing applied to the two kinds of words.

This lack of any significant difference between semantic discrimination ERPs suggests that any difference observed between presentation ERPs averaged on the basis of memory performance is not due to a difference in the way the two kinds of words are processed.

4.4.3 ERPs From Day 1 Averaged By Subsequent Recognition Category

Visual inspection of the waveforms indicates that a difference between waveforms exists frontally in the region 500-924 msec post stimulus, such that ERPs generated to words that are confidently recognised the following day are more positive in that region than those generated by words not recognised or recognised with little confidence. Such a difference is in accordance with the experimental hypothesis and with results from other laboratories. Karis et al (1984) and Fabiani et al (1986) have reported a frontal positivity elicited by the employment of elaborative processing. However, statistical evaluation of the data revealed that this putative effect was not statistically significant.

It may have been the case however, that processing which determined subsequent recognition performance occurred at least partly outside of the recording epoch, since the recording epoch lasted for only 900 msec of the 7 second interval between stimuli. It is therefore possible that processing which took place in the remaining 6 seconds contributed significantly to the later recognition of words, and was thus not indexed by the ERPs. Therefore a second experiment was designed in which the basic procedure was repeated with the difference that a cognitively demanding task was interposed between stimulus items in the semantic discrimination task, with the intention of limiting all recognition performance related processing to the recording epoch (see chapter 5).

4.4.4 Recognition Task ERPs

A number of significant differences were found between ERPs generated during the recognition part of the experiment and these can be divided into middle (300-500 msec) and late (500-924 msec) latency differences and these will be discussed separately.

Before discussing the data it is worth considering what each response category might signify in terms of the dual process model of memory. Successfully recognised words or "hits" can be thought of as words which received sufficient processing on day 1 to allow for the identification of that word as "old". Further, words are likely to be classified with a high level of confidence due to the fact that the encoding context is retrieved from memory and the subject "knows" not only that they have seen the word but that they saw it in the experimental list. This context retrieval is believed to be due to the degree of inter-item processing at presentation. In the same terms, words are identified with low confidence due to the fact that subjects feel the word is familiar but are not sure whether it was in the presentation list or not. This is thought to result from the fact that at presentation the word received only intra-item processing and that at recognition the result of such processing is recognised by a familiarity matching process. Within this theoretical context words falsely identified as old ("False Alarms") can be thought of as having been recently presented to the subject outside of the experimental context and thus having had their familiarity index incremented, or, to put in in terms of Jacoby's theory, increasing their perceptual fluency. Words classified correctly as "new" are words to which the subject has had no recent exposure. Words which are incorrectly classified as "new" (ie "Misses") may have received insufficient intra-item processing to allow them to be classified as "old".

One problem with such an account of the processes underlying the various behavioural responses is the incidence of confident false alarms, since a high level of confidence implies that not only is the word felt to be familiar but also that its context is recalled. It is therefore interesting to note in this connection that in the present study, less than 25% of false alarms are confident, which indicates perhaps, that it is difficult and unusual to make confident false alarms, as the above theory would suggest.

(A) Middle Latency Differences (300 msec-500 msec):

Between 300-500 msec post stimulus, ERPs generated by words which were confidently and not confidently recognised as "old" words differed significantly from ERPs generated by words which were confidently and non-confidently identified as "new" words. Thus, ERPs to words perceived as "old" generated greater positivity than ERPs generated by words perceived as "new". Such an effect has been shown previously by several studies (Neville et al 1986, see figure 3:13; Friedman and Sutton, unpublished data, see figure 3:16; Karis et al 1984, see figure 3:12; Johnson et al 1985, see figure 3:15; Sanquist et al 1980, see figure 3:11 - compare hits with correct rejections). Thus this effect appears to be a robust and reliable one.

The fact that the neural activation is selective for words which were correctly recognised as "old" indicates that such identification depended upon prior occurrence of the word during the semantic classification task. Such identification due to prior occurrences is most probably the result of the activation of a familiarity checking mechanism which is thought to constitute part of the recognition process. There are two reasons for believing it to be the result of this process rather than the retrieval of context.

1) if the activity were the result of the retrieval of encoding context, due to the extent of elaboration a word received, then ERPs generated by words which were non-confidently recognised (which are thought not to have received such processing) should have differed from ERPs generated by the confidently recognised words. Since this is not the case, a process common to both responses (ie familiarity checking) was probably responsible for the ERP effect.

2) The second reason is the similarity between the present results and ERP differences obtained in studies of the repetition effect. Paller et al, (unpublished data) have suggested that the repetition effect is an index of the degree of familiarity updating an item receives at first presentation and Jacoby has suggested (Jacoby and Dallas 1981) that perceptual fluency, which he posits as the underlying mechanism of familiarity updating, is the mechanism also underlying repetition effects. Both hold that recognition memory involves, in addition, the retrieval of the encoding context.

If then, ERPs generated by first and second occurrences of words in repetition tasks show similar effects to those observed here it would strongly suggest that the activation of the same mechanism (ie familiarity updating/perceptual fluency enhancement) is giving rise to the present effects.

Rugg (1985, 1986; Rugg and Nagy, in press) has reported similar results to those reported here, in studies of the ERP correlates of the repetition of words in a lexical decision task. Words were found to generate ERPs of greater amplitude when they were presented for the second time than when first presented (see figure 3:17). The present data strongly resemble Rugg's results. Both demonstrate an increased positivity to repeated words in the 300-600 msec latency range.

Such similarity raises the question of the exact nature of the present differences in the light of Rugg's suggestion that rather than reflecting an enhancement of the Late Positive Component, the data reflect the suppression of the N400 component in the case of words which have been "primed" by prior occurrence. With respect to the present data, such an interpretation would imply that the correctly identified "new" words generated an N400 component due to not having been in any way semantically primed by prior occurrence in the semantic discrimination task and that correctly identified "old" items generated activity which attenuated the N400 component. However, the interpretation of repetition related ERP effects has not been fully resolved yet and the present data do not directly bear on the issue.

Thus, to conclude, the fact that similar ERP activity is generated by both confident and non-confident hits and the similarity of these effects to those generated by repetitions, suggests that the present ERP effects reflect the activation of a "familiarity checking" process such as has been proposed by Mandler (1980). Words which had been the objects of intra-item processing during the semantic discrimination task triggered the mechanism and were identified as old.

(B) Long Latency Differences (500 msec-924 msec):

The results show that confident hits, confident correct rejections and misses generated activity which was significantly more positive than that generated by non-confident hits and false alarms. These results can perhaps best be understood as resulting from the activation of mechanisms responsible for the retrieval of the encoding context. There are two reasons for such a conclusion.

1) ERPs generated by confident hits (which are thought to result from the retrieval of context) differ significantly from ERPs generated by non-confident hits (which are thought not to depend on such retrieval).

2) False alarms, which are largely determined by the "familiarity checking" process, exhibit a similar pattern of activity to ERPs generated by non-confident hits.

It is proposed that some of the words already identified as "old" on the basis of "familiarity checking" alone (between 300-500 msec) underwent further retrieval related processing which led to their being confidently recognised and which in the ERP gave rise to enhanced positive activity. It is possible that this further processing represents the activation of mechanisms of the "search" or "recall" contribution to recognition memory.

These data are not in agreement with results from several other laboratories, which have shown a significant difference between ERPs generated by recognised words and ERPs generated by non-recognised words (Sanquist 1980, Karis et al 1984). Karis reports that P300s generated by recognised words were significantly larger than those generated by non-recognised words (see figure 3:12). Sanquist et al (1980) reported large differences between ERPs generated by hits and misses, such that the LPCs generated by hits were some 100uv larger than those to misses (figure 3:11).

Karis interprets these results in terms of both the "target" effect and the confidence of decision (see p 3-33). Such an account appears to bear little relation to the present data however, since targets in this context would be successfully recognised "old" words and non-targets would be successfully recognised "new" words (correct rejections). In this study the ERPs generated by words in these two conditions did not differ. Karis suggests further, however, that the increased amplitude of P300 components to successfully recognised words may have been due to the fact that such responses were made with a high degree of confidence. P300 amplitude has been found to increase with the confidence with which a decision is made (Hillyard et al 1971, Paul and Sutton 1972, K.C. Squires, Squires and Hillyard 1975a, 1975b). The difficulty with such an account in the present case however is that it is not clear that the enhanced positivity in the 500-924 msec region of the waveform is an enhancement of the P300 component alone. While the positivity which peaks just after 500 msec may reflect a P300 component (in that its amplitude is maximal at Pz) the enhanced positivity is sustained until the end of the epoch. This implies that the observed effect is due to a long lasting widespread positive wave beginning at approximately 500 msec which may mask the P300 component.

In conclusion, the present results indicate that words which are responded to as "old" with low confidence, on the basis perhaps of familiarity alone, generate activity which is significantly less positive than activity generated by other words responded to as "old". The greater positivity generated by confident hits, confident correct rejections and misses takes the form of a long latency positive wave which may reflect the activation of further retrieval mechanisms such as search for retrieval context. An alternative explanation is that the positivity is the result of decisions being made with high confidence. It would be helpful to conduct a study in which ERPs generated by confident and non-confident misses could be differentiated, since if the latter account were true, confident misses should produce activity significantly more positive than that produced by non-confident misses.

CHAPTER 5

EXPERIMENT 2

5.1 INTRODUCTION

Results from a number of laboratories have indicated that during presentation of stimuli, stimuli which are more easily retrieved from memory elicit ERP activity that is more positive, from about 400 msec onwards, than do stimuli not retrieved (eg Karis et al 1984, Neville et al 1986, Paller et al, unpublished data). These positivities have been distinguished on the basis of the type of encoding process performed upon words at presentation. There is some evidence that elaborative or inter-item processing gives rise to enhanced positivity at the frontal recording site (Karis et al 1984, Fàbiani et al 1986). Experiment 1 attempted to replicate such findings and to distinguish between effects related to different types of encoding, on the basis of the different confidence levels of recognition.

However, although ERPs generated by words subsequently confidently recognised appeared to be more positive than ERPs generated by other words, this effect did not reach significance. It was suggested that this may have been due to the fact that the activation of processes on which retrieval may have depended were not restricted to the period of time during which ERPs were recorded thus making it possible that retrieval-related processing may have occurred after this time and been "missed" in the ERPs. The present experiment attempted to control for this possibility by restricting the processing of stimuli to the length of time over which ERPs were recorded.

5.2 METHODS

5.2.1 Design

In this study, subjects underwent an incidental learning task. The type of encoding thought to have taken place during this was assessed by performance on a subsequent test of recognition memory. ERPs were recorded from each word during the incidental learning test and were averaged on the basis of whether each word was successfully identified or not in the recognition test, and with what degree of confidence. Processing related to subsequent recognition performance was thought to be restricted to the time over which ERPs were recorded, by ensuring that between each stimulus item, subjects were engaged in a demanding cognitive task. It was predicted that ERPs generated by words which were later recognised would exhibit enhanced positivity compared to ERPs generated by other words.

5.2.2 Subjects

The subjects were 10 right handed undergraduate students, seven of whom were females. All had normal or corrected to normal vision and none had any familial sinistrality.

5.2.3 Tasks

The kind of tasks employed were the same as used in experiment 1. Subjects firstly underwent a semantic discrimination task followed 24 hours later by a recognition memory task.

The semantic discrimination task differed from that in experiment 1 in two ways. The first was that semantic discrimination decisions alternated with a series of verification decisions. In each of these, subjects were required to verify whether a solved simple arithmetical statement was true or not. The second difference was that whereas in experiment 1, subjects were required to perform each semantic discrimination as quickly as possible, in this study, subjects were required to wait for a response prompt after each word before responding. This was to rule out any possible contribution to the ERP data of motor-related ERP activity.

The recognition test differed from that used in experiment 1 in that stimuli were not presented at a fixed rate. Presentation of each test item was triggered by a response being made to the preceding item, and thus the rate of presentation depended entirely upon the subject's rate of responding. The recognition test differed in this way because in this study, ERPs were not recorded during recognition testing, and thus there was no requirement for recognition items to be presented at a fixed rate.

5.2.4 Stimuli

The stimuli consisted of 200 animate and 200 inanimate nouns and 200 simple solved mathematical problems (eg 8 + 5 = 15) half of which were true and half false. As in experiment one, half of each type of word were randomly selected for inclusion in four presentation lists, each of which contained 25 animate and 25 inanimate nouns. The remaining 200 nouns served as distractors in the recognition test list, which was formed by adding to each presentation list the same number of animate and inanimate nouns, re-randomising item order and concatenating the resulting four lists together. Following each noun in the presentation lists a mathematical problem was inserted.

Two practice lists were also constructed, the first consisting of 20 nouns and 20 problems, acting as a "presentation" list for the 40 noun "recognition" practice list. The method of stimulus display was the same as in experiment one, but the stimulus presentation parameters differed from the previous experiment.

(i) Presentation: a fixation point was displayed for 500 msec followed 150 msec later by stimulus 1 (noun) which was displayed for 200 msec. 974 msec after stimulus 1 onset a 1 second response window began, indicated to the subject by the presentation of a response cue. 100 msec after the response window ended, stimulus 2 (problem) was displayed for 5 seconds. The next trials began as soon as stimulus 2 presentation ended. The total ISI was 7.22 seconds.

(ii) Recognition: there were no fixed parameters in the recognition stage of the experiment. The subjects were allowed to respond to each stimulus as soon after stimulus onset as they wished, and a new stimulus was presented following each response.

5.2.5 Procedure

As in experiment 1 subjects were tested on two consecutive days. On day 1 subjects were given the semantic classification and true/false discrimination tasks, and on day 2 they were given a forced choice recognition memory test.

5.2.5.1 Semantic Discrimination Task -

Following electrode application subjects were seated in front of the TV monitor with their heads supported by a chin rest and the index finger of each hand resting on the levers of two microswitches. They were informed that they were required to classify the nouns as either animate or inanimate and to classify each problem as true or false, as accurately as possible by pressing one or the other microswitch levers following the response cue. Subjects were informed of the importance of maintaining fixation and avoiding movement during the period from fixation dot onset to the offset of the response cue. Practice trials were given to the subjects before presentation of the experimental lists.

"Animate" and "true" responses were always made with the same hand and "inanimate" and "false" responses made with the other. Hand of response was counterbalanced over subjects. Presentation list order was not counterbalanced since the lists had been concatenated together to make one list.

5.2.5.2 Recognition Task -

There was no electrode application on during the recognition task and subjects were seated in front of the video monitor and told to respond at their own speed to each word by pressing one of four switches corresponding to the response categories: "confident: seen before", "not confident: seen before", "confident: not seen before" and "not confident: not seen before". Allocation of response finger was the same as in experiment 1. Hand of response was counterbalanced across subjects.

5.2.6 Behavioural Responses

No reaction times were recorded. Subjects' semantic classification responses and their recognition responses were recorded.

5.2.7 ERP Recording

ERPs were recorded to every word in the presentation list during the semantic discrimination task. No ERPs were recorded during the recognition test.

ERP montage and recording procedures were identical to those employed in experiment 1.

5.2.8 ERP Analysis

Separate averages were formed for each subject for each word category (animate/inanimate) and for each recognition response category (confident hits, non-confident hits, confident misses and non-confident misses).

5.2.9 ERP Measurements

Procedures for the measurement and statistical evaluation of ERPs were identical to those used in experiment 1.

5.3 RESULTS

5.3.1 Behavioural Data

5.3.1.1 Semantic Classification Task -

Percent-correct classification performance is shown in table 5:1.

TABLE 5:1

Expt 2. Percent Correct Classification Performance

		Animate	Inanimate
% Correct	X	94.9	92.8
	SD	1.7	4.9

Data were analysed in a repeated measures ANOVA with one factor of word type, and no significant difference was found.

5.3.1.2 Recognition Task -

All subjects expressed surprise on day 2 when informed that they would have to perform a recognition task.

Subjects' percent-correct recognition performance is shown in table 5:2.

TABLE 5:2

Expt 2. Recognition Performance Expressed as Percentage of Old and New Words

		% of Old Words		% of New Words	
		Hits	Misses	CR	FA
Confident	Mean	45.1	16.5	38.2	15.6
	SD	20.1	14.4	21.8	14.8
Non Confident	Mean	19.9	19.1	28.9	17.4
	SD	9.8	9.1	16.8	9.8

The data indicate that subjects tended to show greater confidence when correct that when incorrect.

Subjects' recognition performance, analysed separately for animate and inanimate words is shown in table 5:3.

TABLE 5:3

Expt 2. Recognition Performance Expressed as Percentage of Animate and Inanimate Words

		Con Hit	Con Miss	Non Con Hit	Non Con Miss
Animate	Mean	52.4	12.6	19.6	15.4
	SD	20.6	13.8	9.6	7.1
Inanimate	Mean	37.7	19.4	20.2	22.7
	SD	20.2	15.5	10.5	11.9

The data were entered into a two-way ANOVA with levels of word type and recognition category. Analysis revealed a main effect of recognition category ($F_{(3,27)} = 6.86$ $p < 0.005$) which was clearly due to the large number of hits relative to other categories and an interaction of recognition category with word type ($F_{(3,27)} = 22.67$ $p < 0.0001$). Scheffe testing revealed that this was due to the fact that the difference between animate and inanimate words confidently hit was greater than the difference between animate and inanimate words in any other recognition category.

5.3.2 Electrophysiological Data

5.3.2.1 ERPs Averaged According To Semantic Classification Task Performance -

The grand averages are shown in figure 5:1.

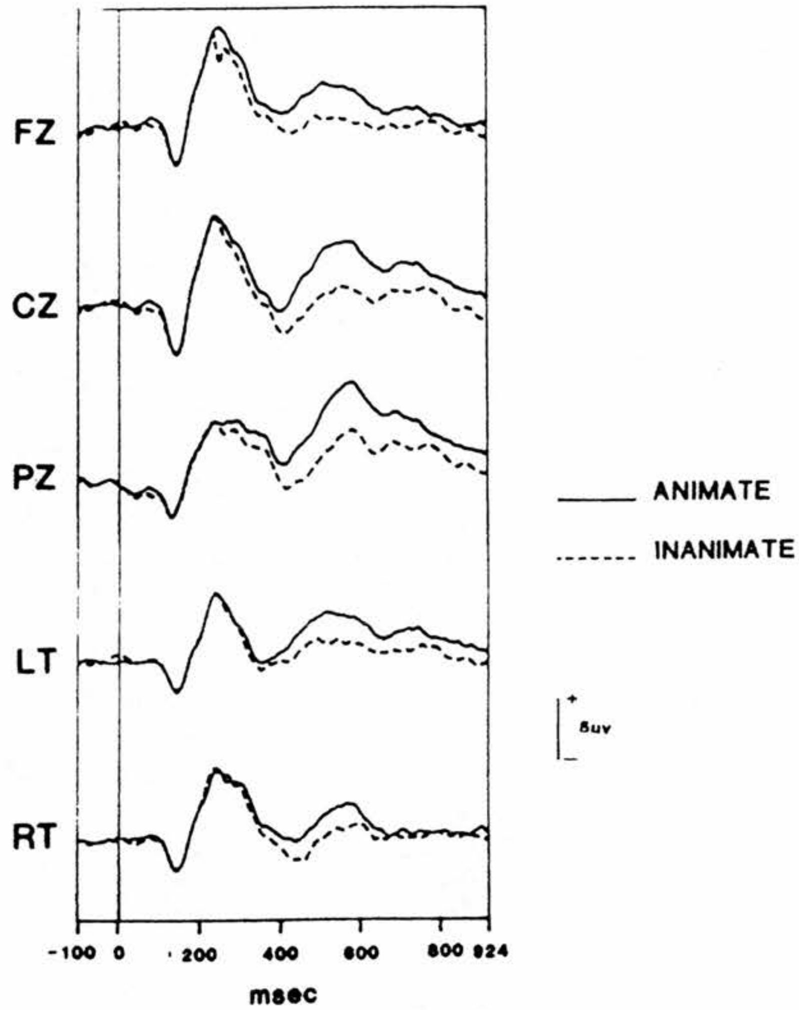

FIGURE 5:1. Grand average waveforms elicited during day 1, averaged according to the semantic class of the words at all five recording sites.

It is clear that large differences exist between the waveforms. The difference seems to have a distinct onset at about 220 msecs and seems to fall into three sections; the first beginning at about 225 msec and going on until just after 400 msec; a second, starting at just after 400 msec and going on until about 800 msec; a third, beginning at 800 msec and continuing until the end of the epoch.

Measures of mean amplitude at each of these three regions were taken (244-412 msec, 412-780 msec and 780-924 msec) (see table 5:4) and the data were entered into a repeated measures ANOVA with factors of recording site and condition.

Table 5:4 Experiment 2: Semantic discrimination task.
ERP ampltude measures (uV)

1. 244-412 msec

		Fz	Cz	Pz	LT	RT
Animate	Mean	4.52	3.43	4.34	2.15	3.18
	SD	3.45	3.12	3.27	2.28	2.37
Inanimate	Mean	3.14	2.30	3.19	1.65	2.55
	SD	3.19	3.58	3.52	2.63	2.88

2. 412-780 msec

		Fz	Cz	Pz	LT	RT
Animate	Mean	2.27	3.69	5.89	2.97	1.26
	SD	3.01	3.30	2.81	1.58	1.68
Inanimate	Mean	0.23	0.64	2.61	1.20	0.08
	SD	3.23	2.96	2.85	1.88	1.33

3. 780-924 msec

		Fz	Cz	Pz	LT	RT
Animate	Mean	0.49	1.62	3.26	1.42	0.68
	SD	4.58	5.99	4.96	2.15	2.92
Inanimate	Mean	0.32	0.21	1.67	0.17	0.36
	SD	5.50	5.85	5.30	2.44	2.59

(i) 244-412 msec: ANOVA revealed only a main effect of condition in this region, ($F_{1,9} = 7.55$ $p < 0.05$)

(ii) 412-780 msec: ANOVA revealed main effects of site ($F_{2.3,20.6} = 5.87$ $p < 0.01$) and condition ($F_{1,9} = 66.43$ $p < 0.0001$) and a site by condition interaction ($F_{2.1,18.6} = 9.72$ $p < 0.005$) in this region. Scheffe post hoc testing revealed that this interaction was due to the fact that waveform differences at Cz and Pz differed from those at Fz and both temporal sites (see figure 5:2).

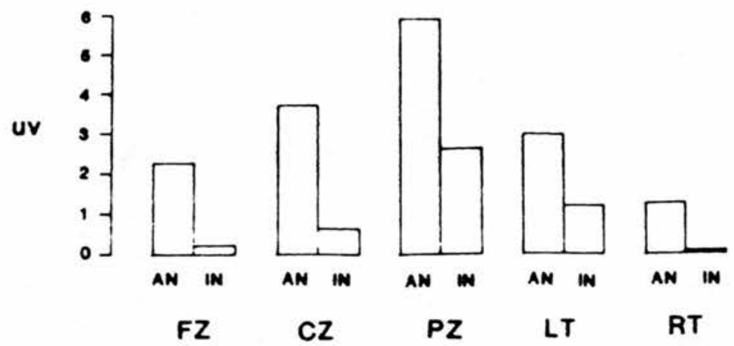

FIGURE 5:2. Histogram showing values of mean amplitude measurements of ERPs averaged according to the semantic class of words in the latency region 412-780 msec. Values for each condition at all 5 sites are shown and it can be seen that differences between conditions at Cz and Pz differ from the differences at the other sites. AN = Animate; IN = Inanimate.

(iii) 780-924 msec: ANOVA revealed only a main effect of condition in this region ($F_{1,9} = 10.72$ $p < 0.01$).

5.3.2.2 <u>ERPs Averaged According To Subsequent Recognition Memory Performance</u> -

As in experiment 1, there were too few confident misses to allow the generation of separate averages for confident and non-confident misses. Misses were pooled together and a single average ERP for misses was generated. Figure 5:3 shows the waveforms associated with the three conditions.

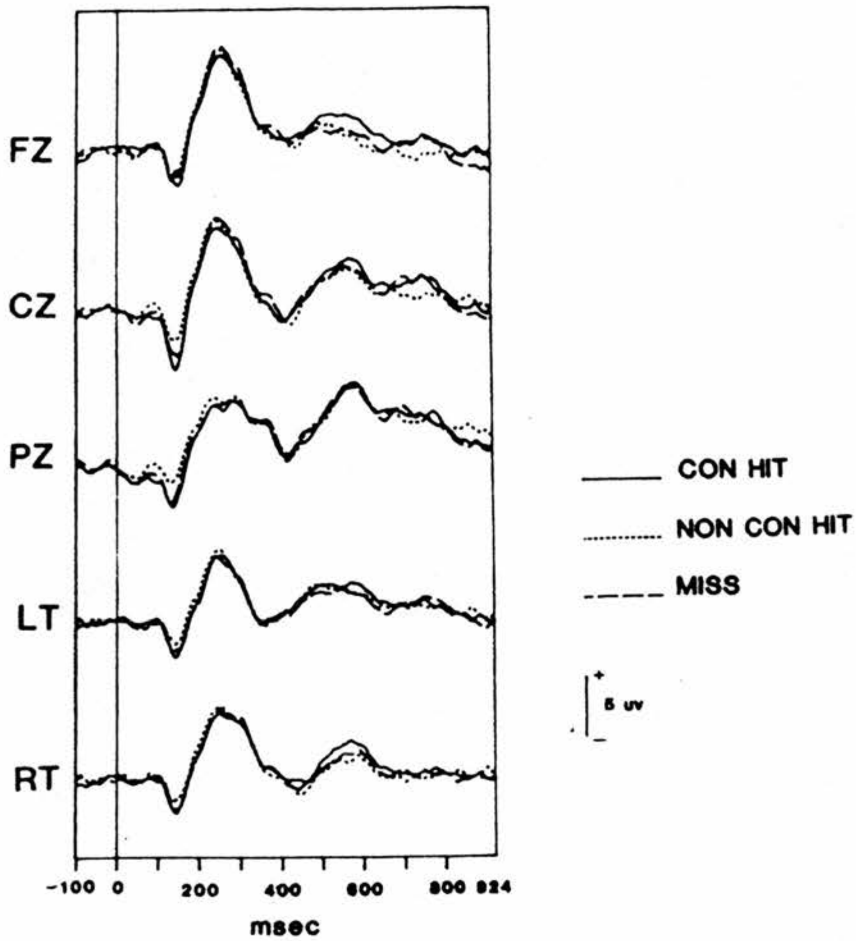

FIGURE 5:3. Grand average waveforms elicited on day 1, averaged according to the subjects' recognition performance on day 2, at all 5 recording sites. CON HIT = Confident Hits; NON CON HIT = Non Confident Hits.

It can be seen from figure 5:3 that waveforms differ in two obvious ways;

(i) the N100 component is more positive in the non-confident hit waveform than in the other two waveforms, especially at Cz and Pz.

(ii) Frontally at 400-700 msec post stimulus the confident hit waveform is more positive that the other two waveforms.

As in experiment 1, quantification of the ERP data took the form of both peak measures and the measurement of the mean amplitude in selected regions of the waveform. Three peak measures (N100, P200 and a Late Positive Component were taken and the mean amplitude of the two segments of the waveform (400-700 msec and 700-924 msec) were measured (see Tables 5:5 and 5:6).

TABLE 5:5

Expt 2. Peak Measures (uV)

1. N1 Peak Amplitude

		Fz	Cz	Pz	LT	RT
CH	Mean	-4.3	-5.6	-4.1	-3.3	-3.3
	SD	2.4	3.2	2.2	1.6	1.7
NCH	Mean	-2.7	-3.0	-1.8	-2.4	-2.5
	SD	2.4	2.7	3.1	1.7	2.3
MISS	Mean	-3.5	-4.5	-3.6	-2.9	-3.4
	SD	2.4	2.5	2.2	1.6	1.8

2. P2 Peak Amplitude

		Fz	Cz	Pz	LT	RT
CH	Mean	9.1	8.5	6.7	6.5	6.7
	SD	3.1	2.1	1.9	2.0	2.7
NCH	Mean	9.6	8.8	7.9	7.0	7.2
	SD	2.9	3.7	4.5	2.4	2.8
MISS	Mean	9.6	8.8	6.8	6.4	6.7
	SD	4.1	3.8	4.0	2.5	2.8

3. P3 Peak Amplitude

		Fz	Cz	Pz	LT	RT
CH	Mean	3.9	5.8	7.6	4.4	3.6
	SD	3.8	2.1	2.4	2.6	3.1
NCH	Mean	4.0	5.2	8.4	4.4	3.0
	SD	4.7	3.1	3.6	2.7	2.4
MISS	Mean	2.9	4.6	7.8	3.6	3.3
	SD	4.3	2.4	2.6	2.8	2.2

(i) Peak measures: ANOVA of N100 peak amplitude data revealed only a main effect of condition ($F_{(2.0, 17.7)} = 3.64$ $p < 0.05$). ANOVA of LPC peak amplitude across all 5 sites revealed a main effect of recording site (F

1.9,15.5 = 7.15 p < 0.01).

TABLE 5:6

Expt 2. Area Measures (uV)

1. 400-700 msec Mean Amplitude

		Fz	Cz	Pz	LT	RT
CH	Mean	1.7	2.1	4.2	2.5	1.3
	SD	2.7	2.5	2.4	1.9	1.8
NCH	Mean	1.0	1.7	4.5	2.0	0.4
	SD	3.7	3.5	3.7	2.2	1.8
MISS	Mean	0.6	1.5	4.1	1.7	0.3
	SD	3.4	2.5	2.4	2.3	2.3

2. 700-924 Msec Mean Amplitude

		Fz	Cz	Pz	LT	RT
CH	Mean	0.7	1.6	3.1	1.2	0.6
	SD	4.7	5.7	5.2	2.1	2.7
NCH	Mean	-0.3	1.0	3.4	0.8	0.2
	SD	6.5	7.1	5.8	3.2	3.8
MISS	Mean	-0.5	0.7	3.0	0.9	0.1
	SD	4.0	4.8	4.2	2.1	2.2

Since visual inspection of the data indicated that the LPC peak differed according to recognition category at the frontal site, analysis was conducted on the data from Fz alone. This revealed a main effect of condition (F 1.3,10.3 = 6.0 p < 0.05).

(ii) Mean Amplitude Measures. Mean amplitude measures were taken from two regions of the waveform, 400-700 msec and 700-924 msec. ANOVA of these data revealed no significant effects.

5.4 DISCUSSION

5.4.1 Behavioural Data

Animate and inanimate words were equally well identified although there is a tendency in the data towards better performance for animate words. This may be related to the finding that unlike experiment 1, more animate words were correctly recognised than inanimate.

5.4.2 Semantic Classification ERPs

The results show large differences between the two conditions at all three regions from which measurements were taken. It is clear that these data are very different to those obtained in experiment 1 where no differences between ERPs generated by animate and inanimate words were found. Since very similar results to the present data were obtained in experiment 3, full discussion of the causes of these differences and their implications for possible memory-related effects will be reserved until the discussion of experiment 3 (chapter 6).

5.4.3 ERPs Averaged On The Basis Of Subsequent Recognition Performance

5.4.3.1 N100 Differences -

Analysis of the data indicates that the peak amplitude of N100 components elicited by confident hits and misses is larger than the amplitude of N100 components elicited by non-confident hits. It is not clear what this may reflect although differences in negativities at this latency are often thought to represent differential activation of attentional or trace-matching processes (eg. the Nd wave, Hillyard and Picton 1979, Naatanen 1975; target selection negativities, Harter and Previc 1978, Aine and Harter 1984a, 1984b; The Na wave, Ritter et al 1982;

The N200 wave, Snyder and Hillyard 1976, Naatanen 1978, 1980). The difficulty with such an account in the present data is that the conditions which might be expected to share the same level of attention ie confident and non-confident hits generate different N100 potentials. At present, there seems to be no adequate explanation of why words subsequently easily recognised and not recognised at all should receive different attentional/matching processing to words less easily recognised.

5.4.3.2 Differences At 600 Msec Post Stimulus -

In the light of our experimental hypothesis the most important finding of this experiment was a difference, frontally, in LPC amplitude between the waveform generated by confident hits and those generated by misses and non-confident hits. It must be noted however that this is only significant when the other four sites are excluded from the analysis and that even then it is only significant at the 5% level. It is unclear from these rather tentative differences whether or not the conclusion drawn from experiment 1, that effects may have been present but "missed" by ERPs, was correct. To some extent, limiting the processing period has given rise to an effect which, at Fz alone, reaches significance. However it is not clear that this is an effect that was previously occurring over a longer period of time much of which was missed by the ERPs, or whether it is the same kind of frontal difference seen in experiment 1, but which due to some unspecified difference between studies, reaches significance. This question cannot be resolved from the present data.

On the basis of an observed effect in experiment 1 and on the basis of stronger effects in other studies (Karis et al 1984, Fabiani et al unpublished data) it is tentatively concluded that the present data reveal evidence of a memory-related difference between ERPs recorded during the presentation of words. In view of the fact that ERPs have been shown to distinguish between different encoding processes (Paller et al, unpublished data), it is worth considering whether the present effect reflects either of the two processes thought to be responsible for these previously observed effects. It was suggested in the introduction that the distinction between confidence levels should distinguish between encoding processes due to the fact that a word "confidently hit" is thought to reflect inter-item, elaborative encoding processes at presentation, while a word "non-confidently hit" is thought to reflect intra-item processing at presentation. On this basis the observed difference between ERPs may reflect the activation of "elaborative" processing conducted upon "confidently hit" words. In this connection, the data of Karis et al (1984) and Fàbiani et al are of particular interest since they also recorded frontal ERP differences between memory conditions, which they interpreted to reflect the selective activation of elaborative processing. The present data differ however from the results of Paller et al, (unpublished data) and Neville et al (1986) who report finding ERP correlates of elaborative processing which occur equally at all three midling sites. At present, the reason for this discrepancy is unclear. The issue will be discussed further following experiment 3.

Although the present study has provided some evidence for a possible frontal ERP correlate of elaborative encoding the effect is not very large. In view of the data from other laboratories which indicate large processing-related differences (Karis et al 1984, Neville et al 1986, Paller et al, unpublished data) it is important to try to discover why in the present study these differences were much weaker, if they exist at all. One important difference between the present study and those of Karis et al (1984), Fabiani et al (1986) and Paller et al, (unpublished data), is that these studies used recall as an index of retrieval whereas in the present study recognition was used. Words which are recalled are likely to have received more elaborative processing than words recognised in a recognition test, which may be recognised on the basis of familiarity only. It had been thought that the difference in confidence levels of recognition decision may have distinguished between encoding processes so that words recognised with a large degree of confidence could be thought to have received more elaborative processing than other words. Since this is reflected in the ERPs only weakly, it is possible that recognition with high confidence is not as good a test purely of elaborative encoding as recall is. There may be a quantitative difference between ie it is possible that more of the words in a "confidently recognised" category are so classified due to a strong familiarity response, than words in a "recalled" category, where "familiarity" will presumably have made very little contribution.

This fails however to explain the results of Neville et al (1986) who showed large memory-related ERP effects basing their averages on performance in a forced-choice recognition test. The major difference between their study and the present one is that the lag between presentation and recall differs in the two studies. In the present one recognition occurred 24 hours after presentation, whereas in Neville's study recognition occurred shortly after the presentation task. The short space of time between presentation and test is likely to ensure that many more words are recognised on the basis of familiarity alone than on elaborative processes, since it is proposed (Mandler 1980) that the effects of familiarity incrementing and checking are transient, and the strength of such encoded representations of the physical features of the item is related to how recently they were established (Jacoby and Dallas 1981). It is possible that in Neville et al's experiments, the category "recognised" contained more words processes at an intra-item level than does the "confidently recognised" category in the present experiment. The ERP correlates of such intra-item processing may then mask any inter-item ERP effects which may also have been present. It is interesting in this connection that the effects reported by Neville et al are reflected at all three midline sites whereas the "elaborative" effect observed by Karis et al and by Fabiani et al was only seen frontally.

In conclusion, the present study has indicated that ERP correlates of inter-item processing may be manifested frontally, taking the form of an enhanced positivity of the LPC generated by words processed at such a level. The possibility has been raised that this is the same effect as has been reported by another laboratory (Karis et al 1984, Fabiani et al 1986), but that it is considerably smaller due to the fact that recognition with high confidence is a poorer index of purely elaborative processing than recall. A further experiment was therefore conducted, in which the present incidental learning paradigm was retained but retrieval tested by means of free recall. It was expected that if the effects reported in the present study were reliable and the interpretation correct, the frontal effect should be considerably enhanced in the next study (see chapter 6).

CHAPTER 6

EXPERIMENT 3

EXPERIMENT 3

6.1 INTRODUCTION

In the previous two experiments (chapters 4 and 5), evidence was obtained which suggested that Late Positive Components (LPCs) generated by words presented in a semantic discrimination task which were subsequently correctly recognised, were more positive at the frontal recording site, than LPCs generated by words not recognised or recognised with little confidence. These data were thought to reflect the activation of cognitive inter-item, elaborative processes involved in the encoding of stimuli and to be the same as effects observed by Karis et al (1984) and Fabiani et al (1986).

Two questions remained unresolved however. Firstly, it was not clear why the effects seen in experiments 1 and 2 were much smaller than those observed in the studies of Karis et al and Fabiani et al. Secondly, there was a discrepancy between these data and data from other laboratories indicating that elaborative processes generate ERPs of enhanced positivity at all midline recording sites (Paller et al, unpublished data, Neville et al 1986).

In answer to the first of these problems, it was tentatively suggested that recall performance, which was used by Karis et al and Fabiani et al as their index of retrieval, was a better index of the degree of elaborative processing words received at presentation than were confident recognition decisions. This implied that ERPs generated by words later recalled should more accurately reflect the activation of such processes that ERPs generated by confidently recognised words. To test if this was why effects seen in experiments 1 and 2 were comparatively small, the present study was conducted, in which the same presentation paradigm was utilised but a recall test replaced the forced-choice recognition test used in the previous experiments.

It was thought too, that such a design might cast light upon the relation of above frontal "elaborative" effects to the data of Paller et al (1986) and of Neville et al (1986), suggesting that effects arising from enhanced elaborative processing were present at all three midline sites. If a frontal positivity to retrieved words was replicated using the present design it would suggest that the more widespread effects observed by other laboratories may be due to factors other than the degree of "elaborative" processing employed.

Another factor which may have contributed to the apparent contradiction between experimental results is that the recording epoch used in experiments 1 and 2 (924 msec post stimulus) was considerably shorter than that used in similar studies, some of which have recorded EEG activity for as long as 1400 msec post stimulus. It is possible that late memory-related effects reported by other researchers (eg Friedman and Sutton, unpublished data) may have been missed in experiments 1 and 2 due to this difference in recording epoch length. In the present study the recording epoch was extended to 1436 msec post stimulus.

6.2 METHODS

6.2.1 Design

In this study subjects underwent, firstly, a semantic decision task, followed by a test of free recall. ERPs were recorded to words presented during the discrimination task and averaged on the basis of performance on the following free recall test. The experimental hypothesis was that the previously reported enhancement of positivity at the frontal site to confidently recognised words should be larger in the present experiment.

6.2.2 Tasks

The semantic discrimination task and the arithmetical "filler" task employed in this study were identical to those employed in experiment 2. Following each presentation list, subjects were engaged in mental arithmetic for 5 minutes to ensure that only long memory encoding was tapped in the retrieval test. This consisted of a series of tasks such as counting backwards in steps of 8 from 300. Following this, the subjects were asked to write down on paper as many words as they could remember from the preceding presentation list. Subjects were given 15 minutes to do this during each recall session.

6.2.3 Subjects

The subjects were 12 right handed undergraduate students, 8 of whom were female. All had normal or corrected to normal vision and none reported any familial sinistrality.

6.2.4 Stimuli

The stimuli consisted of 200 animate and inanimate nouns and 200 simple solved arithmetical problems. Four presentation lists were made up each consisting of 25 animate and 25 inanimate nouns. Following each noun a mathematical problem was inserted. A practice list of 20 nouns and 20 problems was also generated.

The method of stimulus presentation was identical to that used in experiments 1 and 2 but the presentation parameters differed in certain respects. A fixation point was displayed for 500 msec, and 150 msec later stimulus 1 (a noun) was presented for 200 msec. 1436 msec after Stimulus 1 onset, a 1 second response window began, indicated to the subject by the presence of a response cue. 100 msec after the response window ended

Stimulus 2 (a mathematical problem) was displayed for 5 seconds. The next trial began as soon as Stimulus 2 presentation ended. The total ISI was 8.2 seconds.

6.2.5 Procedure

All testing took place in one session lasting approximately 2 hours.

Following electrode application, subjects were seated in front of the TV monitor with their heads supported by a chin rest, the index finger of each hand resting on the levers of two microswitches. They were informed that they were required to classify the nouns as either animate or inanimate by pressing one or other microswitch lever as accurately as possible following the response cue and to classify each problem as true or false as fast and as accurately as possible by pressing one or other of the microswitch levers. Subjects were informed of the importance of maintaining fixation and avoiding movement during the period from fixation dot onset to the offset of the response cue.

"Animate" and "true" responses were always made with the same hand and "inanimate" and "false" responses were made with the other. Hand of response and presentation list order were counterbalanced across subjects.

The subjects were shown four presentation lists. Following each list they were engaged in mental arithmetic for approximately 5 minutes. Following this the subjects were asked to write down all the words they could remember from the preceding list in any order and to indicate beside each, whether they were absolutely certain, fairly certain, or unsure (by marking a 1, 2 or 3 respectively) that the words had been in the list. Subjects were given 10 minutes to complete this task. The next presentation list was presented immediately afterwards.

Subjects were told that each list would be followed by a recall test but were urged to concentrate upon the classification task and not consciously try to remember the stimuli.

6.2.6 Behavioural Responses

Subjects' semantic classification and recall performance was recorded. Only correctly recalled words about which subjects were very or fairly certain were counted in the "recalled" category. This was done to rule out of the analysis ERP correlates of guesses which it was thought would constitute the "unsure" category.

6.2.7 ERP Recording

ERP recording montage was identical to that employed in experiments 1 and 2. Recording procedures differed from previous experiments in that EEG was sampled on-line at a rate of 1 point per 6 msec starting 100 msec before stimulus onset and continuing for 1536 msec thereafter. All other procedures were identical to those employed in experiments 1 and 2.

6.2.8 ERP Analysis

Separate averages were formed for each subject for each word category (animate/inanimate) and for each recall response category (recalled and not recalled).

6.2.9 ERP Measurement And Statistical Evaluation

The principals of ERP measurement and methods of statistical analysis used, were identical to those used in experiments 1 and 2.

6.3 RESULTS

6.3.1 Behavioural Data

6.3.1.1 Semantic Classification -

Performance on the semantic classification task is shown in table 6:1.

Table 6:1
Experiment 3: Percent Correct Semantic Classification Performance.

		Animate	Inanimate
% Correct	Mean	81.5	80.6
	SD	20.3	22.5

Subjects distinguished animate and inanimate words equally well.

6.3.1.2 Recall Performance -

Table 6:2 shows the overall free recall performance expressed as a percentage of all words presented.

Table 6:2
Experiment 3: Recall performance for each subject expressed as the percentage recalled of the total number of words shown to each subject.

Subject		Percentage
1		19.0
2		18.5
3		12.0
4		16.0
5		20.5
6		15.5
7		28.5
8		18.5
9		58.0
10		19.0
11		16.0
	Mean	22.0
	SD	12.6

It was also found that the majority of recalled words were recalled with high confidence and there were very few "fairly sure" or "uncertain" responses.

Table 6:3 shows the relative contribution of animate and inanimate words to the total recalled. Approximately twice as many animate words were recalled as inanimate.

Table 6:3
Experiment 3: Relative contributions of animate and inanimate words to total recalled words.

	Animate	Inanimate
Mean	68.0	32.0
SD	9.8	9.8

6.3.2 Electrophysiological Data

6.3.2.1 Semantic Discrimination -

Grand averages of ERPs averaged on the basis of the semantic discrimination task are shown in figure 6:1. It can be seen that, as in experiment 2, ERPs elicited by inanimate words were of greater amplitude than were ERPs elicited by inanimate words.
These differences occur at two regions. The first, occurring predominantly at Pz, consists of differences starting as early as 100 msec and continuing until about 420 msec. The second, consist of a difference between waveforms beginning at about 520 msec and continuing to the end of the epoch. Amplitude measures were taken from these two regions of the waveforms (100-426 msec and 522-1050 msec) and the data entered into a two way ANOVA with factors of condition and site (table 6:4).

(i) 100-426 msec: No significant results were found in this region.

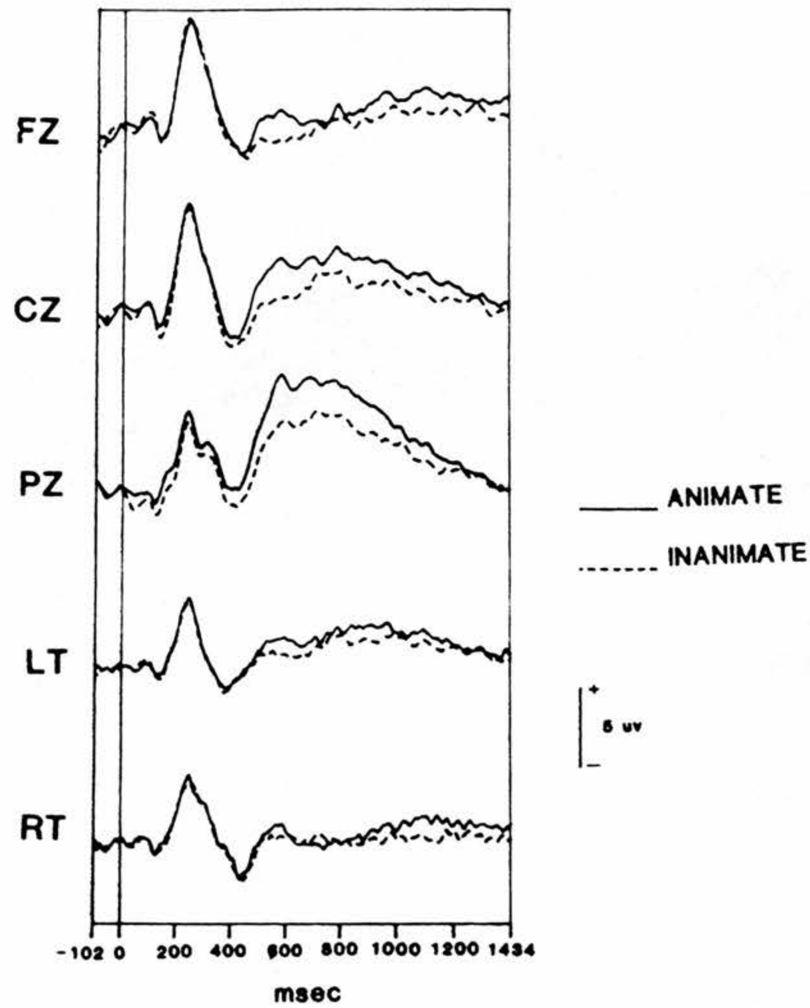

FIGURE 6:1. Grand average waveforms of ERPs averaged according to semantic class of words, animate and inanimate, at all 5 recording sites.

Table 6:4
Experiment 3: Semantic Discrimination Mean Amplitude Measures (uV)

1. 100-426 msec

		Fz	Cz	Pz	LT	RT
Animate	Mean	2.39	2.06	1.92	0.95	1.28
	SD	2.28	2.63	3.05	1.36	1.60
Inanimate	Mean	2.41	1.58	1.04	0.82	1.15
	SD	2.15	1.99	2.87	0.94	1.00

2. 522-1050 msec

		Fz	Cz	Pz	LT	RT
Animate	Mean	1.32	3.41	6.22	2.26	0.60
	SD	3.66	4.47	3.60	2.86	2.52
Inanimate	Mean	0.40	1.76	4.07	1.53	0.34
	SD	3.25	3.69	3.61	1.90	1.76

(ii) 526-1050 msec: Analysis of the amplitude values from this region revealed main effects of condition ($F_{1,9} = 7.48$ $p < 0.05$), site ($F_{2.3,20.5} = 6.1$ $p < 0.01$) and a significant interaction of site by condition ($F_{2.4,21.5} = 3.96$ $p < 0.05$). These results indicate that the differences in this region are significant at the three midline sites only. Post hoc analysis using the Scheffe test confirmed this was the case (see Figure 6:2).

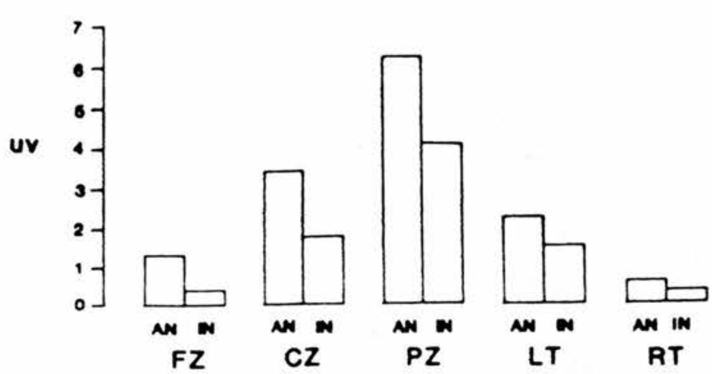

FIGURE 6:2. Histogram of the values of mean amplitude measurements in the latency range 522-1050 msec for ERPs averaged on the basis of semantic discrimination. Values for each condition at all 5 sites are shown.

These differences are very similar to those found in experiment 2. The results from the semantic discrimination tasks from all three experiments will be discussed below.

6.3.2.2 <u>Subsequent Recall Performance</u> -

EXPERIMENT 3

The grand averages of the ERPs averaged on the basis of subsequent recall are shown in figure 6:3.

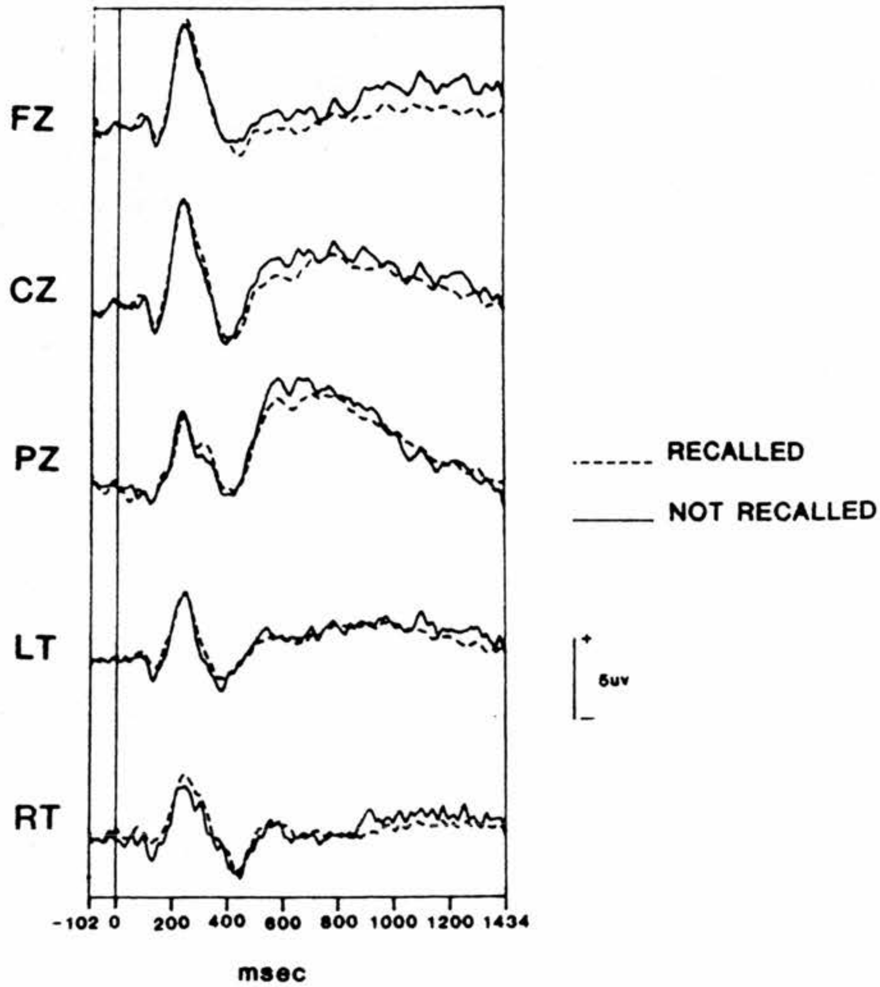

FIGURE 6:3. Grand average waveforms of ERPs averaged according to subsequent recall performance, at all 5 sites.

The differences between waveforms appear to fall into two parts, the earlier difference extending from 400-750 msec and the later difference (predominantly frontal) from 800 msec until the end of the epoch. Amplitude measures were taken from these two regions (table 6:5) and entered into repeated measures ANOVA with factors of recording site and condition.

Table 6:5
Experiment 3: Mean amplitude measures of ERPs averaged according to recognition category.(uV)

1: 400-750 msec

		Fz	Cz	Pz	LT	RT
Recalled	Mean	0.60	2.29	5.06	1.32	0.21
	SD	3.77	3.80	3.01	3.23	3.50
Not Recalled	Mean	0.38	1.42	4.23	1.05	0.03
	SD	3.21	3.68	3.61	2.15	2.62

2: 864-1428 msec

		Fz	Cz	Pz	LT	RT
Recalled	Mean	2.73	2.13	2.18	2.12	1.35
	SD	4.46	3.51	2.39	2.86	1.83
Not Recalled	Mean	1.16	1.51	2.30	1.59	0.71
	SD	3.49	3.75	2.65	1.66	1.75

(i) 400-750 msec: ANOVA revealed a main effect of recording site only ($F_{2.4,22.0} = 8.13$ $p < 0.005$).

(ii) 864-1428: ANOVA revealed only a main effect of condition ($F_{1,9} = 5.22$ $p < 0.05$). The ERPs elicited by words which were subsequently recalled were of greater amplitude than of those elicited by words which were not recalled, in the later region of the waveform. Although there was no significant interaction of condition by site it appears from inspection of the averages that this effect is maximal frontally. An analysis of Fz amplitude data alone from this region revealed a significant effect of condition ($F_{1,9} = 5.65$ $p < 0.05$).

6.4 DISCUSSION

6.4.1 Semantic Discrimination Task

In both this experiment and the previous one, large differences were observed between ERPs elicited by animate and inanimate words. These results indicate that subjects processed animate and inanimate words in different ways. One possible explanation of this processing difference is that subjects may have taken animate words to be a "correct" or "yes" response and inanimate words to be a "wrong" or "no" response (Craik and Tulving 1975). This would correspond with the fact that recall of animate words was better than that of inanimate words since a number of studies have reported that words eliciting "yes" or "correct" responses are better recalled than those eliciting "no" responses (Craik and Tulving 1975, Eysenck and Eysenck 1979, Schulman 1974). The present data may reflect ERP correlates of such a difference in processing.

This raises the question however, of why no such differences were seen in the data from the semantic discrimination task in experiment 1. It is possible that in experiment 1, the stimuli were not treated in the way described above. Only in experiments 2 and 3 are there differences in the number of animate and inanimate words retrieved from memory, and thus in both experiments where ERP differences were seen, animate words were better retrieved than inanimate words. Since processing animate words as "correct" and inanimate words as "incorrect" is thought to correlate with improved recall for the "correct" words, and since in experiment 1 no such retrieval advantage for animate words is found, it is suggested that in the semantic discrimination task in experiment 1 subjects did not view animate words as "correct" or inanimate as "incorrect" responses. It is not clear why such a difference should exist. The only difference between the tasks was that in experiment 1, responses were speeded and RTs measured, whereas in experiments 2 and 3 they were not. It is possible that under the constraints of making decisions as quickly as possible subjects adopted a different strategy for discriminating between words than the one used in the delayed response paradigm. What this alternative strategy may be is unclear.

The relation of these semantic discrimination task ERP effects to the retrieval based effects is also uncertain. However, since twice as many animate words were recalled as inanimate words, and ERPs generated by animate words were significantly more positive than those generated by inanimate words, the possibility that the observed memory-related effects may be due simply to these discrimination effects cannot be ruled out. This does not necessarily mean that the memory-related effects have therefore nothing to do with encoding processes, since some researchers have argued that the enhanced recall of "yes" items is due to the greater degree of elaborative encoding performed upon those items (Craik and Tulving 1975, Schulman 1974).

6.4.2 Subsequent Recall

Differences between waveforms were observed in the later region of the waveform (864-1428 msec). In view of the fact that the experiment attempted to manipulate the degree to which the averages of ERPs generated by retrieved words included words which received elaborative or inter-item processing, it is suggested that the greater amplitude generated in this region by words later recalled reflects the activation of an elaborative processing system.

These data correspond well with those reported by Karis et al (1984) and Fàbiani et al (1986) in which words thought to have received elaborative processing generated ERPs which were more positive between 300 and 1300 msec post stimulus at the frontal recording site (see figure 3:5). It is therefore possible that the present results reflect a single ERP difference extending from 400 msec to 1434 msec post stimulus, although analysis of the earlier region did not show that the waveforms differed significantly. Whatever the form of the effect, it is proposed that the present effect reflects the fact that, at presentation, words which later were recalled received inter-item processing in addition to intra-item processing, and that the enhanced ERP positivity reflects the activation of this additional inter-item processing.

The present data seem to indicate that recall is a better indicator of the type of processing received at presentation than is recognition decision confidence. It had been proposed that words confidently recognised were, like recalled words, words which had received both types of processing at presentation, but the differences between the results from the present experiment and those from experiments 1 and 2 indicate that words may have been confidently recognised due to having received familiarity incrementing of such a degree that they were recognised with confidence. This implies that confidence level is possibly not as good a way of distinguishing between the type of processing undertaken at presentation, as had been supposed. It appears that items which are strongly familiar may be responded to with a high degree of confidence, even though the encoding context has not been retrieved from memory. It would be more useful in the future therefore to utilise tests which are tests specifically of implicit and explicit memory (eg tests of the repetition effects and recall respectively).

The present results differ, however, from data obtained in another study using just such a test of explicit memory. Paller has reported finding memory-related ERP differences at the three midline recording sites. These take the form of enhancements in the LPCs of these ERPs (see figure 3:10). He has concluded that these effects are due to activation of elaborative encoding processes for the same reasons outlined here, ie, that words subsequently recalled receive both intra- and inter-item processing, unlike words not recalled, which receive only intra-item encoding. An important difference between the present study and that of Paller et al is that his study utilised cued recall. The first three letters of each word were used as the cues. In such a design it is possible for recognition factors based on intra-item processing to play a large part in retrieval performance. Words stems could generate any of 5 possible words. Familiarity associated with the one previously presented could allow a correct recall response to be made, without implicating the activation of inter-item processing. Thus the test Paller used, in which part of the target word is re-presented as the cue, is not necessarily a test of explicit memory involving the retrieval of the encoding context. A test involving free recall, as in the present study and that of Karis et al (1984) would be more likely to obtain differences on the basis of explicit memory activation.

The results of Neville et al (1986) are also at variance with the present data since they too have reported that ERP effects related to elaborative processing are manifest at all three midline sites. However, since the retrieval test used in this study was a forced choice recognition memory test with no use of confidence categories, such an inference as to the nature of the encoding differences seems unwarranted. As has been pointed out above (chapters 2 and 3) performance on recognition memory tests depends both on intra-item and inter-item processing and ERPs generated on the basis of subsequent recognition performance are likely to manifest activity associated with both types of encoding process. The results of these studies are further discussed in chapter 8 in which some synthesis from the several studies investigating ERP correlates of encoding processes is attempted.

In conclusion, the present study has provided evidence for the existence of ERP effects which are related to the activation of elaborative or inter-item processing at presentation as distinct from the activation of intra-item processing. These differences took the form of an enhancement of positivity in ERPs generated by recalled words, occurring only at the frontal recording site, from about 800 msec until the end of the epoch. These results will be discussed further in chapter 8.

CHAPTER 7

<u>EXPERIMENT 4</u>

7.1 INTRODUCTION

In experiment 1 it was suggested that differences between ERPs recorded during the recognition test, observed at 300-500 msec post stimulus reflected the activation of a "familiarity checking" process which is thought to contribute to the recognition process. Such activation, it was suggested, was marked by increased positivity relative to activity generated by items for which no such processing took place. The activation of such a process was thought to underlie similar findings in studies of ERP correlates of repetition effects (Rugg 1985). Such activation may well contribute to other observed memory-related effects in ERPs recorded during retrieval (Karis et al 1984, Sanquist et al 1980, Neville et al 1986, Friedman and Sutton 1986, Johnson et al 1985).

The other major process thought to contribute to recognition memory is that of "retrieval of encoding context" (Jacoby and Dallas 1981). It was suggested in chapter 3, that one way to study the ERP correlates of different encoding and retrieval processes was to analyse subsequent retrieval response on the basis of the level of confidence with which a decision was made, since it was assumed that a "high confidence" response implied that the encoding context of the item had been retrieved. In experiment 1, which utilised such a design, a large difference was observed in the ERP activity generated by words to which confident hit and non-confident hit responses were made, in the 500-924 msec region of the waveform. It was suggested that the enhanced positivity to confidently recognised words might be due to the activation of retrieval of context mechanisms. It was also noted, however, that an explanation in terms of confidence level, ie enhanced positivity to all items to which a confident response is made, could not be ruled out since the ERP activity of the other high confidence response category (ie confident correct rejections) was marked by enhanced positivity also.

EXPERIMENT 4

It was suggested in chapter 3 that an alternative method of differentiating the ERP activity related to different encoding and retrieval processes would be to average ERPs on the basis of performance on tests which are believed to reflect one or other process. Thus it was suggested that performance on a lexical decision task might reflect the degree of intra-item processing a word receives at presentation, while the performance on a test of recall might reflect the degree of intra-item processing a word receives at presentation. Such a design has been employed by Paller et al (1986) to study the relative contributions of encoding processes to ERP activity elicited during initial presentation of stimuli, and similarly in experiment 3 of the present experimental series such a free recall test was utilised to investigate whether ERP activity recorded during presentation exhibited the frontal elaborative encoding related positivity reported by other laboratories.

The present study utilised this design to investigate the proposed ERP correlates of retrieval observed in the later part of the waveform in experiment 1.

The obvious problem with utilising such a design to study the ERP activity associated with retrieval processes is that to record an ERP, the subject must be presented with an "event" for the related time-locked processing to be recorded and that during free recall no eliciting stimuli are presented to the subject. For this reason, it is necessary to use the paired associate design where the recall of a particular item is elicited by the presentation of a part of the information associated with, and encoded with that item. In the present study, pairs of words were learnt together, and recall of the second item was elicited by presentation of the first member of the pair. Although in such a design, activity associated with the recognition of the first member of the pair may be reflected in the ERPs, the only way the second item can be retrieved is if processes associated with the retrieval of context are employed. Thus any possible retrieval-related ERP activity will be reflected in a difference between ERPs generated by words whose associates are recalled and those generated by words whose associates are not recalled.

7.2 METHODS

7.2.1 Design

The aim of the experiment was to compare ERPs generated by words whose experimentally learned associ tes were either retrieved or not retrieved from memory. Subjects were required to study word pairs, following which the first member of each pair was re-presented to the subject and the subject was required to recall the associate of that item. ERPs elicited by the re-presented first items were recorded.

7.2.2 Subjects

The subjects were 8 male and 7 female right handed undergraduate students, only one of whom had taken part in EEG studies before. All had normal or corrected to normal vision.

7.2.3 Stimuli

The stimuli consisted of 240 one or two syllable nouns selected from the Battig and Montague word norms (1958). They all had high values above 5.5 (on a scale extending from 1 to 7) on the 3 dimensions of frequency, concreteness and imagability. The words were randomly paired with one another. No pair whose members were, in the judgement of the experimenter, synonyms or highly associated were allowed. The word pairs were divided into three presentation lists, each consisting of 40 word pairs.

Each word pair was typed onto a blank 5" by 3" record card. They were centred on the card with the words typed side by side with a dash separating the words.

During presentation each pair was shown to the subject for 5 seconds during which time the subject was required to associate the words together by imagining the objects to which the words referred. This encoding strategy was used because it was thought that this was the optimal strategy for remembering the words and that requiring all the subjects to do this would preclude effects on recall performance due to encoding strategy differences.

Each recognition list was composed of the 40 first items from each word pair from each list, randomly re-ordered. Each word was displayed at moderate contrast on a TV monitor. A fixation star was presented for 500 msec and was followed 150 msec later by the stimulus which was displayed for 200 msec. The response window began 1434 msec after the stimulus onset and was signalled by the brief presentation of a plus sign on the screen. The response window lasted for 9 seconds. The total ISI was approximately 11 seconds.

Subjects were required to write down the second item of each pair during the 9 second response window.

7.2.4 Procedure

Each subject was tested in a single two hour experimental session. Following electrode application subjects were seated in front of the TV monitor in the experimental room. The nature of the task was explained to the subject. They were told to look at each of 40 word-pairs, imagine the objects and attempt to associate the two objects together in some way. The cards were placed face down in front of the subject. Subjects were required to pick up cards and study the word-pairs one at a time. When the experimenter said the word "next" they were they were required to place the card they were studying face down and pick up another.

Following study of all 40 word-pairs subjects were given arithmetical problems to complete for 5 minutes. The subjects were then told to rest their heads on the chin rest and to rest their hand on the table in front of them. Beside their right hands lay a pen and a piece of paper with 40 numbered spaces on it. Subjects were told to recall the associate of each first item presented on the screen, but to remain as still as possible until the start of the response window was signalled. They were required to write down the associate in the space provided for that trial, to put a dash in that space if they could not recall the associate, or to write "N.S." (ie not seen) if they had missed the stimulus due to blinking or writing down the associate of the previous item. They were told not to guess and to write down the answer only if it were recalled before the response window began ie not to attempt to retrieve the item during the response window.

Following each list subjects were given a few minutes to rest before learning the next 40 word-pairs. The order in which lists were learned and tested was counterbalanced across subjects.

7.2.5 ERP Recording

EEG was recorded during the test phase, during a 1536 msec epoch beginning 102 msec before stimulus onset. EOG was also recorded. Montage, sampling rate and filtering procedures were identical to those employed in experiment 3.

7.2.6 ERP Analysis

ERPs elicited by words whose associates were recalled and by those whose associates were not recalled were entered into separate averages. ERPs elicited by words which were not seen and those in which eye artefacts were detected were not included in the averages.

7.3 RESULTS

7.3.1 Behavioural Data

The percent-correct recall performance is shown in table 7:1.

Table 7:1
Experiment 4: Recall performance for each word list, expressed as a percentage of the number of words in each list.

	LIST 1	LIST 2	LIST 3	TOTAL
Recalled	46.4	48.3	51.2	48.8
Not Recalled	37.2	35.3	39.0	37.4
Not Seen	16.4	16.4	9.6	13.8

Overall, more words were recalled than were not recalled but nevertheless a large percentage of words were not recalled. It can be seen too that the consistency of performance between lists is very high.

7.3.2 Electrophysiological Data

3 subjects' data were excluded from the ERP averages due to insufficient numbers either of artifact free ERPs or of responses in one of the two behavioural categories.

The grand average ERPs are shown in figure 7:1.
It is clear from these that differences between waveforms exist at all three midline sites and to a lesser extent at the two temporal sites. The ERPs generated by words whose associates were recalled are of greater positivity than those generated by words whose associates were not

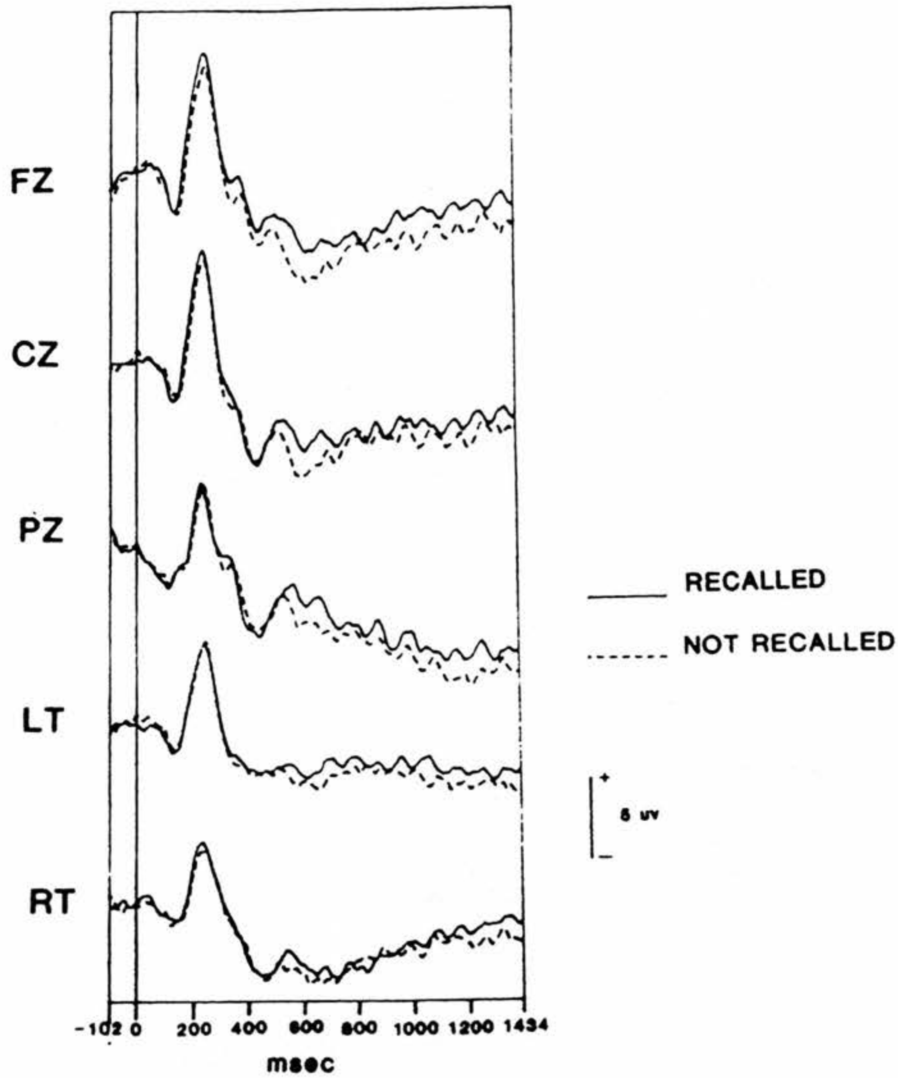

FIGURE 7:1. Grand average waveforms of ERPs generated by paired-associates, averaged according to subsequent recall performance of the other associate. Waveforms are shown at all 5 sites.

recalled. Inspection of the waveforms indicates that differences may be present in two regions of the waveform, between approximately 500-750 msec and from 840 msec until the end of the epoch. Using the same criteria as in previous experiments, the mean amplitude of two region of the waveform were measured: (a) 540-720 msec and (b) 840-1428 msec. The data are shown in table 7:2.

The measures were entered into a repeated measures ANOVA with factors of condition (recalled and not recalled) and site.

Table 7:2
Experiment 4: Mean amplitude values (uV)

1: 540-720 msec

		Fz	Cz	Pz	LT	RT
Recalled	Mean	-3.82	-4.68	-3.37	-2.87	-3.87
	SD	6.05	6.33	8.18	4.45	3.66
Not Recalled	Mean	-5.84	-6.42	-4.82	-3.74	-4.58
	SD	4.93	6.12	8.45	3.75	3.31

2: 840-1428 msec

		Fz	Cz	Pz	LT	RT
Recalled	Mean	-2.27	-3.90	-6.51	-2.82	-2.14
	SD	3.69	3.23	5.51	2.32	1.83
Not Recalled	Mean	-3.58	-4.67	-7.64	-3.58	-2.64
	SD	3.51	3.87	6.83	2.33	2.18

(i) 540-720 msec: The analysis of amplitude measures in the 540-720 msec region of the waveform revealed a main effect of condition ($F_{1,11}$ = 5.86 $p < 0.05$). The amplitude of words whose associates were recalled was significantly greater than the amplitude of words whose associates were not recalled.

(ii) 840-1428 msec: The analysis of the amplitude in the later region revealed no significant effects.

7.4 DISCUSSION

These data indicate that the words whose experimentally learned associates were successfully recalled from memory generated ERPs of greater amplitude in the 540-720 msec region of the waveform than did words whose associates were not recalled. Although visual inspection of the waveforms indicated that other, later, differences might exist, they were not statistically significant. The implication of these results, in view of the experimental hypothesis outlined in the introduction, is that this difference represents the activation of processes involved in the retrieval of an item's encoding context.

There is, however, an alternative explanation for these results based on the fact that in this experiment the ERPs recorded were those elicited by previously presented words (ie the first members of each associ te pair). It might be the case that words whose associates can be recalled are also those which, on re-presentation, are recognised as familiar, and therefore that the resulting ERP activity represents only the activation of recognition based on a word's familiarity. The major problem with such an account, however, it that ERPs were found to differ according to retrieval category. For this alternative account to be true, it would have to be assumed that only words whose associates were recalled were "familiar" to the subject. In view of the short interval between learning and recall, it is doubtful whether such an assumption is valid. Subjects studied each pair carefully and were tested for memory only five minutes following the end of each presentation list. In view of the suggestion made by both Mandler (1980) and Jacoby (Jacoby and Dallas 1981) that intra-item processing depends to a great extent upon processing of the physical features of a stimulus item and that the effects of such processing decay over time, it is unlikely that there are many differences between words in terms of their "familiarity" at the time of recall. It is more likely that the ERP activity recorded from all words manifests "familiarity checking" related activity.

However, this alternative remains a possibility and in future studies using such a design, it might be helpful either to give subjects a recognition test in addition to the recall test to see if words whose associates are recalled are better recognised, or to compare the recall results with activity recorded from words in a task such as a lexical decision task which is thought to index "implicit" memory. This sort of comparison has been conducted by Paller in the case of ERPs recorded during presentation (Paller 1986).

The relation between these data and those of experiment 1 is complicated by the fact that it was concluded from experiments 2 and 3 that high confidence of recognition is not necessarily a good test of the degree of inter-item processing a word receives at presentation. Recall in which the recall of context is much more likely to be necessary, is a better way of discriminating between the kind of processing received at presentation. Nevertheless, in experiment 1 large differences between conditions thought likely to reflect different processes were found in the later region of the ERPs and in view of the present data it is proposed that the results from experiment 1 reflect the same processes as are thought to have been reflected here. Nevertheless such a conclusion is tentative. It could only be substantiated by showing that the possible alternative explanation for the data from experiment 1, that differences were due to the degree of confidence employed in each decision (irrespective of the retrieval processes involved), is invalid. It is difficult to conceive how these two factors of memory and confidence level could be separated since one of the concomitants of strong memory is that there is increased certainty concerning the item.

Such a study would have to compare ERPs generated by stimuli to which confident decisions were made, irrespective of the memory status of those stimuli, with ERPs generated by stimuli to which confident decisions with respect to the memory status of the stimuli were made. If there was no difference between ERPs generated in the two conditions, it would strengthen the suggestion that the effects were due to con idence level alone. If there was a difference, it would suggest that the observed ERP effects may well have little to do with confidence per se.

EXPERIMENT 4

The relation of the present data to those recorded by other laboratories is complicated by the fact that none of the previous attempts to record ERP correlates of retrieval has specifically attempted to distinguish activity on the basis of the type of processing involved in retrieval. All the previous studies which have found differences either between activity generated by "new" items and "old" items (Sanquist et al 1980, Karis et al 1984, Neville et al 1986, Johnson et al 1985, Friedman and Sutton, unpublished data) or between activity generated by successfully retrieved and unsuccessfully retrieved items (Sanquist et al 1980, Karis et al 1984) have used only recognition tests which do not allow for such discrimination between the processes involved in retrieval. The data of these previous studies therefore reflect an amalgam of activity related to both types of retrieval process. The relation between the present data and those of other studies will be further discussed in chapter 8 where a synthesis from the various studies will be attempted.

One feature of the data is worthy of further discussion, however. Figure 7:1 indicates that in all the waveforms a large degree of negativity is discernible. This appears to begin as early as 400 msec and to last until the end of the waveform. It seems to influence both recall categories equally. It is possible that this negativity consists of the presence in the waveforms of a CNV (Contingent Negative Variation) potential. One of the paradigms is which CNV have been recorded is that in which motor responses are being held in readiness (Hillyard 1973). At least one part of the CNV is thought to be related to preparation to make a motor response (Loveless and Sandford 1973, 1974a, 1974b: Weerts and Lang 1973, Rohrbaugh and Gaillard 1983). In the present study, subjects were waiting to make a motor response from the time they had recalled the associate until the end of the epoch and this may have given rise to a CNV.

In conclusion, it is proposed that the present study has identified the ERP correlates of processing involved in the recall of a stimulus item. On the basis of current theories of encoding and retrieval this process may be that of the recall of encoding context of an item. The implications of such data for both ERP interpretation and cognitive theory are discussed in chapter 8.

CHAPTER 8

CONCLUSION

8.1 INTRODUCTION

In the preceding chapters, experiments were reported in which the ERP correlates of cognitive processing taking place during both the encoding and the retrieval of words were studied. In this concluding chapter, the suggested conclusions will be summarised, following which the relation of these results to both physiological and psychological theories of encoding and retrieval will be discussed.

8.2 SUMMARY OF CONCLUSIONS

8.2.1 ERP Correlates Of Encoding Processes

In experiment 1, ERPs were recorded during the presentation of verbal stimuli and the ERPs generated by these words were averaged according to the recognition response and level of response confidence made to the words in a later test of recognition memory. The data revealed that ERPs generated by words which were subsequently correctly recognised with a high level of confidence tended to be more positive, in the 500-700 msec region of the waveform, than ERPs generated by other words, particularly at Fz, but that this tendency did not reach significance. The possibility that this lack of significance of effects was due to a lack of strict correspondence between the time spent processing and the ERP recording epoch was investigated in experiment 2. The data from this experiment were similar to those recorded from experiment 1 with a similar tendency to greater positivity generated by confidently recognised words at the same latency.

It was suggested that the failure to replicate the strong encoding related ERP effects observed in other studies (Karis et al 1984, Neville et al 1986, Friedman and Sutton 1986) might be due to the fact that high confidence in response is not as good a test of specifically elaborative processes as is recall which was used in other studies. Therefore a study utilising recall as the retrieval test was carried out and the data from this revealed a significant difference between ERPs generated by words later recalled and words not recalled. This took the form of enhanced positivity between 800-1400 msec which was pronounced at the frontal site.

The data from these three studies were similar in that in all three there were indications of an enhanced frontal positivity generated by words which were thought to have received elaborative or inter-item processing at presentation.

These data are in agreement with the results of Karis et al and Fàbiani et al who reported similar frontal retrieval-related activity which they also attributed to the activation of elaborative processes. On the basis of their data and the present data it is proposed that retrieved words elicit ERP activity which is of greater amplitude at the frontal recording site than words not retrieved or retrieved with low confidence.

It is further proposed that at present the best explanation for this enhanced positivity is that it reflects the activation of elaborative encoding processes. This is thought to be the case for two reasons: (i) Karis et al and Fàbiani et al have reported finding such positivity among subjects utilising elaborative processing, whereas subjects employing non-elaborative rote learning strategies generated differences of a different nature between retrieval categories. The latter effects were interpreted as an enhancement of P300 amplitude in ERPs generated by recalled words. (ii) According to current theories of encoding and retrieval, there are good reasons for thinking that words which are later recalled must have received elaborative inter-item processing whereas words which are not recalled will have lacked such processing. Thus a difference between ERPs generated by the two types of words may well reflect such an encoding difference. One caveat at this point is that in experiment 3 it was found that an important processing difference between words recalled and not recalled, not necessarily dependent upon the types of mnemistic encoding process performed, was that recalled words tended to be " mate" words. To substantiate the above account of the data, it will be necessary to show that at presentation there are no systematic differences between the way words are processed except those thought to be involved in the inter-item processing of words.

Other data bearing on possible encoding related effects upon ERPs have been reported by Paller et al, (unpublished data), Neville et al (1986), Friedman and Sutton (unpublished data) and Sanquist et al (1980), all of whom have reported finding an enhancement of positivity in ERPs generated by words later identified as "old". These effects are similar in the fact that they are manifested at all three midline recording sites and are interpreted as reflecting an enhancement of the Late Positive Component. It is suggested that these data reflect the activation of both elaborative and non-elaborative processing at presentation. There are two reasons for drawing this conclusion: (i) None of these studies ensured that words later retrieved from memory had received only elaborative processing at presentation. This was because most used recognition memory tests to assess retrieval, performance on which is thought to reflect both encoding processes (Mandler 1980). One study which did attempt specifically to do this by using a recall test (Paller et al, unpublished data), failed to exclude the influence on intra-item processing on performance on the recall task. (ii) The results obtained, ie enhancement of the LPC resemble those of Karis et al which indicated that enhancement of the LPC was manifested in the ERPs of subjects who were using non-elaborative encoding at presentation.

Other data bearing on the issue of ERP correlates of encoding related processes are reported by Paller et al, (unpublished data). Words which were later found to be facilitated in a subsequent test of implicit memory were found to generate ERPs which were more positive than ERPs generated by words not facilitated. This positivity took the form of a long latency amplitude difference occurring at all three midline sites. Paller has suggested that these effects are the result of the activation of intra-item processing at presentation. Since words which were not facilitated surely lacked such processing, the effects reported by Paller represent at least in part the activation of such processes. It is not known however, what other processing may have been conducted on words for which facilitation was found, such as inter-item processing, which may also contribute to the observed effects.

It is possible to conclude from these studies and the present ones that ERP correlates of different encoding processes have been demonstrated. These consist of: (i) An enhancement of positivity at Fz which reflects the employment of elaborative or inter-item processing. (ii) A long lasting enhancement of positivity present at all three midline recording sites which reflects <u>at least</u> the activation of intra-item processing; (iii) Enhancement of the LPCs of ERPs at all three midline sites. The cause of this enhancement is not known and it is impossible at present to attribute it to either process.

8.2.2 Retrieval Processes

Experiments 1 and 4 addressed the question of whether differences in brain activity during retrieval, associated with the activation of one or other of the retrieval processes postulated in recent cognitive research (ie "familiarity indexing" and "recall of encoding context") are manifested in the scalp recorded ERP. These studies sought to determine whether ERPs generated by nouns differed according to whether the nouns or their associates were successfully retrieved or not.

Two apparently separate "retrieval" effects were found in experiment 1.

(a) The earlier ERP differences (300 msec - 500 msec) consisted of an enhanced positivity in ERPs generated by words which were correctly recognised as "old", compared with ERPs generated by words which were correctly recognised as "new". This effect was interpreted as reflecting the activation of recall processes based on the familiarity which a stimulus item possesses. There were three reasons for this interpretation: (i) The data reported by Rugg (1985, 1987; Rugg and Nagy in press) which indicated that ERPs generated by repeated words in a lexical decision task were more positive than those generated by words not repeated, were very similar to the effects seen in experiment 1 between 300-500 msec. This suggested that the present effects represented the same process. (ii) Current theories of memory suggest that the processes responsible for facilitated performance on tasks such as lexical decision tasks are those which are thought to be sensitive to the familiarity of an item (Jacoby and Dallas 1981, Paller 1986), rather than those sensitive to the degree of elaborative processing. (iii) Words which were thought to have been recognised on the basis of the two different retrieval processes did not generate differing ERPs in this region of the waveform. The process common to both therefore, ie the recognition of familiarity, was thought to be responsible for the difference between ERPs generated by these words and those generated by "new" words.

These results cast light upon data from other laboratories which have reported finding similar differences between "old" and "new" words (Sanquist et al 1980, Karis et al 1984, Friedman and Sutton, unpublished data, Neville et al 1986, Johnson et al 1985). These all report an enhancement of the amplitude of LPCs in ERPs generated by "old" words compared with ERPs generated by "new" words. It is possible that these effects reflect the same process posited as the basis of the present data, ie the identification of words as "familiar". The same problem with using recognition tests without assessing confidence level which was identified in discussion of the presentation ERP effects, is present here also. The fact that a word which is recognised generates different ERPs than words not recognised, does not allow the individual process responsible to be identified. The use of confidence levels may provide one way of discriminating between them in that shared ERP effects are likely to be elicited by processes common to both, and ERP differences between confidence categories are likely to reflect the activation of one or the other process.

(b) Later effects (500-924 msec) were also observed. It was reported that ERPs elicited by confident hits, confident correct rejections and misses, were significantly more positive than ERPs elicited by false alarms and non-confident hits. It was thought that the data could be accounted for on the basis of an enhancement of positivity in ERPs generated by responses which are highly confident (Paul and Sutton 1972, K.C. Squires et al 1975). However it was proposed that a more likely explanation was that words which were recognised due to the activation of the process described as retrieval of encoding context (Mandler 1980, Jacoby and Dallas 1981) generated ERPs which were more positive in this region than words which were recognised due to the activation of "familiarity checking" processes alone. This was thought to be the case because the two conditions which were thought to differ most in respect of retrieval processes employed ie confident and non-confident hits (and also false alarms since they were largely non-confident responses made on the basis of familiarity) differed most in terms of their respective ERP activity.

To replicate these supposed retrieval-process related effects, a further study was conducted which explicitly aimed to record ERP correlates of retrieval-of-context processes. Words whose associates were recalled generated ERP activity which was more positive than the activity generated by words not recalled. This difference became evident at about 500 msec and continued until the end of the recording epoch. This increased positivity was thought to represent the activation of retrieval-of-encoding processes. Recall is thought to depend upon the retrieval of context alone. Differences between ERPs generated by recalled and non-recalled words are therefore likely to reflect selective activation of this process.

These results are similar to those of experiment 1 in that, from 500 msec post stimulus onwards, words thought to have been retrieved due to retrieval of encoding context generate ERP activity which is more positive than that generated by other words. This provides some support for the suggestion made earlier that the results from experiment 1 represent ERP correlates of different retrieval processes. Data from other laboratories which have compared ERPs generated by words retrieved and words not retrieved from memory are in accord with the present data in that they too report that words later retrieved generate greater positivity that words not retrieved (Karis et al 1984, Sanquist et al 1980). These effects also seem to consist of long latency amplitude differences which occur at all three midline sites. However, these results do not discriminate between the possible underlying processes. They do indicate, however, the reliability of ERP differences based on the activation of retrieval processes.

8.2.3 Conclusion

At both encoding and retrieval, ERPs have been found to differ according to whether the items eliciting them are retrieved from memory. It is proposed that these effects are due to the activation of specific encoding and retrieval processes and that by using tests of retrieval which are thought to to be sensitive specifically to individual processes, the activity generated by different encoding and retrieval processes can be distinguished.

8.3 RELATION OF FINDINGS TO PHYSIOLOGICAL PROCESSES

The proposals made above, that the scalp recorded ERP manifests neural activity related to encoding and retrieval processes, raises the question of whether these data help to determine where such activity occurs in the brain. The encoding effects due to elaborative processing seem to be concentrated at the frontal site, and it might be supposed that these data provide evidence to support a role for the frontal lobes in elaborative memory processes. On such a supposition they could be seen to support the theory proposed by Warrington and Weiskrantz (1982) who have suggested that there exists a frontally mediated "dynamic cognitive mediational memory system in which memoranda can be manipulated, inter-related and stored in a continually changing record of events" (p 272). They suggest that it is by recourse to this system that subjects recall or recognise events as having the attribute of "memories". Their primary evidence for this suggestion comes from their studies of the neural deficit involved in the amnesic syndrome. They suggest that the sufficient lesion in the syndrome serves to disconnect the temporal lobes from the frontal lobes which are normally linked by projections to the frontal cortex from the thalamus. They suggest that such a disconnection between the semantic memory system subserved by the temporal lobe structures and the frontal mediational system accounts for the finding that amnesics can demonstrate long-term learning and retention under certain conditions and with certain types of material, tasks in which the subjects do not have to "know" that they remember the task or the stimuli. In many tasks in which they perform poorly, they are explicitly asked to report what they recall or to recognise something, tasks requiring the activity of a cognitive mediational system.

Although Warrington and Weiskrantz propose that this system is active during retrieval it seems probable that such a system might be active during encoding as well in normal subjects. However the evidence cited for such a system is slight. Although some studies have shown that frontal lesions affect performance on certain memory tests such as maze learning (Milner 1965), memory for salience (Shallice and McGill 1983) and paired-associate learning (Hecaen 1964), these results can be explained by defecits in other postulated frontal lobe functions such as those related to problem solving strategies. Warrington and Weiskrantz's claim therefore is a tentative one and it would be unwise to suggest that the present results reflect the activation of such a system.

A more important reason for caution however, is that the location of the generator site for the frontally recorded effects is unknown. It may well not be located in the frontal lobes. It is impossible from the present data to suggest where the generating sites for either the encoding effects or the retrieval effects might be.

Some evidence has been found suggesting that the hippocampus is the generator of the P300 component (Halgren et al 1983). If the hippocampus is indeed involved in the generation of memory related scalp recorded potentials it seems more likely that these would be the memory related effects on P300 amplitude postulated by Donchin (1980, Karis et al 1984). These effects are related to an "updating" process in Donchin's account which may well reflect some kind of "familiarity indexing" process in the terms of the Mandler/Jacoby theory of encoding and retrieval. In this case it seems unlikely that the scalp ERPs which have been found to be generated in the hippocampus are the basis for either the elaborative encoding effects or the "recall of context" retrieval effects.

In conclusion then, the relation of the present data to putative brain generators is unclear at the moment. The most likely site for encoding and retrieval effects, both of which involve considerable semantic processing, seems to be a site responsible for the inter-relation of stimuli and their further processing. If indeed a frontal mechanism such as that described by Warrington and Weiskrantz exists, then that would be a good candidate. Whether or not both encoding and retrieval are subserved by the same site is also unclear however, especially since the observed retrieval effects appear to occur equally at the three midline sites, if not at all sites. While research into the putative generators of ERPs is at a fascinating stage it is at present impossible to use such data to suggest where in the brain the memory-related effects found in the present experiments are generated.

8.4 RELATION OF DATA TO COGNITIVE THEORY

The second major question to be addressed is to what extent the present data contribute to an understanding of the cognitive mechanisms involved in the encoding and retrieval of stimuli. Here again there is a certain amount of circularity since while the proposed explanations of the data may confirm some cognitive theories they also largely depend on those theories.

CONCLUSION

On the one hand, the proposed interpretations of the present results are derived from the cognitive framework proposed by Mandler and Jacoby and their colleagues. Their framework, which involves two types of encoding activity (intra- and inter-item processing) and two corresponding retrieval processes (familiarity indexing and retrieval of encoding context) has been taken as a cognitive framework which is clearly defined and reasonably well established, within which to try to understand the data obtained in the present studies. It might be argued that the adoption of such a framework may in some way have limited the interpretation of data.

On the other hand, the method adopted here seems to be the best way to proceed with research into ERP correlates of cognitive processes. It was argued in Chapter 1 that an important recent trend in ERP research has been that researchers have adopted well established and understood cognitive frameworks within which to interpret their data rather than simply listing the behavioural correlates of certain interesting ERP components, and that this has been a sign of progress. The experiments reported in this thesis have followed that pattern and it is suggested that this has given the present studies a wider application than just to one area of ERP research, in that the data have implications for cognitive accounts of encoding and retrieval. The data have been seen to fit well into the Mandler/Jacoby model and it may be the case that the present studies have described the natural correlates of elaborative encoding and recall of encoding context. If this is indeed the case then this provides researchers with an important tool in the study of the differences between the processes involved in encoding and retrieval. One problem in such research has been to find a behavioural measure of each process independent of the others, and the provision of independent neural measures would be an important answer to this problem. It might be possible to study the conditions under which each process is active and at what stage of the processing of a stimuli they occur, by studying the neural correlate. This may even prove to be the only adequate method of studying some aspects of encoding and retrieval since separating the effects of the various processes on behavioural measures, is very difficult.

It must be said however, that at present this stage has not yet been reached, and the present data do not directly have implications for the Jacoby/Mandler account. It is essential first to clearly establish that the ERP effects observed do in fact reflect the activation of these encoding and retrieval processes.

8.5 FURTHER DEVELOPMENTS

The experiments discussed in the foregoing chapters have gone some way towards demonstrating that certain ERP components reflect the activation of particular encoding and retrieval processes. Not only do the data seem to fit such an account but the studies have shown that when the experimental variables are manipulated in order to ensure the activation of a particular cognitive process, the ERP activity supposedly related to that process is present. Two types of study will be needed to establish more conclusively the link between process and ERP activity: Firstly, it is important to establish a double dissociation ie not only should the supposed neural manifestation of a process be present when that process is thought to be active, but in addition, it should be absent when that process is thought not to be active. Secondly, it is important to compare ERPs recorded by words thought to have undergone different types of processing within the same paradigm. This has been attempted already by Paller (1986). Thirdly, a stronger case can be made if it can be shown that the degree of the activation of each process correlates with the size of the supposed ERP correlated activity. Nevertheless such studies could not demonstrate that the co-varying ERP activity was not in fact generated by a separate cognitive process which was integral to the encoding process but distinct from it, such as the allocation of cognitive resources. However, the discovery of ERP activity which was always co-incident with and which co-varied with the degree of elaborative processing, would be as useful a tool to cognitive psychology as finding a manifestation on the scalp of the actual neural activity generated by the process.

Following such studies, the correlated ERP activity could serve to function as an important measure of the degree of activation of such encoding and retrieval processes.

8.6 CONCLUSION

In conclusion, it is suggested that the experiments reported in this thesis demonstrate the existence of ERP correlates of encoding and retrieval processes. It is further maintained that this research follows the pattern of recent trends in ERP research, in that the ERP data are interpreted in the light of well understood theories of cognitive function. Particularly in the field addressed here, ie the study of correlates of memory-related processes, the present design seems to be a powerful tool in elucidating such ERP correlates. The usefulness of these data to theories of brain function and in particular of how the brain subserves memory processes, depends on further elucidation of the neural generators of ERP components. Their relevance to cognitive theories depends upon the confirmation of the present interpretations of the observed effects. If this can be done such ERP correlates will be a vital tool in the study of cognitive processing underlying the acquisition and retrieval of memories.

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