Electrophysiological Correlates of Cognitive Function

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To : My Mother & Father
and
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This thesis is concerned with the investigation of the relationship between mental processes and slow potential changes recorded from the scalp. The evidence for a relationship between a particular example of event related potentials (ERPs), the contingent negative variation (CNV) and cognitive processes is reviewed. The psychological concepts employed are ill-defined and the mechanisms generating slow potential changes poorly understood. Furthermore, the CNV is widely reported as if it were a unitary phenomenon, despite evidence for topographic differences, and task dependent variations in the components of the wave form. The classical CNV recording paradigm (simple warned reaction time) is a special case which has resulted in the misinterpretation of the relationship between slow potential changes and cognitive processes.

The experimental programme involved the adaptation of a number of cognitive tasks to the CNV recording paradigm and the investigation of the relationship between slow potential changes and performance at a range of scalp sites. Two hypotheses were tested, that cognitive activity is localized in specific cortical regions, thus leading to hemispheric asymmetries in function, and that task difficulty and CNV amplitude are inversely related. The strategy adopted was to employ at least two levels of difficulty on any task investigated so that comparisons with an active baseline or anchor experiment were possible. Since the value of the CNV as a dependent variable is enhanced by its general applicability to cognitive processes a variety of tasks were employed including signal location, recognition memory for words, symbols and faces and mental rotation.

Results of a number of these studies support the view that performance differences are correlated with differences in potential for two levels of difficulty of a task. Furthermore, these correlations are commonly localized to specific scalp sites.

A number of technical limitations in the recording system were identified and studies using a system designed to resolve some of these are reported.

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Index terms : cognitive psychophysiology
cognitive negative variation

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CHAPTER 1 Mental Processes and Brain Function

1.0 The Problem

To be curious about the determinants of human behaviour, particularly those aspects of behaviour which are part of an individual's covert mental life appears to be one of the defining characteristics of humanity. The extent to which non-human species share this characteristic is a much more contentious question (Griffin, 1982). The desire for an understanding of the basis of mental life is both pervasive and persistent.

In its traditional form the relationship between higher mental processes and brain function, or the mind-body problem, has been the subject of investigation and analysis by a diversity of techniques, from the philosophical to the purely technological. The long history and variety of approaches attests to the importance of the issues at stake. It is only in relatively recent times that the relationship between mental and neural processes has been amenable to empirical analysis.

Technical developments in recording activity in the nervous system and correlating this with observations and measurements of behaviour are the basis which makes this work possible. Thus the fundamental idea which informs the work reported in this dissertation is that:

> for each behavioural phenomenon there exists a set of neural correlates that can in

> principle be observed objectively (Mountcastle, 1978)

Dualistic theories which posit an extra corporeal entity, commonly referred to as 'mind', are explicitly rejected. Instead, it is assumed that the nervous system, in combination with some other events of an experiential kind, is sufficient to explain the emergence of properties which have formerly been subsumed under the term 'mind'.

In practice, the development of our understanding of the emergent properties of a system as complex as the nervous system is not far advanced and the contribution that the work reported in this dissertation makes to the development of that understanding seems miniscule when considered in the context of the problem outlined above.

Perhaps it is as well to redirect our attention to more mundane levels of analysis rather than be led into the realms of philosophical discourse which are beyond the competence of this author. When an individual performs a task this involves the activation of a number of neural subsystems. Theoretically the analysis of any task should enable the identification of a number of "elementary mental operations" (Chase, 1978) which are the subset of the available range of elementary operations employed in this task. It is quite possible that the composition of the subset of mental operations employed will change with subsequent performance, and will also vary between individuals.

These elementary operations involve 'cognitive systems' (Posner, 1982) which are analogous to organ systems in that they consist of:

> differentiated structures made up of various cells and tissues adapted to the performance of some specific function and grouped with other substructures into a system (Websters New American Dictionary, 1982)

Cognitive systems therefore depend on differentiated brain structures even though these may be widely distributed within the nervous system (Posner, Pea and Volpe, 1981). The question of localization of function, or the identification of cognitive systems subserving a particular task, which is of critical importance to this dissertation, has two aspects:

1. The recognition of the functional aspects of that subsystem;
2. The anatomical specification of the subsystem on the basis of functional evidence.

The attribution of higher mental processes or functions, to activity in specific brain sites also raises the issue of the definition of the term 'function'. Attempts to investigate localization of function based on the shifting sands of

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idiosyncratic definition are bound to encounter difficulties. The problem appears to be one of matching the level of analysis of the psychological process with an appropriate level of analysis of neural function. Two examples from the history of investigations of brain-behaviour relationships serve to illustrate the difficulty. The phrenological movement introduced by Gall (1758-1828) postulated that the brain comprised mental faculties which were localized in the cerebral cortex. The strength of the faculty was determined by the size of the cortical region associated with it, and furthermore the size of the cortical region could be measured by the examination of the topography of the overlying cranium. Despite the lack of evidence to support the theory of phrenology the idea of localization of function proved sufficiently tenable to encourage others to explore the issues further. Some limited success in this line of investigation has been reported by Geschwind and Levitsky (1976), and Witelson (1977) with a region called the planum temporale, part of the temporal lobe which apparently is systematically different in size between the hemispheres, the left being larger than the right, and this has been further related to the asymmetries which are the basis of hemispheric specialization for language.

The work of Gall was ultimately dismissed because both the behavioural and the neural definitions were inadequate.

On the other hand, a more reductionist approach was adopted by Sherrington (1906) who considered that the appropriate level of analysis of behaviour was the reflex arc comprising receptor, conducting path and effector. In this case both the anatomy of the system and the behavioural correlate were clearly defined, but clearly the results from this line of investigation have only provided a limited impetus to our understanding of higher mental processes.

The problem is in choosing the appropriate level of analysis of brain function and task (Hillyard and Bloom, 1982). Perhaps the starting point for making these choices is in our knowledge of the anatomy of the nervous system.

1.1 Neuroanatomical Bases

The identification of structural patterns in a system estimated to comprise thousands of millions of units (Weiskrantz, 1973) and some 10^{14} synaptic interconnections between these units (Wood, 1983) is a task of considerable difficulty. In the context of this dissertation, the task is further complicated by the need to choose an appropriate level of resolution of structural patterns to match the measures of brain function utilized in the experimental investigations. Furthermore, anatomical studies provide an essentially static view whereas the analysis of task performance demands techniques which are sensitive to the dynamic changes in the systems involved.

For the purpose of this dissertation, it is legitimate to limit our investigations to the cortex, since this area is prepotent in the performance of tasks involving higher mental processes and is also the source of the brain potentials recorded on the surface of the scalp known as the electroencephalogram (EEG).

Cytoarchtectonic investigations of the neocortex reveal a laminated structure (Bodian, 1967) in which the layers are defined by the grouping of various cell types. On the basis of variations in the packing density of these cells and the relative development of the layers a number of maps of the cortex have been prepared. Perhaps the most widely used of these is the work of Brodman (1909). These investigations provided a potential basis for the functional differentiation of regions of the cortex. More recently there have been attempts to produce maps based on afferent and efferent connectivity to the cortex (Peele, 1961) which would provide a more satisfactory basis for investigations of the relationships between brain and behaviour.

The prevailing view is that particular regions of the cortex by virtue of the input-output connectivity are involved with particular elementary mental processes. For example, experimental investigations involving both stimulation and ablation as well as the clinical observations of people with lesions in these regions all suggest that the precentral motor cortex is intimately involved in the control of movement (Penfield and Rasmussen, 1950). This does not imply that motor function resides there, and there alone, but rather that this region is prepotent in the control of motor output.

Mountcastle (1978) developed the concept of the cortical column, as the basic functional unit in the cortex. It comprised:

> a vertically arranged group of cells heavily interconnected in the vertical axis running across the cortical layers and sparsely connected horizontally (Mountcastle, 1978, p 36)

On this basis it is possible to envisage the cortex as a collection of columns stacked side by side with little interconnection laterally but with individual afferent and efferent connections via subcortical structures. Each of these units is functionally significant hence localization in the sense that specific cortical columns have a limited set of roles to play in the orchestration of behaviour is possible. These roles may be duplicated in a number of columns and any column may be more or less involved in any task. Columns tend to be clustered in groups according to external connectivity and function and therefore it is not necessary to envisage spatial resolution down to the level of the column, but rather more extensive regions containing groups of similarly acting columns.

The cortical column by virtue of the connections with other brain structures is part of a distributed system which subserves the performance of a task.

1.1.1 Neuropsychological Evidence

Extensive evidence documenting the relationship between behavioural changes and injury or lesions of the brain has accumulated since the first systematic reports in the nineteenth century, and from these observations the specialised area of investigation known as neuropsychology has emerged (Beaumont, 1983; Dimond, 1980; Hecaen, 1972; Walsh, 1978). While the practical objectives of this approach are directed towards the amelioration of the consequences of injury and deterioration of the brain and rehabilitation of the individuals involved there has been a concerted attempt to incorporate the clinical observations of patients into the developing theoretical understanding of the relationship between brain and behaviour. Until recently the structural loss incurred with injury or lesion could only be clearly assessed at post mortem. The advent of Computerised Axial Tomography has enabled the identification and measurement of some lesions in the living patient, and therefore provides a complementary data source to the controlled lesion studies of non-human species. The logical problems of drawing inferences from studies of the behavioural effects of lesions are widely recognised (Chow, 1970; Walsh, 1978). It would be valuable if parallel investigations of the normal human processes were to provide complementary measures of the normally functioning brain.

A review of the clinical neuropsychological literature and the experimental neuropsychological literature reveals an interesting contradiction in the interpretation of the data from each of these sources. In the clinical literature the localization of function hypothesis permeates the work, but a relatively superficial review of cases on any disorder will reveal contradictory examples to the rule proposed by localization theory (Geschwind, 1970). The experimental literature on the other hand is much more equivocal. Starting with the work of Flourens (1824) and more recently exemplified by the work of Lashley (1950) a number of investigators argue that the brain operates on a much more wholistic basis than that suggested by the radical localizationist hypothesis.

Mountcastle's (1978) proposition that "distributed systems" provide the neural basis for complex functions appears to offer a hypothetical resolution to this contradiction but also a problem. The distributed system provides an inherently flexible system in which a functionally homogeneous cortical region can be intraconnected in many ways. The system represents a variety of potential flow paths for information and the dominance of any pathway at any one time is a consequence of dynamic properties of the system. All that could be predicted is that some of a limited set of subsystems would be prepotent in the performance of a task.

Localized lesions would therefore lead to subtle performance deficits on various tasks, rather than total disruption of task performance unless the lesions were very extensive. Thus regions of the cortex larger than the cortical column, but smaller than one of the main lobes participate differentially in various tasks. Measures of relative activity in various cortical regions should therefore provide some indicator of patterns of involvement.

1.1.2 Asymmetrical Function of the Brain

Possibly the most influential hypothesis in the context of questions of localization of function emerging from neuropsychological studies, is the suggestion that the left and right cerebral hemispheres are functionally asymmetrical. The initial reports by Dax (1836) and later Broca (1865) (see Boring, 1957) pointed out the strong relationship between lesions of the left hemisphere and disorders of language. Since that time the disruption of language skills consequent upon left hemisphere damage has been thoroughly investigated.

One general finding converging from this extensive literature is the variety in the patterns of deficits observed, suggesting that the global term 'language function' refers to a range of subfunctions, some of which remain undisturbed by specific lesions and others of which are disrupted. This conclusion is consistent with the views developed by Wernicke (1874) that localization was possible at the level of simple perceptual and motor functions. Geschwind (1965 a,b) has developed the work of Wernicke into the theory of 'disconnexion syndromes' as a basis for modern neuropsychology, in which the relationship between subsystems which subserve these basic processes are disrupted by lesions.

One of the most radical examples of the 'disconnexion syndrome' is provided by the series of split brain patients investigated initially by Sperry, Bogen and Gazzaniga (1969). This evidence consists of a series of case studies of patients who had undergone radical surgery as a means of controlling epilepsy which had previously failed to respond to traditional methods of treatment. Clearly each of the cases presented with considerable neurological disturbance over an extended period prior to surgical intervention, a factor which much of the resulting literature expressing enthusiasm for the hemisphere asymmetry hypothesis fails to take into account. The split brain studies were interpreted as supporting the asymmetry of function, but it is something of an overgeneralization to regard these results as indicative of the situation in the neurologically normal individual (Miller and Whitaker, 1983).

The hemisphere asymmetry hypothesis has also been tested in neurologically normal subjects. This work has tended to employ either stimulus lateratization as an independent variable and a performance measure as dependent variable, or response lateralization as a dependent variable. The recent attempts to summarize much of this evidence (Gazzaniga, 1970) suggest that patterns of interhemispheric involvement do not follow the simple verbal, visuo-spatial distinction which was the conclusion derived from much of the early literature. Rather, changes in the conditions under which a task is performed, such as changes in the perceptibility of stimulus material, lead to the laterality effects (Bryden and Allard, 1976; Hellige, 1976; O'Boyle and Hellige, 1982).

Lateralization of the response demanded in the context of a particular task and the interference effects of a concurrent task utilizing the same hemisphere have supported the asymmetry hypothesis but of course these are quantitative differences which do not indicate that the other hemisphere has no involvement in the task.

The impression emerging from much of the recent literature suggests that early interpretations of hemispheric asymmetry must be revised. The situation is more complex than that originally envisaged and it may be necessary to monitor the patterns of activity in the brain at various stages of task performance to detect interhemispheric changes in patterns of activation. It is possible that different stages of a task may involve different patterns of activation of the hemisphere. It is in this context that more direct measures of brain function may be useful.

1.2 Spatiotemporal Localization of Function

Localization of neural events in the cortex which are concomitant with psychological processes demands a measurement technique sensitive to the spatial arrangement of the cortical mosaic of columns outlined previously and the temporal dynamics of task performance. Two main approaches have emerged, one based on regional changes in metabolism and the other on neural events. Both supposedly reflect activity in this part of the nervous system.

Measurement of metabolic activity is based on the uptake of radioactive tracers. In one technique, Positron Emission Tomagraphy, radioactively labelled glucose molecules are sensed by an array of detectors, giving a spatial resolution of the order of 1-5 millimetres and a temporal resolution in minutes (Raichle, 1979). In the other, participants in the experiment inhale a gas including radioactively labelled Xenon and by monitoring radioactivity levels, rates of blood flow to different regions can be determined. Tasks such as silent reading have been shown to involve increased bloodflow in limited areas of the cortex (Risberg, 1980).

The possibility of direct measurement of neural events involved in psychological processes is an attractive prospect and this has been pursued by the implantation of microelectrodes into single cells or near small groups of cells in animal preparations (Hubel and Weisel, 1962). In humans there have been a limited number of cases of long term implantation of fine wire electrodes from which some recordings have been made (Sheer, 1961). To my knowledge none of these studies has included a detailed investigation of unit or small group activity while the subject carried out specified cognitive tasks. A somewhat less direct approach with important practical advantages has been developed. This involves measurement of the minute fluctuations in potential difference from electrodes on the scalp and is known as the electroencephalogram (EEG). The prevailing view is that these potentials bear a temporal relationship to the post-synaptic potentials in some thousands of pyramidal cells in layers three and five of the cortex (Creutzfeldt, 1974; Elul, 1972). The problem of understanding the mental correlates of the EEG was usefully illustrated by the analogy between EEG recordings and listening to the activities of a factory from an outer wall (Margerison et al., 1967). To take the analogy further, if one were to arrange a large number of listening devices to provide simultaneous measurement at different points on the walls of the factory then perhaps the results would enable the monitoring of relative activity levels in particular regions of the factory. This approach would become even more informative if one were to arrange the delivery of loads of specific raw materials to the factory at particular times. Presumably changes in the level of activity at different recording sites would reflect the processing of this raw material. In this form, the analogy nicely illustrates the basis of two methods of experimental analysis of the EEG. The continuous voltage fluctuations provide an irregular wave form which can be analysed to indicate the relative proportion of various frequency components in the spontaneous wave form. Early in the history of the use of the technique the significance of the so-called Berger rythmn was observed (Adrian and Matthews, 1934). In particular the emergence of the alpha rythmn in relaxed inactive subjects and its rapid desynchronisation to beta activity when a stimulus is presented has long been utilized as a demonstration of the change of state in the cortex with a change in behaviour.

The other approach is based on attempts to identify events in the sequence of information processing which are timelocked to the original stimulus. By the use of a computer to digitize samples of the voltage level at specified intervals, and average these over a number of trials it is possible to enhance the response to the stimulus (signal) relative to the background activity (noise) such that evoked responses are easily observed as a sequence of potential fluctuations at fairly consistent latencies from stimulus onset. As the research on Event Related Potentials (ERPs) has accumulated the consistency of responses within a particular modality across individuals has been emphasised. From these observations the concept of the 'component' of the ERP, a single wave at a particular latency, and often recorded more effectively at particular sites, has emerged. Because one of the common information processing models, which dominates the interpretation of the psychological aspects of this work, posits a linear system, many have been quick to suggest that specific components may reflect specific processing stages and thus the activity in the particular neural processors. Deflections of the ERP are divided into three latency bands, early, medium and late on the basis of the relative effectiveness of different variables influencing the amplitude of the component waves. Roughly, the early components, up to about 100 milliseconds appear responsive to the physical characteristics of the stimulus, the midlatency (100 msec - 250 msec) components to the attentional state of the subject and the later components the subjects response to the demands of the task.

A further useful distinction focuses on the exogenous and endogenous nature of the various elements of the ERP. The essential difference is that exogenous components are determined mainly by the characteristics of the external stimulus whereas endogenous components reflect more closely the internal state of the individual. As one progresses along the timebase of the evoked response from early to late components the relative importance of exogenous and endogenous activity changes. Early components are more exogenous in nature, later components more endogenous. It is the endogenous components which form the focus of interest in this dissertation, and in particular one species of endogenous component known as the 'contingent negative variation'. The contingent negative variation (CNV) was initially reported (Walter, Cooper, Aldridge, McCallum and Win~~d~~ter, 1964) on the basis of recordings in a simple reaction time paradigm. In the interval between the warning signal and the imperative signal a negative going slow potential change was identified which was dubbed the CNV.

Wood (1983) has compared the spatial and temporal resolving power of the techniques mentioned above. Positron Emission Tomography is able to resolve functional changes at a spatial sensitivity of millimetres, but temporally at only some 30 minutes. Regional cerebral blood flow, on the other hand, is only spatially sensitive to some 2.5-3.0 cm, but is able to resolve temporally down to some four minutes. The EEG is comparable to regional cerebral blood flow in its spatial resolution but is able to provide temporal resolution of the order of milliseconds. Recently Cohen (1972) has reported a new development, the magnetoencephalogram, which is based on measurement of current flow and is able to resolve spatially down to millimetres while maintaining the temporal sensitivity. As yet few studies using this approach have been reported.

The possibility that EEG based measures of brain function and particularly some characteristics of ERPs reflect information processing in a relatively direct way strengthens the claim that these phenomena should be the subject of considerable further investigation. On the basis of the temporal sensitivity of the technique and the similar time scale on which many psychological phenomena are recorded the possibility that this group of phenomena provides access to physiological events with clear psychological significance is attractive to a number of workers (Hillyard and Kutas, 1983).

1.3 Behavioural Bases

To understand the relationship between localized cortical function, in the form of event related potentials, and elementary mental processes involving specific cognitive subsystems requires an experimental paradigm in which the task loads heavily on a specific and clearly defined mental process. In practice this is very difficult to achieve. Firstly, the definition of psychological processes is not adequately developed to enable clear identification and operationalisation. Secondly, there are some difficulties devising experimental tasks which are also suitable for recording event related potentials. Thirdly, because of the inherent adaptability of the human participant, the same task may be tackled by quite different strategies, even by the same performer on different trials.

The development of the cognitive model of the human information processor is a consequence of the realization that the individual brings something to the stimulus situation which is just as potent as environmental events in determining the ultimate form of behaviour. In the normal flow of events surrounding behaviour, rather than passively responding to the environment, the organism actively selects aspects of the stimulus array which are supposedly appropriate to the needs of the moment. Gregory (1975) examining the need for cognitive concepts identifies the following features; (i) the self initiation of behaviour, (ii) responses can be made to the inferred features of objects or situations, and these inferences depend on background knowledge, (iii) the absence of a stimulus can be as effective in initiating behaviour as the presence of a stimulus. One of the main objectives of the cognitive movement has been to develop a model of the human information processor which enables an understanding of the mental framework which is used to interpret environmental events and organise actions. Since the early 1960's these ideas have been the focus of considerable research. In reviewing this literature, Newell (1973) has criticized the lack of a coherent theoretical framework. This shortcoming becomes particularly problematic when the concern is to relate mental processes to underlying neural processes. If the need is to develop an organizing framework then perhaps a starting point can be identified in the common time base of both the mental and neural events. Implicit in the human information processing model is a delay, during which processing is carried out, and this delay has provided an important tool in the investigation of mental processes.

By systematic modification of the task requirements, and therefore presumably the demands on different cognitive systems, the response delay can be influenced. Differences in response latency have, therefore, been used to investigate and develop the model of putative cognitive subsystems. The advantage of the event related potential as an indicator of brain function in this context is that the time base of event related potentials is of the same order as the latencies of the response commonly recorded in purely behavioural studies.

Mental chronometry, the investigation of response latencies in mental tasks, is a well explored approach to the identification of underlying cognitive processes (Posner, 1978). Early observations were concerned mainly with individual differences in response speed and the speed of transmission in the nervous system (Fitts and Posner, 1969). Donders (1868) developed the technique to incorporate more complex choice reaction time tasks. He identified three types of reaction time; type a, simple reaction time, one stimulus and one response; type b, presentation of five stimuli each of which required a separate response; type c, the presentation of one of five stimuli, only one of which requires a response. The method proposed, 'the subtractive method', meant that by taking the 'a' reaction from the 'c' the time for discrimination could be obtained. On a rather intuitive basis Donders claimed that the latency differences recorded were a direct consequence of the involvement of separate differentiable mental processes.

More recently this approach has been adopted by Sternberg (1969) who has developed the "additive factors method". Information processing tasks demand a sequence of independent processing stages, in which transformations are performed on the information. Experimental manipulations have their effect by influencing one or more of the processing stages, and consequently the time taken in processing. The task usually employed consists of a set of a small number of items to be remembered (the positive set) which are followed by a probe stimulus. The task is to decide whether or not the probe corresponds to any of the items in the positive set. By manipulating four factors, stimulus quality, size of the positive set, response type and relative frequency of the two response types, Sternberg was able to conclude that each factor influenced different processing stages. His interpretation of the data has come in for considerable criticism, particularly with respect to the independence of processing stages.

A number of workers have attempted to overcome the invalid assumptions identified above. Sanders (1980) suggests that the logical difficulties and empirical disparities in the literature can be resolved by assuming that the choice reaction time task consists of six stages which provide a common base for the performance of a wide variety of tasks. Time spent processing in each of these stages is thought to be manipulable by separate independent variables. Table 1.1 below illustrates the stages identified and the relevant independent variables. Essentially the suggestion is that a general purpose information processing system provides a basis which can be modified according to specific task demands.

Table 1.1

Suggested Stages on the basis of Typical Additive Effects

Stage	Typical Additive Variable
Preprocessing	Signal contrast
Feature extractions	Signal quality
Identification	Signal discriminability, word frequency
Response choice	S-R compatibility
Response programming	Response specificity
Motor adjustment	Instructed muscle tension

Other workers (McLelland, 1979; Posner, 1978) have been unwilling to accept the assumption of linearity of processing stages and as an alternative have proposed various hierarchical models in which processing stages may overlap. For example, Posner (1978) suggests that letters and words can be subject to processing by two separate structures, one based on physical codes and the other on a name code.

The theories proposed as a consequence of the work in this area suggest that the demands of a task lead to the activation of necessary cognitive systems. In some cases this occurs automatically, and in others active attention to the task is required, and where this is the case, processing of material not sharing the same cognitive system is inhibited (Posner and Snyder, 1975). Thus, localised activation of appropriate systems is a basic assumption of these interpretations of information processing.

This is an important departure from traditional arousal theory, which posited a generalized arousal system. The Yerkes-Dodson law which is illustrated by a series of inverted curvilinear relationships between performance and level of arousal for different levels of task difficulty did not refer to arousal in a limited number of specific subsystems. Recently a number of workers have drawn attention to the incompatibilities between the available data and a unitary arousal system. For example, Lacey (1967) reported observations of the dissociation of arousal in autonomous subsystems given different task demands. In a simple reaction time task most autonomic measures show a pattern of activation, while in the interval between the warning and the imperative signal the heart rate decelerates. Interestingly Lacey also proposes that EEG changes in the interval between warning and imperative signal are a direct consequence of cardiac deceleration (1967).

Eysenck (1982) in reviewing the evidence suggests that a single arousal mechanism or process is no longer able to account for the performance data accumulated in this field of investigation.

At this stage the competing claims for various alternative arousal systems cannot be adequately resolved. For the purposes of this dissertation the important conclusion is that the unitary position is no longer tenable, and this allows for the possibility of patterns of activation across different cortical regions, reflecting the involvement of different cognitive systems.

The methods of investigation outlined above have been used in tasks which have intuitive appeal and inherent plausibility in the light of the main features information processing models. Few, if any, can be justified on any more rational grounds than this. Common to all of these views, however, appears to be a general subdivision of the information processing sequence into a sensory encoding phase, a storage and manipulation phase, and a response organization and execution phase. The boundaries between these phases are very difficult to define.

The evaluation of any measure of brain function as one variable in a correlation with a behavioural measure should encompass all phases of information processing, but in particular, if the relationship between cognitive processes and brain function is to be addressed, there should be some concentration on the central processes of storage and manipulation. Furthermore, the utility of a particular measure of brain function will depend on its applicability to a wide range of experimental tasks which may only loosely adhere to the main theoretical framework, rather than the systematic reexploration of one task which is carried out in an attempt to understand any particular information processing model. Just as the response latency measure has been shown to have wide applicability to a number of tasks, so a measure of brain function should also have similarly general applicability.

The rationale behind the choice of most of the experimental work reported in this dissertation is firstly to concentrate on processes which are essentially cognitive in nature (rather than sensory, or motor) and secondly, to explore correlations between brain function and cognitive processes in a number of experimental settings, thus enabling the general validity of the approach to be evaluated. The one exception to this general approach is the experiment reported in Chapter 5. In this instance, the simple reaction time condition enabled a check on the results being obtained in the experimental setting developed for this series of studies and a replication of the findings commonly reported in the literature on the CNV.

1.4 Conclusions

In this chapter the problem which is the focus of the dissertation has been articulated and the basis for an empirical investigation of the problem delineated. In particular the characteristics of the anatomical arrangement of the system, the consequences of lesions for behaviour, the spatio-temporal mapping of functional characteristics of the system and the behavioural correlates of the normal system have been considered.

A concern with the behavioural aspects has led to the identification of the main features of cognitive processes, the role of imagery as an encoding process and the way these characteristics can be operationalised in tasks to be performed by participants in the experiments.

CHAPTER 2 The Electroencephalogram as Dependent Variable in Psychophysiological Experiments

2.1 The EEG and Psychophysiology

The CNV has been chosen as the index of cerebral function to be employed in the investigation of relationships between brain function and behaviour in this dissertation. Initially it is necessary to consider the evidence that the EEG does provide information about brain function, and furthermore, that the EEG responds predictably when the participant in an experiment undertakes the task demanded in that situation. In particular, it would be expected that tasks chosen to elicit patterns of localized activation in the brain would also elicit similar patterns in the EEG activity. Thus, tasks in which asymmetry of function in the cerebral hemispheres has been identified would be expected to elicit differences between hemispheres in level of activation or suppression of variables derived from the EEG.

From the earliest reports of recordings of the EEG by Caton in 1875 and Berger in 1929 there has been interest in the possibility that EEG or measures derived from it might provide a suitable index of cerebral function, and a correlate of mental processes. Caton in 1875 was the first to record spontaneous electrical activity from the exposed cortex of a rabbit. He obtained records of both spontaneous activity in the absence of specific stimulation and evoked potentials while visually stimulating the animal with a lamp. Lindsley (1969) has suggested that he may have even observed the CNV which was to be rediscovered later by Walter and his colleagues (1964).

The initial recording of spontaneous brain activity from the scalp of the normal human was reported by Berger in 1929. For some time these findings gained little acceptance in scientific circles. It was only when Adrian and Matthews (1934) demonstrated the 'Berger Rhythmn' to a meeting of the Physiological Society at Cambridge that the phenomenon gained wider recognition (Walter, 1953).

2.2 Physiological Bases of the Electroencephalogram

Cells in the central nervous system generate a range of electrochemical events which are potential bases for scalp recorded potentials (Perkel and Bullock, 1969). The generation of the complex continuous wave of the EEG is thought to result from post synaptic potentials in large numbers of cells in the third and fifth layers of the cortex (Elul, 1972: Creutzfeldt, 1974). A number of investigators have demonstrated the correlation between action potentials at this level and the amplitude and phase of low frequency extracellular macropotentials (Fox, 1970).

Potentials recorded at the scalp are the averaged and attenuated resultant of activity in some thousands to millions of cells in the vicinity of the recording electrode, thus limiting the spatial sensitivity of the technique. Recordings are unable to provide information about activity in individual cortical columns; however, it is known that the cerebral mosaic of cortical columns is organised into larger functional groupings which reduces somewhat the seriousness of this limitation (Peel, 1961).

The process of the generation of a scalp recorded potential can be illustrated by Picton's (1980) description of events in neurons of a primary projection area on receipt of an afferent volley from the thalamus:

> the initial activation results in depolarization of the pyramidal cell body causing a local negative potential and corresponding source in the apical dendrites. Thus the dipole initially generates a positive wave at the surface of the cortex. Soon the apical dendrites are depolarized and the recording from the surface becomes negative (Picton, 1980)

This account of the generation of sensory event related potentials probably also satisfactorily explains the generation of slow potential changes, like contingent negative variation.

Transcortical recordings, where one electrode is placed on the cortical surface and another in the underlying white matter, demonstrate a polarity inversion between the surface and deeper cortical activity suggesting that the EEG is generated in the superficial layers of the cortex. Intracranial recordings therefore support the neurogenic origin of EEG activity (Papakstopoulos and Crow, 1976).

The anatomy of the cortex has some implications for the interpretation of potentials recorded from the scalp, and particularly for attempts at localizing activity. The cortical surface is characterized by deep fissures and specifically the cerebral hemispheres are divided by a longitudinal fissure down the midline. The cortical mantle folds into this fissure so that cortical columns in the wall of the fissure are transverse with respect to the scalp, whereas those at the surface of the cortex, away from the fissure, are radial in orientation. The spatial relationship underlying generators of scalp potentials recorded from electrodes near the midline is therefore more difficult to interpret than in records taken from sites further from the midline. Also there is some evidence (Drasdo, personal communication) that the hemispheres are not perfectly symmetric in the cranium, and therefore scalp electrodes are slightly misplaced. Studies of the topography of changes in the EEG might do well to avoid recording from midline sites as these are a special group requiring careful interpretation.

2.3 Analysis of the Electroencephalogram

The wave form that makes up the

electroencephalogram is probably best imagined as a harmonic complex of waves of various frequencies which are occasionally sinusoidal in form. Decomposition of this wave form into its constituent sinusoidal frequencies thus provides one method of analysis. Electroencephalograms are conventionally described as patterns of activity in up to five frequency ranges: delta, less than 4Hz; theta, 4-7Hz; alpha, 8-12Hz; beta, 13-30Hz and gamma, more than 30Hz. The usual approach is to measure the relative power in specified frequency ranges as an indicator of processing changes. These frequency bands are regarded as having some functional significance.

The alternative approach to analysis is based on the time domain. In this case potential changes embedded in the ongoing EEG are thought to reflect information processing activity. Analysis is based on the assumption that these events are time locked to external stimulus events. By recording a number of sweeps of EEG activity in which the stimulus event occurs at a specific time and averaging these sweeps, an average evoked potential can be derived from the background activity.

Of particular importance to the studies of mental processes is the alpha rhythm which is supposed to be apparent when the brain is not actively processing information. The alpha is most prominent over the occipital cortex, and is best observed when the eyes are closed. It is attenuated during attention, especially to stimuli in the visual modality. Alpha rhythm represents the summation of activity in a large number of cells which are in phase, and of which the alpha frequency is the natural periodicity of discharge (Gevins, 1983). It is a characteristic of most adult individuals when not actively processing information. Once processing is initiated the alpha rhythm is 'blocked' or 'desynchronised' and a faster rhythm, beta (13Hz and above) replaces the alpha. Recently Lykken (1975) corroborated and refined the original findings of characteristic alpha frequencies for individuals. Within the alpha range he suggests that an individual and the situation are defined by a particular frequency (Rho) and most activity in the individual in this frequency band occurs in a 3Hz range centred on the characteristic frequency.

Adrian and Matthews (1934), in demonstrating the phenomenon publicly, drew attention to the responsiveness of the alpha rhythm from the eyes closed to eyes open condition. The importance of this observation lies in the relationship to processes of arousal. If the recording system is adequately sensitive the activation of specific cortical subsystems involved in an information processing task should lead to relatively localized changes in the alpha rhythm, and thus provide an indicator of localized brain function. Changes in the relative proportions of power in different frequency bands recorded from different scalp sites commonly provide the evidence for localized activation patterns (Gevins, 1983).

A number of authors have investigated alpha responsiveness in relation to the utilization of visual imagery in various mental tasks. Golla, Hutton and Walter (1943) identified three categories of alpha responsiveness in the EEG which they related to preferred task strategies. Task strategies were determined on the basis of verbal protocols of performance elicited from the subjects. The results of their work are summarized in Table 2.1. Essentially, they found the prescence of alpha rythm was likely to be related to a verbal task strategy.

Table 2.1

Alpha Type and Problem Solving Strategy

(Gola, Hutton and Walter, 1943)

1. M(or minus type)	Visualists
No observable alpha in eyes open or eyes closed conditions.	Visual imagery commonly used.
2. R(or responsive type)	Change from visual
Having alpha in the eyes closed condition but this was attenuated when eyes opened.	Imagery to verbal strategy without difficulty.
3. P(or persistant type)	Verbalizers
Having alpha in both eyes open and eyes closed conditions.	Consistently utilize verbal kinaesthetic imagery.

These findings were largely confirmed by Short (1953) and Short and Walter (1954) who correlated reports of visual imagery with alpha blocking and also better performance on a tactile pattern recognition task with total attenuation of the alpha rythm. A number of other authors (Barratt, 1956; Mundy-Castle, 1957; Oswald, 1957; Slatter, 1960) have questioned this interpretation. In particular they argued that other factors known to influence the alpha rhythm had not been adequately controlled and the classification of subjects into imagers or verbalisers could not be maintained in situations with varying task demands. Other mental activities were just as likely to attenuate the alpha rhythm, and the habitual mode of problem solving might be better envisaged as a continuum, along which subjects moved according to task demands.

The relationship between alpha suppression and various cognitive activities clearly needs further clarification. Gale, Morris, Lucas and Richardson (1972) developed this work by selecting subjects on the basis of measured vividness of imagery using the scale developed by Sheehan (1967) from the Betts questionnaire (1909) and asking them to participate in a variety of tasks which elicited alpha suppression. Their findings suggested that there was some relationship between alpha rhythm and imagery activity. Under eyes open, minimal imaging conditions, vivid imagers had higher mean dominant frequencies. After high imagery words alpha suppression was greater than after low imagery words. In voluntary imaging tasks, greater task difficulty as assessed by performance variables was associated with greater alpha suppression.

Davidson and Schwartz (1977) using voluntary imagery tasks elicited alpha suppression differentially from occipital and sensorimotor regions of the left hemisphere depending on whether the task was visual or kinaesthetic, suggesting that the technique may have value in identifying localized patterns of activity.

Studies of the relationship between imagery and alpha rhythm have been particularly useful in identifying a number of methodological problems which must be taken into account. Generally, the work could be considerably improved by attention to the behavioural demands of the situation, along the lines of Gale et al., (1972) but including measures of performance which could be incorporated into the final analysis. Also, a better understanding of the nature of the alpha rhythm and its significance for brain function and cognitive processes needs to be developed. It is possible that other measures of alpha activity, such as the reciprocal of the abundance, or reciprocal of amplitude would provide a more appropriate dependent variable (Harding, personal communication 1982). Two reviews addressing these issues have been published

(Anderson and Anderson, 1968; Lippold, 1970) but these largely neglect the behavioural questions. Lindsley (1969) summed up the paucity of progress in this area in the following way:

> I am afraid, unfortunately, that we don't know so very much more about the nature of the alpha rhythm or the other rhythms than Berger 'so ably described (Lindsley 1969)

2.4 Hemispheric Asymmetries of the EEG

Asymmetries in the function of the cerebral hemispheres provides the basis for a number of testable hypotheses. Of particular relevance to the issues being examined in this thesis are studies which have focused on hemispheric differences in the EEG. As a result of the development in our understanding of brain organization, tasks which emphasise the use of verbal or visuospatial strategies have been used in attempts to elicit differential modifications in EEG activity between hemispheres. A wide variety of other activities and abilities have been investigated using dependent variables based on the spontaneous EEG, and the alpha rhythm. Reviews of this work by McGuigan (1978), Andreassi (1980) and Gevins (1983) are available.

Asymmetries in the amplitude of the alpha rythm are commonly recorded in the resting EEG, but the functional significance of these differences is not clear. In the clinical context when a resting EEG is recorded, large differences in amplitude across the hemispheres are regarded as a sign of pathology (Kiloh, McComas and Osselton, 1972).

When studying inter-hemispheric differences, it is easy to underestimate the significance of changes in the activity in the hemisphere which is regarded as relatively quiescent in the task. Normally activity in the two hemispheres is integrated, and it is misleading to imagine one hemisphere as quiescent while the other is activated in particular task situations (Searleman, 1977). It is impossible to devise a task that does not involve both hemispheres.

A more valid interpretation considers the relative activation of each of the two hemispheres. This has two aspects: (i) relationship to a simultaneous measurement from the homologous site over the contralateral hemisphere; (ii) the relationship to a baseline measurement when the participant is resting.

The question of the baseline continually plagues studies of this kind (Gale, 1973). Normally experimenters utilize a so-called 'resting' baseline, assuming subjects rest when told to do so. In fact, there is little control over a subject's mental activity in so-called baseline periods and a variety of events might be taking place. For example, if the subject is unfamiliar with the procedures and techniques of the EEG laboratory, there are likely to be many activities requiring explanation. Subject anxiety is well recognized, as is the complexity and ambiguity of the experimental context (Christie and Todd, 1975; Gale and Smith, 1980).

An interesting development in this context is the measurement of cortical coupling (Calloway and Harris, 1974; Yagi, Bali and Calloway, 1976). The results using this simple technique appear to be potentially useful in the study of functional relationships between various areas of the cortex.

Few, if any, of the studies of hemispheric asymmetries in the EEG adequately account for all the methodological issues identified. Even so, few fail to find some evidence for task induced asymmetries. Perhaps the well known bias in the literature against so-called negative results (Furedy, 1974) operates in this area.

The tasks utilized in attempts to elicit hemispheric asymmetries in the EEG fall broadly into verbal/mathematical and visuo-spatial categories, activating left and right hemispheres respectively. Numerous studies have shown that EEG asymmetry shifts as a function of task demands (Davidson and Schwartz, 1976, 1977; Doktor and Bloom, 1977; Doyle, Ornstein and Galin, 1974; Dumas and Morgan, 1975; Ehrlichman and Weiner, 1979; Galin and Ellis, 1975; McKee, Humphrey and McAdam, 1973; McLeod and Peacock, 1977; Morgan, McDonald and Hilgard, 1974; Morgan, McDonald and McDonald, 1971; Osborne and Gale, 1976). However, tasks have rarely been subject to detailed analysis to determine the properties likely to lead to the differential involvement of the hemispheres, and rarely are detailed measures of task performance collected which would enable a consideration of the results in the context of the experimental psychology literature which has been amassed from studies employing behavioural variables only.

Recent studies exploring imagery and visuospatial tasks are important to the question of clearly localized changes in function. From occipital leads, over left and right hemispheres, spatial imagery tasks have been shown to influence alpha amplitude (Morgan, McDonald and Hilgard, 1974; Morgan, McDonald and MacDonald, 1971). At temporal and parietal leads the R/L ratio was shown to be greater for verbal than for spatial tasks (Galin and Ornstein, 1972). During a block design task, the EEG from the right hemisphere of dextrals reduced in amplitude compared with the left hemisphere, while during a writing task the converse pattern of change occurred. It was suggested that the amplitude reduction reflected engagement of a large area of underlying cortical tissue in task associated processing. Furst (1976) used three spatial manipulation tasks and collected crude measures of performance. A significant positive correlation was found between speed of performance and the integrated voltage of occipital alpha; however, he also found a positive correlation between resting asymmetry and performance. Tucker, Stenslie, Roth and Shearer (1981) explored the relationship between mood and imagery ability, and frontal lobe activation. They experimentally induced euphoric or depressed mood states and showed selective impairment of vividness of visual imagery during depression. Using alpha power as a dependent variable, they demonstrated a reduction in the right hemisphere of alpha power during depression.

Ehrlichman and Weiner (1979) considered the problem of task induced asymmetries in an interesting way. Their subjects participated in a range of 17 tasks and an index of EEG asymmetry for each was correlated with subjects' ratings of verbal or imaginal involvement in the tasks respectively. The electroencephalogram was recorded from temporoparietal sites over both hemispheres. They found that verbal processes are a more potent influence on EEG asymmetries than visuospatial processes or visual imagery. Whether individual performance on these tasks reflected a preferred strategy or something more fundamental in terms of neural organization is worthy of future exploration.

The level of self control that subjects can display over patterns of EEG activity, and the relationship of this to performance on various tasks presents itself as the method most likely to resolve some of the problems emerging in studies to date. Correlations between patterns of EEG activity (e.g. inter-hemispheric ratios) and performance have limited utility. A more effective strategy would be to manipulate the pattern of EEG activity independently and relate inter-hemispheric levels to performance, within subjects. An initial study in this context (Roy, Frediani and Herman, 1976) found that subjects were able to regulate EEG power relationships between the temporal lobes of the two hemispheres. These subjects were knowledgeable about theories of hemispheric specialization and this may have influenced their subjective reports of cognitive strategies.

The issue of control over the ratio of activity between hemispheres has also been investigated by Schwartz, Davidson and Pugash (1976). Control over alpha activity in either right or left hemisphere was apparently easily attained and was reliably associated with cognitive activities that would have been predicted on the basis of the earlier task induced asymmetry research. The subjects in this case were naive with respect to theories of hemispheric specialization. If control over inter-hemispheric EEG patterns can be relatively easily attained, it would be valuable to explore this in relation to individual differences in verbal and imagery ability and to performance on relevant tasks.

Recently Ornstein et al., (1980) reported a study in which participants performed a number of spatial and verbal tasks. The studies were controlled for gross motor activity and stimulus characteristics but did not control for differences in oculomotor activity, task difficulty, and level of effort expended. Their findings were that right hemisphere EEG changes accompanied performance of different spatial tasks, but differences between tasks and performance levels confounded any interpretation of simple functional asymmetries.

Gevins, Zeitlin and Yingling (1979 a,b) in a complex study which attempted to control for many of the variables identified above were able to distinguish between tasks on patterns of EEG activity but found difficulty relating these changes to particular perceptual, cognitive or motor aspects of the task. For example, on the basis of their records they were unable to distinguish writing from memory from mere scribbling. In further refinements of this work (Gevins et al., 1979 b,c) the tasks were simplified, motor responses were eliminated, and the EEG analysed was selected to avoid artifacts due to initiation and completion of the task. Each of the tasks resulted in a similar change from a resting baseline, but the patterns of change were indistinguishable between tasks. They conclude that previous studies are particularly weak in that aspects of performance other than the cognitive processes involved were not taken into account adequately.

Testing the localization hypothesis in terms of functional cerebral asymmetries is not the simple task which attracted much of the early work. As studies have accumulated the true complexity of the problem has been revealed. A number of the problems are relatively easily solved. Tasks can be equated for the demands for motor activity, and for the artifacts likely to intrude on the records but two fundamental issues seem particularly resistant to solution: (i) it is extremely difficult to isolate the cognitive operations involved in any task and (ii) it is also difficult to be sure that these are the processes being employed by a participant at a particular time.

2.5 Event Related Brain Potentials

Analysis of EEG records in the time domain using the technique of averaging was first introduced by Dawson in 1954 (Margerison, St John Loe and Binnie, 1967). Since that time the technique has been widely employed in the investigation of a number of clinical and experimental problems. The theory of deriving responses by averaging requires that an electrophysiological event of interest which is not normally apparent due to its low amplitude signal compared with the background EEG activity occurs in the relationship to an evoking stimulus in a brief period of activity on a series of occasions. By summing the activity at each of a number of sampling points in a period for a number of trials in the series and dividing by the number of sweeps, the noise, which is randomly distributed, approximates a straight line and signal events that are time locked emerge from the background activity. The resultant evoked response (ER) is usually presented as a graph of voltage against time.

For example, the generalized visual evoked response (VER) includes a series of recognizable and relatively reliable voltage deflections of varying amplitude.

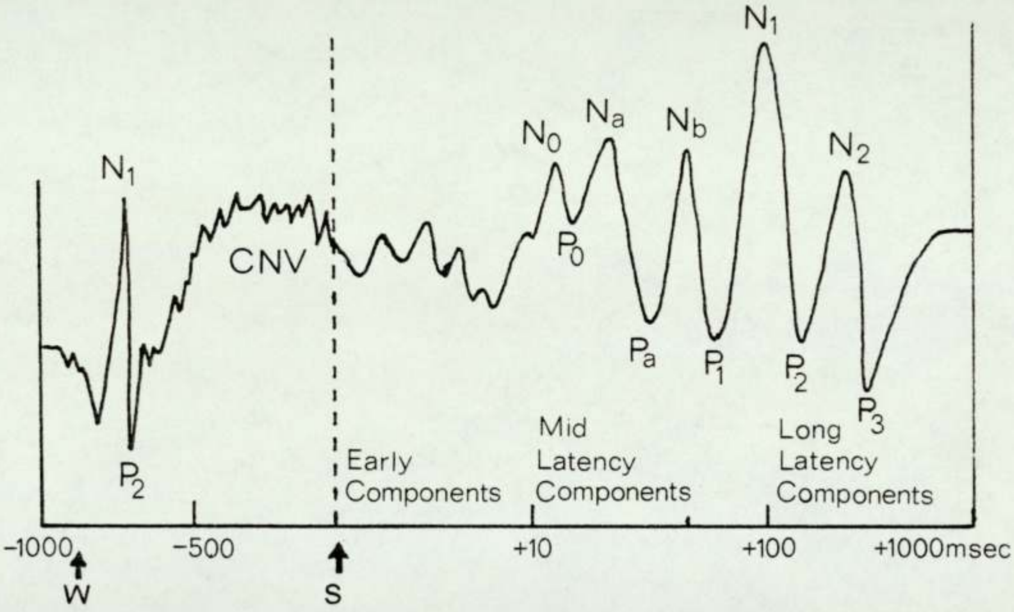

Figure 2.1

Averaged Event Related Potentials
(after Kutas and Hillyard, 1983)

Figure 2.1 depicts just such a generalized wave form. Any deflections in the response is a composite which commonly includes activity from more than one cortical generator. The distinction between deflection and component is important to the question of localization of function. The recording of sensory evoked responses has been widely employed in the evaluation of visual, auditory and somato sensory systems (Regan, 1972; Harding, 1974; Reneau and Hnatiow, 1975; Perry and Childers, 1969). While investigation of the various sensory evoked responses has led to recognition of the importance of psychological factors in determing the form of the evoked response (Regan, 1972), these issues are not of primary concern work in the psychophysical tradition. For any complete understanding of the information processing characteristics of the organism the psychological variables are an essential focus of study.

If the EEG and ERPs derived from it are codes representing brain function then independent variables which influence information processing system should have reliable correlates in EEG activity. Uttal (1967) in evaluating the potential contribution of ERP research to our understanding of the functional organization of the brain discussed the phenomenon in terms of its properties as a signal or a code. If a code, then the properties of the ERP would bear a direct relationship to the processing taking place; if a signal the ERP would be merely epiphenomenal, indicating an event was taking place. Perkel and Bullock (1969) consider the formal properties of codes in relation to neural activity and catalogue potential codes measurable in the nervous system.

The problem is to determine the significance of any component of an event related potential to the organism.

It is in this context that the behavioural demands of our research tasks must be carefully defined to enable a decision as to whether the component of the ERP under consideration is a real code.

For example, subjects participating in an experiment which requires them to "attend" to a specific stimulus commonly demonstrate enhanced amplitudes of some components to the attended stimulus. Research in the area has recently been reviewed by Hillyard and Picton (1979), Karlin (1970) and Hillyard and Kutas, 1983). The various deflections in the ERP are commonly regarded as differentially sensitive to modulation by attentional variables, early responses being determined essentially by the physical characteristics of stimuli and later responses more likely to be influenced by psychological variables. For example, Parasuraman (1978) examined the effects of divided attention on the negative component of the auditory ERP at about 100 mseconds. Previous research (Picton and Hillyard, 1974; Hillyard, Hink, Schwartz and Picton, 1973; Wilkinson and Lee, 1972) indicated that this was the earliest ERP component which could be reliably modulated by attentional changes. Stimuli were presented in either of three channels (left, central, right) and the subject was asked to attend to one, two or three channels. In the one and two channel conditions all possible combinations of channels were included. Stimuli were presented randomly and at either slow or fast presentation rates. Listeners were required to detect occasional signals in the monitored channel and indicate signal presence by depressing a microswitch. Targets were tones which were 3dB greater in intensity than non-target tones, and appeared randomly with a probability of 0.01 in each channel. The results indicated that at fast presentation rates when listeners were required to divide their attention between up to three sources of auditory stimulation the cortical response to each source decreased in amplitude as the number of sources monitored increased. Also, increasing the number of channels monitored at the fast rate from one to three significantly reduced detectability. It is important to note the rigorous behavioural analysis, in this case based on signal detection theory. This is essential in studies attempting to relate neural and behavioural events. A growing literature (see Hillyard and Picton, 1979; Hillyard, Picton and Regan, 1978) supports the view that middle latency components of the ERP (typically N1) are influenced by selective attention, suggesting a relatively high level system which controls selective attention across modalities.

Recently Näätänen (1982) has identified an attention-related potential change which is primarily endogeneous in nature. This has been termed "processing negativity", and is the "difference" wave (Nd) between ERP to stimuli in an attended channel minus the ERP to the same stimuli when they are not attended. Two phases have been identified, the second of which tends to be more frontally distributed than the first. The evidence has been interpreted as suggesting that processing negativity is a sign of early stimulus selection.

Later components of the ERP have also come under scrutiny. Sutton, Braren, Zubin and John (1965) first described a late positive component which was sensitive to the state of the subject. This was a slow positive wave P3 occurring from 250-900 milliseconds after stimulus onset and, referred to as the P300, or the P3. Recent reviews of the research on the P300 have been prepared by Hillyard and Picton (1979), Sutton and Tueting (1975), Picton (1980) and Donchin, Ritter and McCallum (1978). The general eliciting paradigm used in research on the P300 employs simple stimuli to which meaning is imparted by the experimenter. For example, Sutton and Tueting (1973) used a signal detection paradigm, in which subjects were presented two simple click stimuli, the second of which was the signal to be detected at threshold level and the first 30dB above threshold, a supposed artifact of the equipment. The electroencephalogram for four categories of trials, hits, misses, false alarms and correct rejections was averaged separately. In the "hit" trials a large positive waveform appears after the threshold stimulus. No similar waveform is apparent in the "miss" trials. Also, the size of the response to the threshold level click is about three times that of the more intense artifactual click. Normally in auditory evoked response experiments, one would predict a monotonic increase in amplitude of the ERP with increase in stimulus intensity (McCandless and Best, 1966). For the P300 to appear at all the stimulus must be present and correctly detected.

In other experiments, performance feedback (Jenness, 1972), the resolution of uncertainty (Sutton, Braren, John and Zubin, 1965) and the unexpected absence of a stimulus (Sutton, Tueting, Zubin and John, 1967) have all been shown to result in the production of the P300.

The P300 is a phenomenon in the EEG which appears particularly sensitive to psychological manipulation and is, therefore, valuable in mapping the cognitive space of a subject (Donchin, Ritter and McCallum, 1978). In particular, it seems sensitive to situations in which the expectancy of the subject or the subjective probability of events is manipulated and also where stimuli are identified as task relevant. The P300 can also be elicited by the absence of expected stimuli. Sutton et al., (1967) conducted an experiment in which the subject's task was to correctly predict whether a single or double click would be presented in the next trial. The first click elicits the usual exogeneous or sense dominated response, but no P300, whereas the presence or absence of the second click does elicit a P300. Thus it is concluded that some components of the ERP may be "endogenous", and not dependant on external physical stimuli.

The aspect of the attentional process which is emphasised in the studies just reviewed is the ability to detect signals in the external environment. This is commonly termed 'stimulus set'. The ERPs are therefore essentially exogenous in character. An alternative aspect of the process emphasises the deployment of central processing resources, and thus the endogenous nature of the ERP. The use of more complex stimuli, in tasks requiring higher level processing than simple detection loads the task in this way.

A specific point about the basis of ERP needs consideration. The notion of the 'component' has become particularly prominent in the literature. This suggests that ERPs consist of a series of separable potential changes which are specifically sensitive to task related variables and are derived from separate neuronal subsystems. Commonly, components are separated by visual inspection, but recently principal components analysis (Glaser and Ruchkin, 1976) has been applied to the problem of identifying components of the ERP. A more rigorous definition recognizes that any peak in the series composing an ERP may be the result of an interaction between many components. Donchin et al., (1978) define component in the following way:

> it is a set of potential changes that can be shown to be functionally related to an experimental variable or to a combination of experimental variables and is derived from the activity of functionally distinct neuronal aggregates (Donchin et al., 1978, p 353)

It might be expected that the amplitude of various deflections would therefore be partly dependent on the proximity to the appropriate neuronal generators, as well as the necessary eliciting conditions. The division of the deflections of the ERP into early, medium and late components which are differentially sensitive to psychological variables may be reflected in topographic differences in the ERP. Unfortunately most of the research has concentrated on a small number of recording sites and this precludes any systematic analysis of patterns of response across the scalp. This suggests that the assumption of many workers is that ERPs are merely epiphenomena and have a limited contribution to make to the understanding of information processing.

A number of studies have employed more complex stimuli in more demanding tasks as an attempt to tap the central deployment of processing resources. For example, Johnson and Chesney (1974) demonstrated that the same ambiguous physical stimulus evoked a different pattern of response when perceived in either of two forms, depending on the task instructions. Posner, Klein, Summers and Buggie (1973) and Posner (1975) in analysing attentional processes employed a task requiring subjects to make matches on the basis of physical or phonetic criteria. These demands elicited differences in the amplitude of the between stimuli which were the same and those P300 which were different (Posner, 1978).

Chapman (1973) utilized number and letter characters as stimuli in simple comparison tasks for stimuli relevant to the task compared with those not part of the problem and found that the ERP recorded from the vertex was enhanced when relevant stimuli were presented. Gomer, Spicuzza and O'Donnell (1969) utilized the short term memory paradigm developed by Sternberg (1969) with sets of letter stimuli as the target and measured the P300 to probe stimuli. Amplitude of the P300 was greater following positive probe letter presentations than negative, and P300 latency increased with set size. It is suggested that these results should be interpreted as support for a template matching process in short term memory for which the P300 is a sensitive monitor. Kostanelov and Arzumarov (1977) utilized neutral and emotionally significant words as stimuli and presented these at two exposure periods. At the shorter (subliminal) exposure, emotional words, elicited an evoked response whereas no response was recorded to neutral words. Warren (1980) employed a word recognition task and identified differences in potentials as early as 160-190msec. after stimulus onset as well as in the P300. Boddy and Weinberg (1981) utilized a semantic categorization task, where width of category determined processing load. In positive instances of primed categories, responses were faster and amplitudes (N1 and P2) greater, than for negative instances. They attributed this to "spreading activation of logogen" like preconscious word detecting devices within the brain. Measurements of ERP satisfying the criteria for P300 gave equivocal results. The amplitude of an N2-P3 response was larger to positive instances of narrow categories than any of the other conditions. Kutas and Hillyard (1980) utilized a sentence based task in which the last word was either expected or unexpected, and if unexpected, either physically or semantically deviant. They identified a late negative wave (N400) for semantic deviations and a late positive complex for physical deviations and also an asymmetrical slow component in the resting condition.

These results illustrate the point that ERP methods provide a useful tool for the further understanding of brain mechanisms for the processing of complex linguistic stimuli. It is in this context that hemispheric asymmetries in ERP have become the focus of considerable research activity. This development is valuable, since the limitation of recording responses to simple stimuli at a limited range of sites may be misleading if the objective is to develop a comprehensive theory of brain function.

2.6 Hemispheric Asymmetries in Event Related Potentials

The search for indicators of asymmetries in the function of the hemispheres has influenced ERP research. The rationale behind this appears to be that interhemispheric differences in amplitude or latency of ERP reflect in some way the differential involvement of hemispheres. This is not necessarily the case. The relationships between amplitude of response and the processing of the stimulus events is not clearly established other than with detection tasks near threshold levels. The presence or absence of a response is relatively easy to understand, the interpretation in terms of the memory of two responses which differ in amplitude is more difficult. Whether the coded properties of the deflection, which forms part of the ERP, carry information, and if so, the basis of this code needs further clarification. Latency of response appears to be somewhat easier to interpret. Presumably the earlier the deflection, the earlier the activation of the neuronal generation which is the basis of the appropriate component and therefore the more rapidly this phase of processing is completed. The problem of interpretation of hemispheric asymmetries in ERP, if they occur needs considerable development. Three approaches seem to have been employed in this research. In one, relatively complex stimuli are presented, such as linguistic stimuli, and in some cases this is complemented by a task which demands higher level processing of these stimuli. In another, stimuli are lateralised at presentation, and on the basis of known neuroanatomy it is expected that lateralisation of input, will lead to earlier activation of one or other hemisphere.

A further refinement of the general approach is to influence the activation of one or other hemisphere by the task demands, and while the task is being carried out present neutral evoking stimuli, the responses to which are averaged. Presumably the responses in relatively activated hemispheres will be of greater amplitude, as long as the neutral evoking stimuli do not require processing resources which are necessary for task performance. Asymmetries in responses to simple click or flash have been reported by Beck and Dustman (1975), Davis and Wada (1974) and Lewis, Dustman and Beck (1970), whereas Shelburn (1972), Harmony, Ricardo, Otero, Fernandez and Valdes

(1973) and Galambos, Benson, Smith, Schulman and Osier (1978) failed to find evidence of asymmetries. The results in this area are equivocal. It is relatively easy to understand the equivocal nature of the results since it is not clear what the respondent was expected to do with the stimulus.

Early studies using speech stimuli which resulted in hemispheric asymetries in EEG response have been usefully reviewed by Anderson (1978). The amplitude differences in middle latency components commonly recorded (Cohn, 1971; Morrell and Salamy, 1971; Wood, Goff and Day, 1971; Molfese, 1972; Neville, 1974; Haaland, 1974; Friedman, Simson, Ritter and Rapin, 1975) are suggestive of a neural structure for the detection of linguistic features in the left hemisphere. In most cases, subjects were asked to monitor the stimuli and a check was made for accuracy. Wood, Goff and Day (1971) had their subjects make a discrimination, either on the basis of linguistic or acoustic features and found that the ERP from the left leads had a larger amplitude, indicating the involvement of the left hemisphere in linguistic processing.

Molfese (1978) and Papanicolau and Molfese (1978) utilized the principal components analysis technique and found evidence of asymmetries in some components according to expected functional lateralization demonstrating the potential of the technique as an objective method for determining the component structure of a complex wave form.

When the presentation of simple stimuli is lateralized it would be expected that the contralateral hemisphere would be preferentially activated because of more direct information transmission. A number of reports (Eason, Groves, Odon and White, 1967; Eason, White and Odon, 1967; Andreassi, Okamura and Stern, 1975) have shown that the components of ERPs elicited by simple visual stimuli presented in one or other visual half-field are of shorter latency or larger amplitude on the side of the head contralateral to the field stimulated. Similarly, in the auditory modality, comparisons of nonaural, diotic and dichotic stimulation have been made with respect to responses over each hemisphere with lateralized presentation of auditory stimuli. Wolpaw and Penry (1975) identified a component, a positive peak, the latency of which is shorter over the hemisphere contralateral to stimulation. In a later paper (Wolpaw and Penry, 1977) monaural and binaural stimulation were compared and an amplitude enhancement over the contralateral hemisphere was noted. Mononen and Seitz (1977) utilized an interesting dichotic presentation method: in one ear sentence material was presented and in the other clicks which were located at specific points in the sentence. Subjects had to monitor the clicks and identify the parts of the sentence in which they occurred. Contralateral ERPs had significantly shorter latencies than ipsilateral ERPs. It was suggested that the nonverbal click takes on almost linguistic significance in this paradigm. Amplitude measures of middle latency components did not show significant differences but if the cognitive demands of a task are influential,then later components should be susceptible to this form of manipulation, and thus display asymmetries.

Friedman, Simson, Ritter and Rapin (1975) conducted an experiment designed to elicit hemispheric asymmetries, particularly in later components. The task involved detection of words and human sounds when designated as signals. A "no task" baseline was included. The P300 was shown to increase significantly in amplitude with task demands but hemispheric asymmetries were not reliably found. The paper contained a critical analysis of a number of weaknesses in studies of hemispheric asymmetries in ERPs. These include: (i) inadequate use of control (no task demand) conditions; (ii) inadequate control over independant variables; (iii) non-standard recording techniques, especially the lack of a common reference; and (iv) inappropriate statistical techniques. Anderson (1978) also raises another important methodological issue, a systematic bias due to lateral eye movements during cognition. In few of the studies reported has this been accounted for when the data suggest that verbal activation is associated with a characteristic pattern of eye movement activity, which could influence the ERP.

In the visual modality full field presentation of stimuli designed to elicit activity in one or other hemispheres has been investigated by a number of authors. Buchsbaum and Fedio (1969) utilized verbal and non-verbal stimuli matched for physical properties and elicited wave forms that were differentiable. Preston, Guthrie, Kirsh, Gertman and Childs (1977) report more dissmilar wave forms over the left hemisphere when employing word and flash stimuli. Shelbourne (1972; 1973) was unable to report differences between hemispheres when using letter stimuli, forming words or nonsense syllables. Rugg and Beaumont (1978) resolved a number of the methodological problems raised in the early studies. Their technique was to present sets of letters and letter-like nonsense patterns in a target detection task which required verbal or visuo-spatial processing. In their analysis of the first three components of the VER, a shorter latency in the right hemisphere for the first positive component was demonstrated independent of stimulus type. Letter stimuli elicited higher amplitude P230-N265 responses in both hemispheres. Clearly the more rigorous studies have failed to find the pattern of asymmetries anticipated from the early data. In this context, the reports of

Thatcher (1977; 1978) are particularly interesting. Utilizing a task which involved sequences of stimuli, either random dot displays or letters which formed the basis of a letter matching task, he was able to control ERPs to irrelevant stimuli before and after relevant stimuli (letters) and responses to the relevant stimuli. Subjects were asked to match stimuli on the basis of physical or semantic characteristics. Asymmetries in later components of ERP's to the second letter of the pair were recorded, as were asymmetries to the random dot stimulus following the first letter. These are interpreted as indicating a rehearsal process in the interval between stimuli.

When stimulus presentation is lateralised it would be reasonable to anticipate clearer examples of hemisphere differences in ERPs. Buchsbaum and Fedio (1970) utilized verbal and nonsense stimuli and interpret the resultant dissimilar evoked responses from the left and right occipital cortex as an indication of time lags in the pathway to the ipsilateral cortex which result in responses which are less rigidly locked to stimulus presentation.

Rugg and Beaumont (1978) used laterialised presentation of letters as stimulus material and varied the task. Subjects had to analyse the letters verbally or visuo-spatially. They found that with the verbal task, field of presentation influenced the amplitude of middle latency components over the left hemisphere but with the visuo-spatial task field of presentation had no similar effect. Visuo-spatial processing elicited hemispheric asymmetry in late components, the amplitude over the left being greater than the right. The experiment is important in that the critical variable manipulated was the processing strategy adopted by the subject. This elicited significant differences in the ERPs.

Gott, Rossiter, Galbraith and Saul (1977) investigated cerebral specialization in a group of commisurotomy patients and controls. The tasks utilized were simple rhythmic word matching and shape matching and stimuli were presented either bilaterally or unilaterally in right or left visual fields. Verbal processing in the left hemisphere was confirmed for the patient group. Utilizing an analysis based on product-moment correlations of responses to unilateral and bilateral stimulation led to significant differences for both patient and control groups. Verbal stimuli presented to the left hemisphere were equally effective in eliciting ERPs in both patient and control groups. Right hemisphere responses were more variable.

A further strategy that may be adopted is to present simple stimuli while subjects are engaged in a task designed to activate the hemispheres preferentially. Galin and Ellis (1975) had subjects perform either verbal or spatial tasks and during these presented flashes and recorded responses at homologous temporal and parietal sites over both hemispheres. Task dependent asymmetry in EEG alpha power was confirmed and this was correlated with asymmetries in evoked potential power and amplitudes. Their results therefore supported the theory of hemisphere specialization. Ras~~s~~mussen, Allen and Tarte (1977) utilized an arithmetic computation task and double flash stimuli. Compared with a resting baseline condition, ERPs recorded at C3 and C4 during the experimental task showed a significant amplitude asymmetry, those recorded from the left hemisphere being smaller than those from the right.

2.7 Conclusion

This chapter aimed to assess the value of the EEG, and measures derived from it, as tools for the development of our understanding of the neural basis of mental functions. Unfortunately many of the studies have methodological limitations which preclude an unequivocal response in support of the conclusion that lateralized processing leads to asymmetries in amplitude and latency, but suggest that qualified support for further investigations using these techniques is appropriate. Some of the methodological difficulties which need to be accounted for in future studies include:

1. Comparison of results from experimental conditions with well defined control conditions;

2. Recordings from a range of electrode sites using a common references;
3. Careful analysis of task requirements to define the processes involved;
4. The use of performance measures which can be interpreted in the context of the experimental psychology literature generally.

The interpretation of results, particularly in ERP studies, poses a number of problems. The significance of amplitude and latency differences for information processing models requires further consideration. One theme which is evident in the work to date is that EEG and ERP measures can be used as indices of localized activation. This has been developed into a number of tests of the hypothesis that cerebral hemispheres are functionally asymmetrical. Interhemisphere differences are supposed to reflect relative activation across hemispheres.

One area of investigation in which a series of coherent studies is emerging is concerned with the effects of 'stimulus set' or the direction of attention to particular external stimuli on the event related potential. Exogenous potentials have the apparent advantage of a clearer relationship to the physical stimulus. Endogenous potential changes indicating the central deployment of processing resources are more difficult to interpret. It is in this context that the later components of the ERP such as the P300 have become the focus of much work. In the next chapter one particular aspect of the ERP, the contingent negative variation will be evaluated with respect to the contribution it may make as a tool in the investigation of the neural basis of mental processes.

CHAPTER 3 The Contingent Negative Variation

In the last chapter measures derived from the EEG and ERP were evaluated as tools for the development of our understanding of localized activity in the brain in relation to information processing tasks. The evidence available has enabled a number of the problems associated with the interpretation of task related changes in EEGs and ERPs to be identified but does not allow a comprehensive and convincing overview.. On the basis of the data available so far it is concluded that the technique has not yet been fully exploited and is, therefore, worthy of further investigation.

The particular rationale employed in this dissertation is that ERPs will provide an indicator of localized activation of the cortex during task performance. Because of the emphasis in cognitive psychology on the active role of the participant in any information processing task it is appropriate when investigating the localization of activity during higher mental processes to utilize so called 'endogenous' event related potentials. In contrast to the 'exogenous' potentials which are primarily related to the stimulus characteristics external to the participant in the task, 'endogenous' potentials supposedly reflect state changes which are determined primarily by the participant. It is in this context that the contingent negative variation has been chosen as a dependent variable which will provide a suitable measurement of brain function enabling progress in the understanding of mental activity.

3.1 The Contingent Negative Variation

In 1964 Grey Walter (Walter, Cooper, Aldridge, McCallum and Winter, 1964) provided the starting point for an extensive literature based on slow potential changes recorded from the scalp. When an individual establishes the contingency between any two events there is a negative potential shift in brain activity in the interval between the two events and this was called the Contingent Negative Variation (CNV).

Recordings of spontaneous EEG activity from active electrodes distributed widely over the scalp demonstrate slow potential shifts but little has been done to investigate the subjective correlates of these events (Weinberg, 1971). It is possible that the CNV is a special example of just such a potential change, time locked by the associated external stimulus events and response requirements. The recording paradigm commonly utilized for the CNV requires a warning signal (S1), an interval between stimuli (ISI), and an imperative stimulus, (S2), to which a response is usually required. The arrangement is illustrated in Figure 3.1 overleaf, with an idealized CNV wave form depicted on the time base.

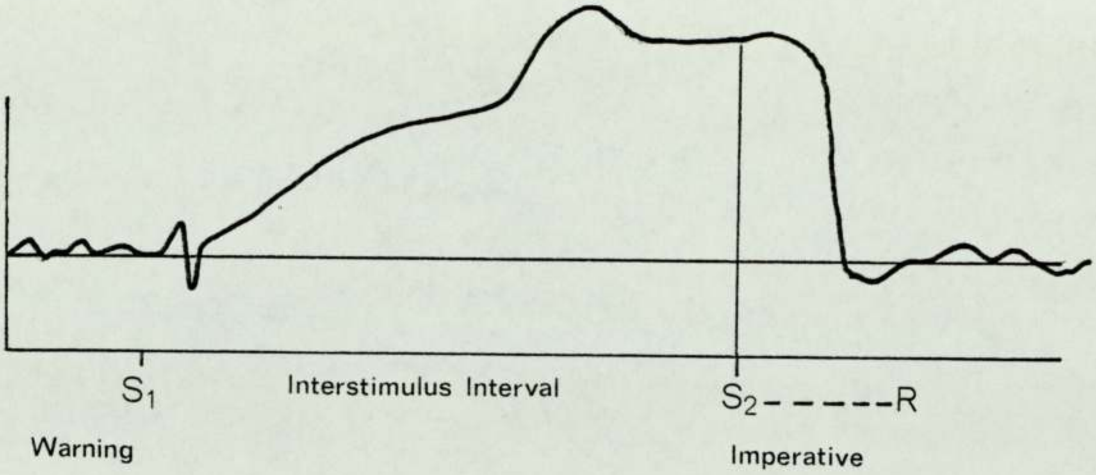

Figure 3.1

Idealized CNV Wave Form, Stimuli and Time Base

The value of a phenomenon such as the CNV for the task of localizing cortical processes which are the basis of higher mental functions depends on its physiological basis, and on the psychological or behavioural significance of the phenomenon for the organism.

3.2 Physiological Bases of the CNV

A number of origins for slow potential changes like the CNV have been proposed (McSherry, 1973). Vascular changes reflecting localized metabolic changes have been rejected because the time course of these changes does not match the time base of CNV changes. Changes in the membrane potential of glial cells follow neuronal changes and probably contribute to potential shifts at the scalp but are not regarded as the primary source. The focus is, therefore, on neuronal systems as putative generators. Slow potential shifts have been recorded from electrodes adjacent to a variety of neuronal aggregates (Rebert, 1971; McSherry and Borda, 1971; Rebert, 1976; Papokstapoulos and Crow, 1976). Presumably, potentials recorded from the scalp are the resultant of widespread neuronal events with the contribution from the more proximal neuronal population being proportionately greater.

Activity in subcortical structures contributes indirectly by influencing events in the neocortex. Comparisons between records from the cortical surface and those from deep in the cortex indicate that negativity at the surface is accompanied by positivity at depth. While the relationship of scalp recorded EEG to underlying neural events is still not completely clear, the generally held view is that activity in the superficial dendritic layer is the most important contributor.

A detailed understanding of the basis of electrical activity recorded from neuronal aggregates is important to any final theory. It is reasonable to assume that local changes recorded within the central nervous system reflect the moment to moment activation of local circuits, but because of the relative spatial insensitivity of EEG recording, the activity at any electrode is a composite from many circuits.

In the context of this dissertation the question of psychological significance relates to the role of the CNV in information processing activities. We can reasonably assume that information processing is based on neuronal events, but this does not mean that the EEG, which is a composite of various neuronal events, directly reflects an information processing code.

However, if it is accepted that function must be localized in the nervous system, even if the systems involved are widely distributed, then it is reasonable to expect that topographic differences in slow wave activity will reflect the pattern of activation of the proximate parts of the system. It would be reasonable to regard slow wave activity as directly involved in information processing only if the slow activity could be shown to significantly modify unit activity. At this stage the only assumption is that regional slow wave activity is associated with regional activation.

In the living human, the nervous system is never quiescent and therefore, activation must be considered as activation relative to other sites and other times. Even during a behaviourally quiescent state, such as sleep, it is clear that the central nervous system is highly active, albeit of quite a different form from that in the working state. The concept of activation (Duffy, 1972) has a lengthy history in psychophysiology. The traditional view holds that activation is unitary, affecting all systems in the organism, while more recent data indicate that complex patterns of activation can be discerned among bodily systems suggesting that more than one arousal system is in operation. It is suggested that recordings from various scalp sites indicate activation of underlying cortical columns. To adequately test this hypothesis patterns of slow wave activity must be measured and these patterns should be influenced by experimental tasks selected on some independent criteria as regional activators. This necessitates recording from electrodes in a range of sites but commonly the number of sites utilized has been restricted. If a poll of the most popular recording site for the CNV was taken, the vertex would be a clear winner. Runners-up would be other sites on the midline (Fz, Pz) conforming to the 10/20 system (Jasper, 1958).

The view that the CNV is a unitary phenomenon has discouraged the search for topographical variations particularly where amplitude variations are small and unreliable and elicitation depends on strong experimental control and sensitive measurement.

3.3 Psychological Correlates of the CNV

Grey Walter's influential paper (Walter et al., 1964) explored the basis of the CNV by using the stimulus components S1 and S2 separately and in combination and showed that the temporal relationship between the two stimuli, and the response requirement, were necessary for the CNV to appear. The initial interpretation of the phenomenon in terms of sensori-motor association was clearly influenced by the conditioning paradigm, which dominated psychology at that time. However, responsiveness of the phenomenon to verbal instruction which was also reported in the initial paper is an important indication of the cognitive dimension. Responses depicted in the original paper were all recorded from the vertex, although topographical variations were reported.

Manipulation of the components of the classical recording paradigm have increased understanding of the CNV. Lengthening the inter stimulus interval (ISI) from 1.0-1.5 sec. to 3.0-4.0 sec. revealed the existence of two components, an early orienting response (OR) and a later readiness potential (RP) (Loveless and Sanford, 1976; Gaillard, 1976) probably equivalent to the <u>Beireitschaftspotential</u> of Kornhuber and Deecke (1965).

Topographical variations have also been documented. Klorman and Bentson (1975) reported that early and late components varied in amplitude between midline parietal and frontal sites. Combinations of tones and flashes for S1 and S2 (Ritter, Roth and Vaughan, 1980) suggest that frontal sites are sensitive to warning signals in the auditory modality, and vertex to the requirement for a motor response. The frontal negativity to auditory warning signals may be a non-specific activation effect. Rorbaugh, Syndulko and Lindsley (1979) have recorded a similar potential with single acoustic stimuli.

The motor response requirement has been a source of some controversy. The evidence is incontrovertible that there is a negative shift in the EEG preceding a voluntary movement (see Desmedt, 1977 and McCallum and Knott, 1976 for collections of relevant papers). The problem lies in deciding whether this is essential to the development of a CNV. A number of authors have reported a CNV in the absence of a requirement for a specific motor response, but it is very difficult to rule out non-specific motor responses which are correlates of information processing in any experimental tasks. Donchin, Gerbrandt, Leifer and Tucker (1972) conclude that the CNV is not contingent on a motor response since the electrical responses following S2 appeared to vary systematically with experimental tasks, in which the motor requirement was constant. Factor analytic techniques applied to these data confirmed the results obtained by visual inspection and measurement by hand.

Similarities between the *Beireitschaftspotential* and the latter part of the response in the CNV paradigm have been noted, although, the different responses were identifiable from topographical variations (Grunewald, Grunewald-Zuberbier, Netz, Homberg and Sander, 1979). There have been attempts to relate the morphology of the wave form to the requirements for a motor response (Nakamura, Fuleni, Kodoboyoshi, 1978). Clearly, the requirement of a motor response interacts with other components of the experimental task, but is not the sole determinant of the CNV.

Following S2, the CNV returns in the direction of the prestimulus baseline whether or not a motor response is required. Wilkinson and Spence (1973) examined the post stimulus resolution of the CNV and concluded that it relates to categorization of the stimulus just presented.

The importance of these basic studies of the CNV lies in two main conclusions:

1. The CNV is not a unitary phenomenon. The negative going shift comprises a number of components which are defined by the specific task demands, and therefore the deployment of specific cortical resources;

2. Topographical variations in the CNV systematically reflect variations in task demands.

The problem of mapping psychological concepts onto our knowledge of brain function is not confined to investigations of the CNV. Usually the task requirements of the experimental situation, or the variables manipulated tend to define the concepts used in discussion. It is probably unrealistic (as Knott, 1972, suggested) to expect a single psychological correlate of the CNV, rather the situation is likely to be a complex interaction of psychological variables. Four interpretations appear to summarize the range, expectancy (Cohen and Walter, 1966; Walter, 1965; Walter et al, 1964) motivation (Irwin, Knott, McAdam and Rebert, 1966) conation (Low and McSherry, 1968; McAdam, Irwin, Rebert and Knott, 1966) and attention (Tecce, Sauvingnano-Bowman and Meinbresse, 1976; Blowers, 1977; Hillyard and Picton, 1979).

Attention has been a recurring theme in attempts to specify a psychological interpretation of the CNV. Commonly, the independent variable which has been manipulated is form of distraction. It is useful to reflect a little on what might be happening in the classical constant foreperiod warned reaction time format. The task encourages the subject to inhibit all behaviour and await a significant sensory event. Inhibition of other irrelevant forms of activity is characteristic of the situation. In this context, it is relatively easy to understand the dissociation of patterns of arousal in various subsystems. The reduced motor demand would presumably lead to deceleration in the heart rate, while the nervous system would be primed for the receipt of external stimulation. In the CNV studies examining attention, the distraction procedure assumes considerable importance since this requires a specific activity in the S1-S2 interval.

Generally the results show that with distraction the amplitude of the CNV is decreased. One finding stands in contrast to this. Blowers (1977) found that the amplitude of the CNV was enhanced and that reaction times were significantly longer in experimental conditions in which subjects selected on the basis of measures chosen to define attentional ability and range of arousal participated in an experimental paradigm in which the distracting stimulus was apparently presented throughout the S1-S2 interval. This is dissimilar to other distracting paradigms and may explain the disparity in findings.

The attentional paradigm illustrates an important point in relation to work on the CNV. The specification of activities of the participant in the S1-S2 interval is of considerable importance to the eventual understanding of the behavioural correlates of slow potential shifts. Unfortunately, the traditional CNV paradigm has given little attention to measuring our understanding of events in this period.

3.4 CNV in Clinical Groups

A number of authors have examined the CNV in clinical groups. Useful reviews of these studies have been presented by Dongier (1973a; 1973b), Shagass, Ornitz, Sutton and Tueting (1978) and Shagass (1976).

The nature and location of lesions has been shown to result in overall attenuation of the CNV as well as localized attenuation over the site of the lesion (McCallum and Cummins, 1973) and enhancement of the CNV after surgical treatment leading to improvement in mental state has been demonstrated in at least some of the cases (Zappoli, Pepini, Briani, Benvenuti and Pasquinelli, 1976). Traumatic closed head injuries also resulted in attenuation of the CNV and interestingly, patients performing worst on Benton's visual retention test took longer to resolve the CNV to the baseline than in control subjects (Rizzo, Amabile, Caporali, Spadoro, Zanasi and Morocutti, 1978).

Attenuation of the CNV and the emergence of the Post Imperative Negative Variation (PINV) have been reported in a variety of psychiatric disturbances (Shagass et al., 1978). In a longitudinal study of bipolar cyclothymic patients, Rizzo, Amabile, Caporali, Pierelli, Spadoro, Zanasi and Morocutti (1979) report attenuation in both manic and depressive phases. In 4 of 5 patients a

PINV was identified in the manic phase and this was interpreted as an indication of the arousing effects of the recording situation. Chouinard, Amabile and Dongier (1977) suggest that an extended PINV indicates a poor prognosis.

In the context of psychopathy and sociopathy (Pety, Benezech, Eschopasse and Noel, 1978; Syndulko, Parlear, Jens, Maltzman and Ziskind, 1975; McCallum, 1973) results are considerably more difficult to interpret. The most convincing evidence appears in situations where a conditioning paradigm is employed (McCallum, 1973) and especially where a noxious stimulus is employed as the imperative signal (Syndulko et al., 1975).

Studies of patients undergoing various neurosurgical procedures and with disorders of supposedly subcortical origin have confirmed subcortical slow wave phenomena found in animal studies bearing a relationship to activity recorded at the level of the scalp (Tsubokawa and Moriayasu, 1978; Podivinsky, 1978; Tsubokawa, Katayama, Nishimoto, Kotani and Moriayasu, 1976/77).

A particularly interesting study in the light of the recent interest in imagery in relation to phobic disorder (Lang et al., 1979) is the study by Dubrovsky, Solyom and Barbes (1978) in which larger amplitude CNV, longer PINV duration and shorter reaction time were found in a patient group using phobogenic stimuli when compared with non-disturbing stimuli. These differences disappeared with successful desensitization therapy. In contrast Klorman and Ryan (1980) found that high-fear subjects tended to produce larger early CNV responses with neutral scenes than with fearful scenes and low fear subjects showed a trend in the opposite direction. In this study no motor response was required and an extended foreperiod paradigm was utilized. While the clinical evidence is relatively sparse and is notoriously difficult to interpret, these results do suggest that changes in slow potential activity can be related to the cognitive dimensions of the clinical problems.

O'Connor (1980a, 1980b) demonstrated the CNV in a group of patients suffering senile dementia, which was of lower amplitude and longer latency than a control group of elderly subjects. Utilizing a range of extended foreperiods the senile group appeared less able to adapt, particularly at the longer intervals and this was interpreted as reflecting the effort expended in adopting an appropriate task relevant set.

3.5 Cognitive Processes and Topographical Patterns in the CNV

The investigation of the relationship of the CNV to cognitive processes requires the manipulation of activities in the S1-S2 interval in a systematic way. For example, studies employing the recording paradigm where the warning signal either indicates the need for a response to the imperative signal or not, subtly influence activity in the ISI. Howard, Fenton and Fenwick (1980) utilizing a clinical population, found a reduction in the contingent negative variation in the NO GO trials compared with the GO. The problem of the motor response requirement unfortunately confounds the findings.

Manipulation of the discrimination task at S1 or S2 produced different shaped CNV (Weinberg, Michaelewski and Koopman, 1976). Information in S1 produced a negative ramp shape, whereas the presentation of information in S2 produced a rapid rise followed by a slow decline in negativity, suggesting the importance of information processing in the generation of the CNV. Similarly, studies in which feedback was delivered on response (Otto and Leifer, 1973) showed enhanced CNV amplitude. Picton and Low (1971) demonstrated that enhancement of the informational content of S2 prolonged the CNV.

Other studies investigating the relationship of the CNV to cognitive processes tend to manipulate activities in the S1-S2 interval more directly. Commonly the aim has also incorporated an investigation of topographical patterns of CNV activity with varying task demands. The hypothesis of hemispheric asymmetries in function in the human brain has been particularly popular. Of the early studies, a number attempted to grapple with the problems of studies of cognitive processes in the ERP laboratory, but were methodologically flawed.

Rubin and McAdam (1972) had subjects peruse a list of 175 words and then recorded CNV's while individual words were presented as S2 in the CNV paradigm. Subjects had to indicate on a confidence scale whether the word appeared on the original list or not. The EEG from only two sites was recorded, the vertex and a site anterior and lateral to T3. Differences between wave forms preceding subjectively certain and uncertain responses were identified.

McAdam and Rubin (1971) employed a task in which subjects initiated the tachistoscopic presentation of an array, one position of which was identified by a dot. The task was to indicate the position identified according to a letter code. Measures of both readiness potential (preceding stimulus presentation) and CNV (between S1 and S2) were taken. Averages were computed in three categories: (i) certain and correct; (ii) doubtful but correct; and (iii) no idea. The amplitude of the RP was a successful predictor of perceptual performance suggesting that a stimulus set had been adopted. Amplitude of the CNV decreased systematically through categories (i), (ii) and (iii), supporting the previous finding that confidence in decision was directly related to amplitude.

The relationship between slow activity in different phases also formed the focus of a study by Donald (1970). Between the warning signal (S1) and task signal (S2) he suggests subjects are in a "hold" phase, and after S2, an "operate" phase. By requiring performance on a task, either a mental arithmetic problem or a short term memory problem, the CNV was sustained for considerable periods after the presentation of the task stimulus. This aspect of the response is normally obscured because S2 and response are very closely related temporally. Findings such as these suggest that the CNV may indicate activity in functional systems related to specific tasks rather than a general arousal system.

Marsh and Thompson (1973) suggested that one of the difficulties in studies of hemispheric differences in the CNV is that a particular task induces a tonic "set" which reduces the phasic responses surrounding the particular stimuli. The original experiment which included verbal recognition and line recognition tasks (Marsh and Thompson, 1973) confounds response requirements, and probably task complexity with task characteristics. A later study overcoming the problem of response requirments demonstrated hemispheric asymmetries in the CNV, the left hemisphere having lower amplitude responses. A similar study (Cohen, 1973) employing visual recognition for words, and line drawings of objects showed that CNV amplitude was related to response accuracy and speed. Larger amplitude CNV was related to correct recognition and shorter RT. Topographic differences in response along the midline suggest that information transactions modulate the CNV. Utilizing a paired associate learning paradigm Peters, Billinger and Knott (1977) were able to demonstrate a modification of the CNV response as learning took place. Response amplitude at Fz, Cz and Pz was inversely related to percent correct recall. They interpreted the result as indicating a change in arousal level with learning.

The problem of defining the component structure of a wave form such as the CNV which is itself derived from many microsystems within the cortex is not simple. While many of the studies outlined so far have identified a number of the important contributing factors few have developed the full power of the technique.

The strength of more recent work derives from the incorporation of a clearer experimental framework. For example, an influential development in the area of memory research has been the work of Sternberg (1966, 1969). Employing the RT measure in an 'additive factor' framework his group has investigated recognition memory for sets of items held in short term memory. Two investigations of this sort have incorporated ERP measures. Roth, Kopell, Tinkleburg, Darley, Sikova and Vaseley (1975) recorded the EEG from Cz. Subjects were presented with a series of digits and asked to hold the set in memory and compare with a probe stimulus which was presented one second after a warning tone. Response time data broadly confirmed the findings reported by Sternberg, of an increase in latency with an increase in set size. Also the CNV amplitude varied with set size, the largest amplitude response being associated with the smallest set size, and CNV resolution became slower as the size of the target set increased. The voltage 300 milliseconds after the probe also showed a significant effect of set size. The same group of workers (Ford, Roth, Mohs, Hopkins and Kopell, 1979) explored age-related changes in ERP using the Sternberg paradigm. Reaction time increased with the number of digits in the memory set, and the rate of increase differed between old and young groups. Amplitude of the CNV decreased with increasing set size but was not significantly different for the two age groups.

Another recent development in memory research has been the idea of "levels of processing" (Craik and Lockhart, 1972). If the task demands require that a set of words is encoded on the basis of orthographic, phonetic or semantic analysis respectively, performance of retrieval depends on the 'level' to which the set is processed. One criticism of the approach has been the difficulty of providing an independent measure of 'level' of coding (Baddeley, 1978). The possibility that physiological measures might provide just such as measure did not escape the original authors (Craik and Blankstein, 1974). Sanquist, Rohrbaugh, Syndulko and Lindsley (1980) utilized ERPs in a study designed to evaluate electroencephalographic measures as a sign of level of processing. The study was not designed to incorporate a CNV measure, but is a demonstration of the power of amalgamation of ERP and behavioural techniques. The experiment was conducted in two phases: (i) a judgement task, (ii) a recognition memory test. In the judgement task, participants had to make a decision whether two words presented separately, two seconds apart were the same or different. In separate blocks of trials, participants were asked to make decisions based on orthographic, phonemic or semantic criteria. The recognition memory phase was based on items used in the judgement task, and sixty 'new' words. Subjects were asked to indicate whether the word was old (seen previously in the judgement task) or new. ERPs were computed for each comparison task for records from Fz, Cz, Pz and P3 and P4. Two components were measured in the ERP using principal components analysis, the late positive component (LPC) and the later 'slow wave'. At the lateral sites (P3 and P4) smaller amplitude components were observed and there were no hemispheric asymmetries. The Late Positive Component (LPC) varied primarily with the type of judgement made in the phonemic and semantic tasks whereas, the slow wave was affected largely by the type of comparison being made. It is suggested that the size of LPC relates to amount of associative activity evoked by a stimulus. More activity, and larger LPC, appear related to subsequent recognizability of the stimulus.

In a more complex recording paradigm involving sentence presentation in both auditory and visual modalities, the CNV was generated and maintained through the sentence until either the response was made or a meaningless component reached. At this point the CNV resolved to the baseline (Goto, Adachi, Utsunomiya, Nalcano and Chin, 1978).

The adoption of more complex information processing paradigms for ERP recording confirm the possibility of a fruitful relationship between the approaches. An interesting trend in the data so far is that amplitude of any CNV appears to be attenuated by increasing task difficulty. This presents some measurement problems since the appropriate dependent variable is the decrease in response with increasing task complexity rather than the absolute amplitude. That is, while a subject is focusing attention on a limited part of the environment and doing little apart from 'expecting', the amplitude of the CNV is enhanced. When asked to process information in the interval rather than just expect this response is attenuated. Possibly topographical differences will provide a suitable explanatory framework, different mechanisms being located in different regions of the cortical mantle. It may also be necessary to reconsider our understanding of the slow potential shift generally. Perhaps positive going trends such as the LPC are related to active processing and negative going trends to inhibition of activity in anticipation of receiving critical information. The relationship between negative and positive components of the response is important in this context.

Problem solving tasks have provided a useful basis for the investigation of the dynamics of slow potential shifts during learning. A number of authors (Borda, 1970; Donchin, Otto, Gerbrandt and Pribram, 1971; Hablitz, 1973; Rebert, 1972) have identified changes in the topography of slow potentials at various stages of learning. In one example (Ben, Thompson, Williams and Marsh, 1974), participants performed a binary choice gambling task with a patterned presentation of the two stimuli. Subjects were set the task of winning as much money as possible by betting on each prediction. By correctly determining the sequence, subjects were able to considerably increase their winnings. Event related potentials were measured at midline sites (Fz, Cz and Pz) for the first thirty trials. Differences between a group successfully predicting the sequence and an unsuccessful group were not significant. At all sites mean CNV amplitudes were lower for the gambling task than they were for a simple RT task, although the differences were only significant with frontal and vertex records. In records taken during the gambling task, mean amplitudes increased from Fz to Cz to Pz and were significantly different.

Stuss and Picton (1978) employed a concept formation task in which subjects were expected to sort visual stimuli according to a predetermined criteria. The EEG was recorded from multiple sites on the scalp and averages were computed for stages of concept formation such as preinsight (subject was still making errors prior to learning the correct criterion) and insight trials (where subject received first positive feedback). During the stimulus slide there is a sustained negative shift in posterior regions and a positive shift frontally. Just prior to the response a readiness potential is superimposed on the sustained negativity which is maximal at the vertex and left frontal sites (for response with right hand). A baseline shift in the negative direction occurred with change in criterion. The CNV was present before appearance of the slide and absent when the subject was involved in a mental arithmetic task. No significant differences were found between the experimental (concept learning) and control (known concept) conditions. Asymmetries in the CNV were not identified and the authors suggest that adequate exploration of this problem might require greater sensitivity in recording systems and more control over subject strategy.

An ingenious approach to the study of concept formation and event related potentials was adopted by Bauer and Nirnberger (1981). Stimulus presentation was dependent on preceding negativity or positivity in the EEG record. The results indicated that concept learning was significantly faster when the stimulus was preceded by a negative shift than when preceded by a positive shift. The EEG was only recorded from central sites (C3 and C4) and the sites were shown to be differentially related to performance suggesting that EEG from each site is independent.

If improved performance on a task is related to the negativity at a particular site, and voluntary control of negativity can be established, then a very powerful tool for the investigation of brain-behaviour relationships is available.

Soon after the initial paper on the CNV (Walter et al., 1964), McAdam, Irwin, Rebert and Knott (1966) reported on the "conative" control of the phenomenon. Recently this aspect has been examined further by a group at the University of Tubingen who have shown that by utilizing biofeedback techniques subjects are able to gain control over slow cortical potentials (Elbert, Birbaumer, Lutzenberger and Rockstroh, 1979). Furthermore, regulation of slow cortical potentials has been shown to influence performance on a variety of tasks including signal detection (Lutzenberger, Elbert, Rockstroh and Birbaumer, 1979) and mental arithmetic (Lutzenberger, Elbert, Rockstroh and Birbaumer, 1981). The same group has also manipulated cortical negativity by applying a DC current to the scalp and has shown that fastest responses in the simple warned RT paradigm were associated with an externally applied vertex positive current which induced a cortical negativity.

3.6 Hemispheric Asymmetries in the CNV

A few authors have chosen to explore topographic variations in the CNV in the context of theories of hemispheric specialization (Butler and Glass, 1974; Donchin, Kutas and McCarthy, 1977). The strategy employed has usually been to select a task that differentially involves the two hemispheres on empirical or intuitive criteria and modify this to enable CNV recording. A number of authors have employed responding hand as the differential activator since the motor strip in the contralateral cortex is known to be the source of the motor outflow for that hand (Bard, 1968).

Donchin, Kutas and Johnson (1974) examined data collected from homologous sites in each hemisphere in two recording sequences, one in which the subject responded with each hand alternately (predictably) and the other in which responding hand was random (unpredictable). They failed to find lateral asymmetries in either condition. Earlier studies of the RP, preceding a voluntary response (Kornhuber and Deecke, 1965, Gilden, Vaughan and Costa, 1966) had reported an asymmetry. Kutas and Donchin (1974) focused on the possibility that the force required was critical to the elicitation of asymmetries in the RP and found supporting evidence in a study in which the response was a squeeze on a dynamometer, calibrated to each subject's response range. Interestingly, they noted that response force accentuated asymmetry but asymmetry does not increase systematically with increasing force. This suggests that force alone is not the crucial factor in determining the ERP but possibly priming of the part of the motor cortex controlling the particular limb which is responding. Donchin et al (1974) examined the problem further using a recording paradigm in which the dynamometer squeeze activated a slide projector. Three phases in the response, each providing different cerebral indices were measured: (i) pre-response interval or RP accompanying the dynamometer squeeze, (ii) post response interval and (iii) click-slide interval immediately preceding slide presentation. Asymmetries related to hand use were identified in the RP. The wave forms in the post response interval and the click-slide interval were symmetric. Apparently there was no specific task demand requiring processing of the slides. While

Donchin et al (1974) claim that analysis of the wave forms by subject did not reveal asymmetry, the results depicted display definite hemispheric differences. In a further study they employed a task (Structure-Function Matching Task) (Levy, 1974), the cognitive demands of which preferentially elicit activity in one or other hemisphere depending on task instructions. Reaction times were recorded as well as CNV from homologous sites at frontal, central and parietal cortex. Asymmetric CNVs were recorded in all match conditions and amplitude over the left hemisphere was consistently higher. The recorded wave forms were subjected to Principal Components Analysis with varimax rotation. Two main factors were identified in the S1-S2 interval and these were regarded as equivalent to the two components identified by Loveless and Sanford (1974; 1975) using the longer inter-stimulus interval, namely, an orienting response and a readiness potential. Where asymmetries were reported they were not always consistent with the purported task requirements, suggesting wide variability in pattern of response by subjects.

Butler and Glass (1974) reported asymmetries in the CNV, while subjects awaited numeric information which had to be memorised, added or checked. Asymmetries were identified for all three tasks, and the amplitude over the hemisphere contralateral to the responding hand was consistently higher. The memory and addition tasks were chosen to preferentially involve the left hemisphere, but since asymmetries were no greater for these than the checking condition, this must be reconsidered. It is possible that the asymmetries recorded reflect a structural difference, due to handedness. Alternatively, the nature of the tasks may not be as hemisphere specific as originally envisaged.

Rorbaugh, Syndulko and Lindsley (1976) explored topograhic variations in the CNV using a 4 second ISI and a simple warned RT task. At the central sites asymmetries were found in both early (CNV) and late (RP) components and these related to the responding hand. Differences were also recorded between the midline sites. The early component is largest from frontal derivations, whereas the late component predominates at central sites.

In a further report (Butler, Glass and Heffner, 1975) subjects were required to make identity judgements on successive words or faces. Verbal material elicited significantly larger CNVs at central regions but faces evoked poor CNVs not differentiable between hemispheres. Significant differences did occur to faces between presentation of the comparison slide and response suggesting differential involvement of the hemispheres while the subject was actively comparing and deciding.

Topographic variations in form have also been reported by Papakstopoulos and Fenelon (1975) in the classical CNV paradigm. While not directly addressing the question of hemispheric asymmetries, their results suggest that the CNV reflects location specific processing rather than a general phenomenon. Differences in form were also reported for midline sites in frontal, central and parietal regions, but differences between hemispheres corresponding to hand use were not evident.

A number of assumptions which appear to have influenced the studies of the CNV need reconsideration. In particular the unitary nature of the phenomenon has come under increasingly active challenge. Results from a variety of sites, and using longer ISIs suggest that the classical CNV is composed of more than one consistent component and the proportional contribution of components varies with site and task. Attempts to employ tasks designed to manipulate cognitive demand have met with varying success. Where it is possible to be reasonably sure the participant is actively processing information then related cerebral responses appear measurable. A number of attempts to provide a theoretical interpretation of slow wave phenomena have emerged (Pribram, 1970; Cooper, McCallum and Papakstopoulos, 1979). These will be considered in more detail in the final chapter where the empirical results collected in this research programme will be reviewed in relation to the literature available.

3.7 Mental Chronometry

One procedure by which the information processing demands could be manipulated was to increase the range of stimuli and responses in the choice reaction time situation. The Dutch physiologist, Donders, was the first to develop a systematic account of mental processes based on reaction times. The measures he employed were: (i) type 'a' reaction, simple; (ii) type 'b' reaction, presentation of any one of five stimuli with a separate response to each stimulus and (iii) type 'c' reaction, presentation of five stimuli only one of which required a response. His theory was that each type reflects a change in the mental functions involved in the task. For example, type 'b' required discrimination, whereas type 'a' did not. By subtraction of appropriate RT's (in this case a from b) it was possible to measure the time devoted to a particular aspect of processing. For a number of reasons, both historical and scientific, interest in Donders' method waned and has only been revived relatively recently. One weakness of this approach is that it assumes the mental processes involved can be added and subtracted from the task without affecting the other components. The important idea was that changes in RT could be used as a monitor of mental processing. By adding and subtracting stages of processing the overall RT would be proportionately increased.

With the increasing influence of the "cognitive movement" particularly since the Second World War, and the development of information theory (Shannon and Weaver, 1949), the RT technique has been used more widely. Perhaps the most important recent influence in this area has been the work of Sternberg (1966, 1969). The experimental paradigm he employed involved manipulating the size of the short term memory load by presenting different sized sets of items. After a short interval, a probe stimulus is presented and the participant responds as quickly as possible indicating if the probe is a member of the target set. In his original report (Sternberg, 1966) digit lists were used as the stimulus material. Reaction time to the probe digit was shown to be a linear funtion of size of set and the slope of the line thus indicated a proportionate increase per item (38 m.sec). The findings were interpreted as a search process involving serial comparison of each item in the target list, and the search being exhaustive, all items in the list are compared with the probe before a response is made. For example, degradation of the probe stimulus (Sternberg, 1967) had an overall effect, increasing response times at all set sizes, but left the slope unchanged.

In his 1969 paper, Sternberg developed the theoretical underpinnings of the technique to enable a more comprehensive study of mental processes. The key features appear to be that information processing involves a series of non-interactive independant stages. If it is possible to identify variables which influence each stage separately then a systematic account of all stages in the processing of information can be developed. Independence of processing stages does not mean statistical independance. A general factor which influences all stages would mean that changes in component times are correlated and therefore the times are additive. This is not the case for variances.

The importance of this work for the research programme reported in this dissertation is that a more sophisticated analysis of behavioural responses (RT) is possible. If the behavioural and neurophysiological measures being recorded are indices of underlying mental processes then some relationship between the two classes of dependant variable would be expected to emerge.

In this chapter the work relating the contingent negative variation (CNV) to cognitive processes has been reviewed. As in the previous chapter, where a greater range of EEG measures was explored the picture emerging is encouraging but not convincing. Encouragement can be drawn from the experimental work since most of the research conducted can be systematically improved to provide more sensitive tests of hypotheses, and from the theoretical interpretations of the results since the concept of the CNV appears to be evolving.

Rather than a unitary phenomenon, components have been identified and the general relationship between cortical negativity (and positivity) and behaviour is being actively explored.

Since the systems utilized in investigating the EEG and ERPs largely predetermine the outcome of studies, the next chapter will concentrate on specifying the desirable characteristics of an experimental system, and listing the characteristics of the systems used and evaluating these in the light of the specifications previously developed.

CHAPTER 4 Experimental Systems

4.1 Rationale

The research reviewed so far has been directed towards the problem of identifying physiological changes, in this case EEG and ERPs which are correlated with covert mental processes. More specifically, the hypothesis that functional asymmetries between hemispheres are also identifiable in asymmetries of physiological variables has been tested as part of this research.

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At this stage it is not possible to single out from the literature a study which has provided the definitive test of this hypothesis. Many tantalising findings have been reported in studies which are flawed methodologically. In effect, the research in this area is at the stage where the search for suitable paradigms and methodologies provides the substantive base.

As a start to the chapter of this dissertation which introduces the techniques utilized in this programme of research it is as well to consider the rationale, which will influence the methods to be employed, and the evaluation of the effectiveness of these techniques.

At the simplest level three criteria must be satisfied by any research programme which purports to provide a test of the localization hypothesis:

1. The formulation of tasks which require cognitive processing

which, on the basis of independent studies, is reliably localized in a cortical region;

2. Monitoring task performance in such a way as to provide a valid correlate which can be interpreted in the context of the experimental literature;
3. The measurement of cerebral function at a spatio-temporal sensitivity which enables localized activation and suppression to be identified.

Unfortunately it is not possible to claim that these criteria have been completely satisfied in the research reported in this study, just as most other work in the area is more or less inadequate on technical grounds. It is, therefore, necessary to make some assessment of the relative effectiveness of the techniques employed, and hence, the value of the results reported. Perhaps the best starting point is a detailed examination of the criteria identified above.

4.2 Cognitive Processes

The choice of tasks which demand cognitive processing is obviously crucial to the success of a research programme designed to investigate physiological correlates of mental processes. An extensive literature on the biological substrates of language in the left hemisphere has accumulated, and this has dominated the development of the hypothesis that mental processes in general are localized. In contrast, the literature on the role of the right hemisphere is less well developed both conceptually and empirically, and may, therefore, reward careful analysis. The problem is to develop an appropriate framework in which non-linguistic cognitive activity might be investigated.

At the outset the difficulties this entails should be recognised, particularly the pervasive influence of verbal mediators on performance of most mental tasks. It is unlikely that a pure task utilizing only non-linguistic abilities, can be devised. It is practically impossible to be sure which processes are employed when an individual carries out a particular task. Perhaps verbal protocols collected during performance, inferences drawn from behavioural measures, and physiological measures can complement each other in such a way as to enhance our understanding of the mechanisms involved.

A seminal work in cognitive psychology defines cognition as follows:

> all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered and used. It is concerned with these processes even when they operate in the absence of related stimulation as in images and hallucinations (Neisser, 1967)

The reference to imagery as a process which is typical of cognition has particular attractiveness as a theme for the programme of research for this dissertation. It is only relatively recently that the concept of imagery has once again become amenable to investigation. For a considerable part of this century the dominance of the behaviourist movement in experimental psychology has discouraged research on such a mentalistic concept. The research which results from the broadening of horizons can be roughly classified by reference to:

1. The demands of the tasks which participants are required to perform;
2. The differences between individuals with respect to the ability to use imagery.

In one chapter (Chapter 8) the question of individual differences in relation to performance of the task will be briefly considered. Richardson (1977) has suggested that two aspects, vividness and control, are orthogonal variables that define individual ability to utilize imagery. The Sheehan (1967) version of the Betts Vividness of Imagery Questionnaire was used to obtain a measure of vividness and the Necker Cube Reversal Task (Richardson, 1977) as a measure of control. The relationship between vividness and control was evaluated for participants in the mental rotation experiments and two groups selected on the basis of extreme values on the control scores. The performance of these two groups wads then compared.

However the main research effort has concentrated on manipulating task demands as a method of approaching the localization of imagery mechanisms. Even a cursory glance at the literature attests to the pervasiveness of the phenomena and to provide a convincing account of the general applicability of imagery in human thought of physiological measures it was decided to investigate a range of tasks rather than concentrate on the detailed investigation of a single more narrowly defined task. An overview of the results obtained would, therefore, provide some indication of the general applicability of physiological measures to the investigation of cognitive activities.

A number of authors (Paivio, 1971; Richardson, 1980) allude to the possibility of mechanisms localized in the posterior quadrant of the right hemisphere which are prepotent for image processing and it is the prospect of a coding mechanism for visual memory which is complementary to the verbal code that proves so attractive and is the basis of an asymmetry hypothesis. The initial focus is, therefore, on imagery as a process which is typically cognitive, and the posterior right hemisphere as the putative site of any imagery mechanism. Three tasks, memory of words, face recognition and mental rotation each of which can demand the utilization of imaginal processes in performance have formed a basis for the research programme. These have been adapted to a recording paradigm suitable for the CNV. A further theme which has developed is the notion of control over imaginal processes. The basis for this development is the belief that if a participant actively manipulates an image in solving a problem then it is more likely that physiological correlates will be measured while that manipulation takes place, and moreover, it reduces the likelihood that the imaginal process is merely epiphenomenal.

It is worth reiterating at this point the general problem which has influenced the development of the research programme, and provides the basis for the selection of apparently disparate tasks for investigation. The problem is to demonstrate the general applicability of physiological measures in answering questions pertaining to the relationship between mental processes and the biological substrate for these. It would be equally valid to adopt other approaches such as the employment of a wide range of physiological variables in the investigation of a more limited range of tasks, or the theoretical development of a specific task using a limited set of physiological measures.

In this dissertation the traditional term 'subject' has been rejected in favour of the term 'participant'. The nature of the interaction with participants is qualitatively different to that with so-called 'naive subjects'. In view of much of the recent work on the social setting and demands inherent in the psychology experiment (Christie and Todd, 1975, Orne, 1962, Rosenthal, 1967) it is valuable to reconsider psychophysiological research with its emphasis on complex recording equipment, attachment of electrodes and requirement to participate in rather obscure, and in some cases, tedious tasks. To treat both experimenter and experimented upon as collaborators in an exercise focusing on a particular problem appears to be a more fruitful approach.

This has the following implications for the induction of participants:

1. Participants are informed in some detail about the preparations and events taking place for the experiment;
2. Participants are not informed of specific hypotheses, but the task is discussed in some detail, particularly the strategies that might be adopted;
3. Participants are debriefed after participating in an experiment, with a view to

deciding just how the task was conducted.

These requirements are unlikely to be controversial since most experimenters follow a similar set of principles even if experimental reports do not always indicate this. Debriefing is a particularly important consequence of this relationship with the participants in the research. It is necessary to elicit some observations from participants which enable the strategies adopted to be identified, albeit crudely. The debriefing also enabled the participant to be informed about the nature of the experiment and the results obtained.

Participants in the experiments to be reported are not a random sample. All took part voluntarily, and in some cases a nominal financial reward was offered. Financial reward was not linked to the level of performance in the experimental task.

The usual details of age, sex, handedness and medication were collected. Because numbers of participants involved in experiments were usually small, it was decided to concentrate on recruiting relatively homogenous samples of right-handed subjects, in whom cerebral specialization is reported to be consistent (Annett, 1975).

From the point of view of data collection the main aim of debriefing was to make simple decisions in response to the questions: (1) Did the participant utilize the strategy indicated at the induction into the experiment ?; and (2) Were the instructions followed ? The validity of these data is questionable. There is some doubt that people can actually recognize the mental strategies they adopt (Nisbett and Wilson, 1977) and there is ample evidence that participants tell experimenters what they think they want to hear.

The case for the reliable elicitation of identifiable cognitive processes rests on:

1. The effectiveness of the induction procedures;
2. Whether the tasks chosen involved the cognitive processes identified.

4.3 Behavioural Responses and Stimulus Presentation

Traditionally the behavioural response employed in CNV research has been the reaction time. From a perusal of the literature, it is difficult to discern a well-developed theoretical rationale for this choice other than the common time base for both neural and behavioural events. If behaviour is a consequence of neural activity then the response time should bear some relationship to the timing of underlying neural events. The expectation, therefore, would be that the longer the reaction time, the more cognitive systems involved and, hence, the wider involvement of neural subsystems or the longer involvement of specific systems.

Where simple and choice reaction time paradigms are employed little consistency is obvious in the many results reported. Rebert and Knott (1973) reviewing some twenty studies could only find a small inverse relationship between CNV amplitude and response time. Perhaps this is understandable considering that the CNV response is clearly the amalgamation of activity in a number of underlying neural systems, and the range of recording sites is limited and certainly does not provide the data necessary to measure relative patterns of activity across the scalp, and thus the differential involvement of underlying neural systems.

The use of RT to identify the cognitive components of various behaviours has recently had a resurgence in the work of Sternberg (1969), who developed the 'additive factors' methodology which assumes that any processing task is carried out by the activation of a limited set of cognitive systems. Response time is influenced by either the number of component cognitive systems involved, or the time taken for processing in any one component system, and the interdependence of components. Sternberg (1969) has reviewed the theoretical bases necessary for the interpretation of RT data. The first proposition is that there are successive functional stages which comprise the task, and thus the mean RT is the sum of the means of the components. A supplementary proposition is that the components are independent, the implication of this being that the component variances are additive. Thus, rather than adding or deleting processing components, as in the Donders model, the amount of processing required of any stage can be manipulated and thus its duration, and this eventually influences the overall RT.

A number of other authors (Posner, 1978; McLelland, 1979) have been unwilling to accept the assumption of the independence of stages, and propose instead a hierarchical model with parallel and overlapping stages with the consequences that RT only represents additional processing in a limited sense.

The research conducted in this programme is not based on the strong assumptions, particularly the independence of stages which form the basis of Sternberg's work. The tasks employed have been designed to provide RT data and it is assumed that the differences between conditions are reflected in differences in RT.

It is well recognised that there is a trade-off between speed and accuracy of response (Eysenck, 1982). In the experiments reported here participants were instructed to respond as accurately as possible and as quickly as possible. The resultant error rates were very small and as a consequence of little use in exploring the issue of the trade-off between speed and accuracy.

After establishing the significance of differences between experimental conditions in the behavioural responses, the results were then subject to a correlational analysis with the index of brain function selected. Throughout the experimental programme stimulus presentation was accomplished by slide projector (Kodak carousel) which was modified to incorporate a shutter mechanism enabling presentation times to be controlled to a sensitivity of a millisecond. Presentation was either onto a rear projection screen, portable screen or wall. Each of the initial experiments were controlled by a purpose built system which included units based on TTL logic to control intervals between stimuli, a tone generator (warning signal) and the slide projector. Potentiometer controls enabled precise presentation times to be achieved. These were calibrated using a millisecond timer before each experiment.

In later experiments (6.4 and 7.3) concluded at Wolverhampton a programme was written for the BBC microcomputer which substitued the computer as a control system. A listing of the programme is incorporated in Appendix I. This enabled all the time elements that go to make up a sweep to be manipulated separately.

Responses were timed to a sensitivity of a millisecond by using a timer which was initiated simultaneously with stimulus presentation and stopped when participants responded by pressing a microswitch. The response was recorded on the hard copy record of the experiment or on floppy disc. Response accuracy was recorded.

Apart from the occasional trial on which a slide jammed in the projector (usually when cardboard slide mounts were used) this system proved very reliable. Three main shortcomings were identified:

1. Inflexibility with regard to preparation of stimulus material;
2. The noise from the slide-progress mechanism occurred in the S1-S2 interval;
3. Inter-stimulus intervals below 2 seconds were not possible.

4.4 Indices of Brain Function

Choosing among the few techniques available for the non-invasive monitoring of cerebral function requires a compromise between levels of spatial and temporal resolution, and also an awareness of the economics of data collection.

The electroencephalogram has to be considered in terms of the information it provides on the dynamics of information processing events, and it is in this context that ERPs provide a valuable source of data. The assumption is that the deflections which make up the ERP are the resultant of components which are a direct reflection of activity in localized processing units. Measurement of latency and amplitude of deflections, and decomposition into the component structures is, therefore, supposed to provide useful information on the processes underlying the mental life of the individual under investigation.

Event related potentials are relatively slow changes in this range of events, and the CNV is at the slowest end of the range of phenomena derived from the EEG. It is probably best envisaged as a slowly changing baseline on which is superimposed faster activity reflecting signal processing. The CNV recording paradigm is itself a somewhat artificial set of circumstances, and thus induces a phenomenon which is really the compression of normal events on to a much shorter time base. The nature of the phenomenon puts particular demands on the recording system, and these will now be considered in relation to the sytems utilized in the experimental programme.

4.4.1 Measurement of Cerebral Function

The first link in the sequence of components of an ERP recording system is crucial for the accurate measurement of potential differences of the order of microvolts at the scalp and also very vulnerable to inteference from artifactual sources. The problems of electrodes for EEG recording in particular (Venables and Martin, 1967; Cooper, Osselton and Shaw, 1974) have been investigated in detail.

O'Connor (1980) lists three electrode qualities which must be controlled: 1. Capacitance; 2. Resistance, which together form the effective impedance at the input stage of the amplifier; 3. The standing potential. A variety of electrode types have been developed which supply these qualities with varying success (Cooper et al., 1974). In the experiments reported here Silver/Silver chloride cup electrodes were used because they were relatively non-polarizable and a low impedance connection to the scalp was fairly easy to prepare. Electrodes were regularly rechlorided. Before use in an experiment electrodes were inspected for faults in the layer of chloride. This type of electrode is employed in a number of EEG laboratories.

Electrodes were affixed to the scalp using collodion glue except in glabrous regions where a proprietory fixing tape ('Blenderm') was utilized. After fixing, a conductive jelly (Neptic) was introduced to the electrode cup to facilitate an effective contact between electrode surface and scalp. Inter-electrode resistances were measured and 10 kilohms was regarded as the maximum satisfactory level.

The International 10/20 system (Jasper, 1958) was used as the basis for placement of electrodes.

This is illustrated in Figure 4.1 overleaf. This locates electrodes over known areas of the cortical mantle. There is some evidence that the brain does not sit symmetrically within the skull (Drasdo, personal communication) so that a spatial error of small proportions between scalp sites and cortex is likely. Also there is likely to be a small error in placement of electrodes (estimated at about 0.5 cm). Thus the level of accuracy of placement of electrodes in relation to cortical sites is limited to the order of one centimetre.

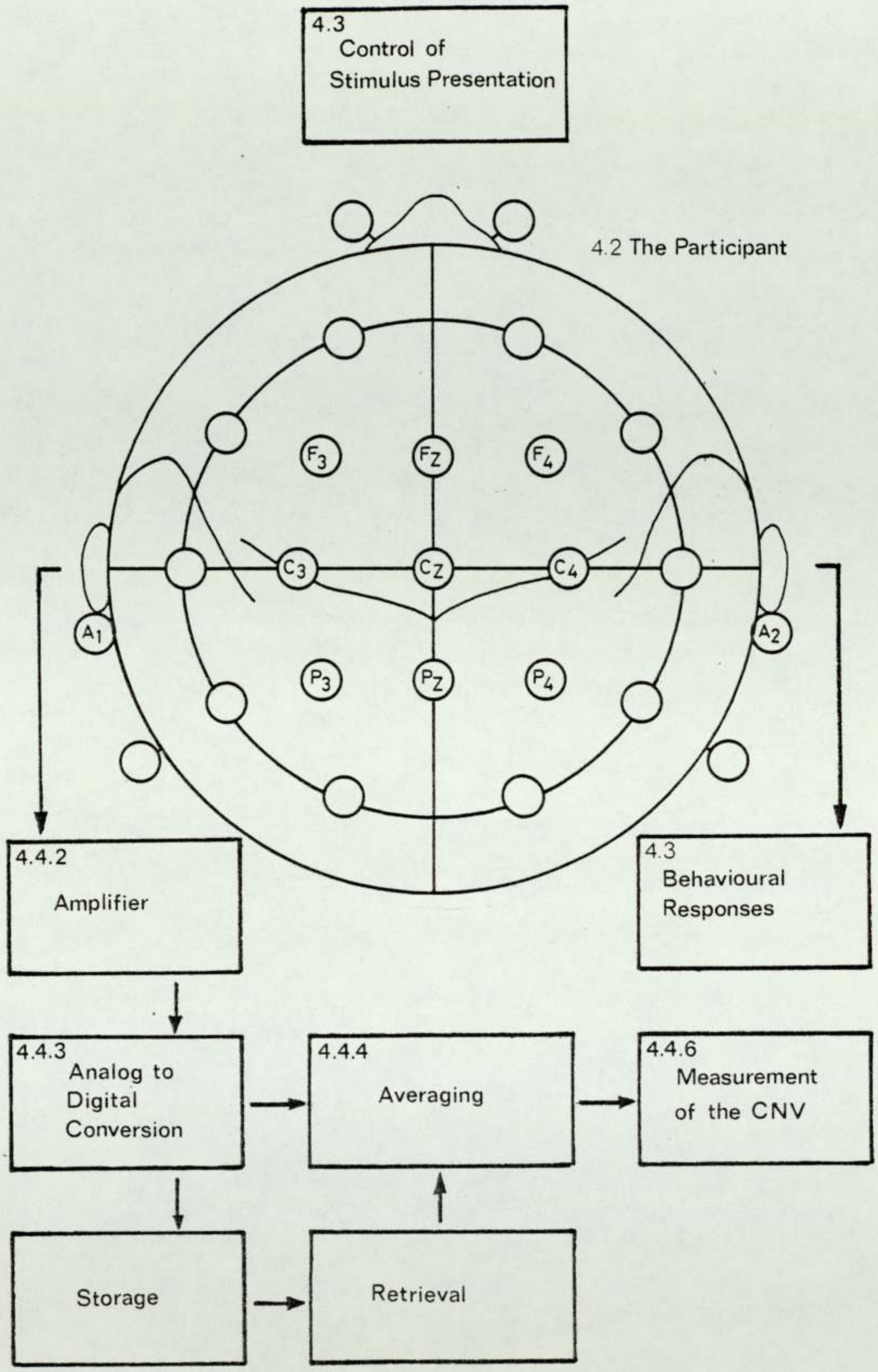


Figure 4.1

Schematic Diagram of Components of Recording System

A common reference recording system was utilized, the paired mastoid electrodes forming the reference. Earth electrodes were placed at the midline sites. A clip-on electrode was placed on the left earlobe and used as the earth for recordings using the 7P511 amplifiers and Grass polygraph.

The accurate recording and localization of slow potential changes is particularly susceptible to inadequacies in electrode preparation, so considerable attention was paid to this part of the system. Choice of electrodes and placement systems is consistent with that in a large number of EEG laboratories.

4.4.2 Amplifiers

Because the potential difference between an electrode at the scalp and the common reference electrode is small (the order of 10 to 100 microvolts) it is necessary to amplify before signals can be effectively analysed. Slow potential shifts like the CNV present particular amplification problems. Due to the recording of artifact differential amplifiers overcome some of these problems by rejecting signals in phase at the two electrodes and amplifying the out of phase signal. Because the CNV is a very slow potential shift, it is necessary to utilize amplifiers which record with fidelity in the low end of the frequency band of the EEG. DC amplifiers are the ideal solution in this respect, but commonly present difficulties due to baseline drift. AC amplifiers with long time constants (ten seconds) are a widely accepted solution. The gain of an amplifier is specific to a particular frequency range and outside that range some loss of signal is expected. The percentage loss of signal at the low end of the frequency band is determined by the time constant of the amplifier and the length of inter-stimulus interval.

Three sets of amplifiers were employed and while some of these were not ideal for the task of CNV recording, it was possible to produce a set of amplifiers which were a closer approximation to requirements. Table 4.1 identifies the specific amplifiers, technical characteristics and the experiments in which they were employed.

Table 4.1

Experiment	Amplifier	Characteristics
5.1, 6.1, 7.1, 8.1, 8.2.	Elema Schonander Mingograph.	TC 3.5 seconds HF cut off at 70 Hz.
6.3, 7.2.	Grass 7P511 (modified).	TC 3.5 seconds 50 Hz notch filter.
6.4, 7.3.	Wolverhampton Polytechnic amplifiers.	TC 10 seconds 50 Hz notch filter.

4.4.3 Analogue to Digital Conversion

Further analysis of the fluctuating voltage signals recorded from the scalp in most computer systems requires conversion to a digital form, and this is the function of the analogue to digital converter (A/D). In effect this equipment samples the voltage sequentially at predetermined intervals and converts this to digital form which is then utilized for later analysis.

Two characteristics define the process of analogue to digital conversion:

1. The sampling rate, or interval between readings of the analogue waveform;
2. The word size of the sample in bits, which determines the amplitude resolution of the averaging system.

The sampling rate is determined by the characteristics of the programme which operates within the limits of some aspects of the hardware (e.g. speed of central processor, analogue to digital conversion rate for successive samples, size of storage). The rule governing sampling rate (Shannon and Weaver 1949) is that a wave form should be sampled at a rate greater than twice the upper limit of the frequency spectrum. Thus if the upper frequency is 50Hz then sampling should be 101 per second or every 10 milliseconds. In the experiment reported here 50 samples were collected per second a sampling rate of once every 20 milliseconds. This was maintained throughout the experiments. Amplitude resolution is a function of the word size of the A/D converter. The number of values possible in a specified voltage range is 2n where n is the number of bits in the word of the A/D converter. Thus in a 12 bit A/D, 4096 values specify the total range of voltages. If the full scale of the A/D is +10.0 volts, then a resolution of 0.0048 volts in the output range of the EEG amplifier is attained.

In the systems used, output ranges of the EEG amplifiers were the same, the scale being +/-1 volt but the word size of A/D converter used at Aston was 10 bits, whereas at Wolverhampton it was 12 bits. The 12 bit system therefore resolved amplitudes more sensitively by a factor of 4, enabling finer amplitude discriminations.

4.4.4 Averaging

EEG recordings incorporate ERPs which are usually of much lower amplitude than the spontaneous activity. Analytical techniques have been designed to deal with the problem of the signal/noise ratio of the EEG and thus reveal ERP. One technique which is commonly employed in EEG laboratories is 'averaging'. The principle on which this is based is relatively simple. Event-related potentials embedded in the ongoing EEG are time locked to events in the external world (exogenous) or internal information processing (endogenous). If the EEG can be sampled over a series of points for a number of trials, each of which includes the stimulus events at the same time and each point in a trial is summed across trials, then the amplitude of random activity is reduced in proportion to the square root of the number of trials being summed (given unlimited bandwidth). Neural activity which is time-locked to internal and external events thus emerges from the noise as the background amplitude is reduced. Simply summing the samples at each point in the sweep enhances the signal/noise ratio and dividing this by the number of sweeps merely sets the amplitude scale for the resultant ERP.

Because of the size of the data store involved in a relatively simple ERP experiment many laboratories average the response continuously. That is, as each trial is sampled it is immediately added to the cumulative total. In this way, the data represented in any individual sweep is immediately incorporated, and is effectively lost for further analysis. Where trial-to-trial variability is assumed to be small this does not present much disadvantage. However, where performance varies considerably from trial-to-trial because different trials represent different experimental conditions and this variation is important to the test of hypotheses, a system employing continuous averaging leads to a loss of valuable data. The alternative is a system in which individual trial data is stored separately and retrieved later to produce averages based on any criteria the experimenter chooses.

The two systems used in the experiments reported differed in this important respect. At Aston the PDP8e provided a continuous average of up to 8 channels and, therefore, individual trial data were left. At Wolverhampton the Altra 50 system utilizes a back-up store on floppy disc in which all data are placed and retrieved for _post hoc_ averaging, thus enabling trials to be sorted on behavioural criteria.

Averages computed on the system at Aston were displayed on a Tektronix 611 storage oscilloscope and then plotted to a prepared format on a Bryans X-Y plotter (model 1010). A calibration signal (5 microvolts) was included on the plot. Because the plots were presented in a standard format different sweep lengths are represented by the same plot length. This must be taken into account when visually inspecting averages.

Averages from the system at Wolverhampton were plotted on a Tandy Plotter Printer (Mode 1) to a standard format.

4.4.5 Measurement of the CNV

Figure 4.2 depicts an idealised CNV wave form. A number of measures derived from this wave form are used as dependent variables and the relative advantages of these is the subject of considerable controversy. The discussion at the second International CNV Congress, held in Vancouver in

1971 (McCallum and Knott, 1973) produced a disparity of opinions. On the one hand Tecce and Donchin argued for a standardized measurement procedure applicable in all laboratories to facilitate the accumulation of basic normative data, whereas Walter and Lacey suggested that this would be unduly inhibiting. Perhaps premature standardization would unduly influence the search for the relationship between physiological bases, psychological influences and the various features of the waveform.

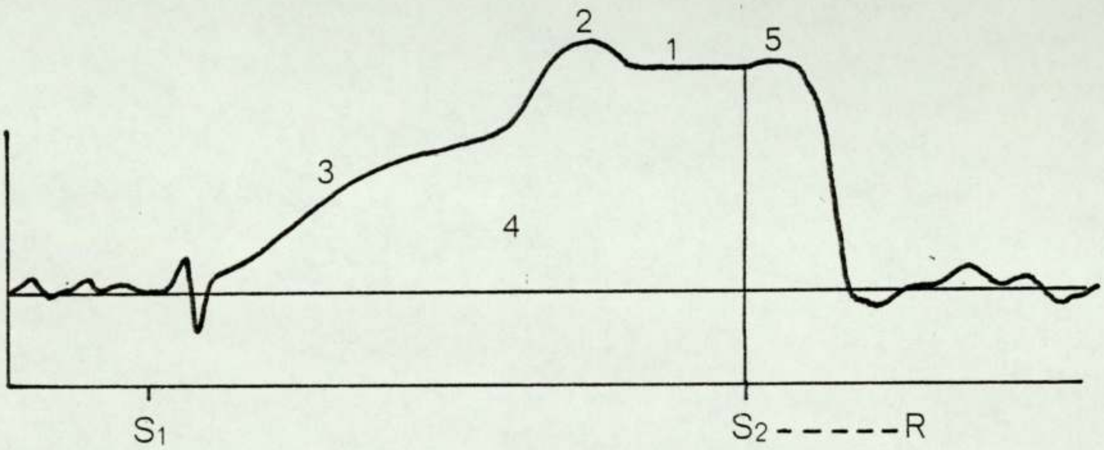


Figure 4.2

Generalised CNV waveform indicating Dependent Variables commonly Recorded

S1 = warning signal
S2 = imperative signal
ISI = inter stimulus interval
R2 = response

A variety of dependent variables which have been utilized by various workers are identified by number on the diagram and these are explained below. (Useful discussions of the measurement of the CNV are included in John, Ruchkin and Vidal (1978) and O'Connor (1980)):

1. Amplitude immediately preceding onset of the imperative signal;
2. Maximum amplitude, sometimes for specified part of the S1-S2 interval;
3. Slope of response. Two forms have been discussed (Tecce, 1972): (a) ramp like, gradual shift; (b) sudden change in level;
4. Area under curve, often area delimited by specified time points;
5. Post-imperative negative variation: amplitude or persistence of waveform beyond imperative signal.

Another approach derived from the recognition that an ERP is formed from a number of components is to analyse the waveform in an attempt to identify the subcomponents of the CNV which are then subject to measurement. This can be accomplished by the application of principal components analysis (John et al., 1978) or the identification of multiple components by extending the ISI so that clearer temporal differentiation is possible (Loveless and Sanford, 1974).

In the experiments reported here, the dependent variable chosen is the amplitude immediately prior to the imperative signal with reference to a baseline derived from the record prior to the warning stimulus.

4.5 Baseline for CNV Measurement

A persistent controversy in the CNV literature concerns the appropriate baseline for measurement of the response. Commonly amplitude measures are taken with reference to a pre-stimulus baseline which is either the computed mean or visually derived mean of a number of points prior to the presentation of the warning signal. The assumption underlying the use of this baseline is that between trials the subject returns to a 'resting' level which approximates zero voltage. In adopting a strategy for a task it is possible that a participant systematically modifies the resting level thereby influencing the CNV. Using a warned foreperiod RT task Gaillard and Naatanen (1980) were able to demonstrate that enhanced CNV amplitudes were found when pre-S1 levels were more positive, suggesting that the Law of Initial Values (Wilder, 1950) can be shown to operate in these circumstances.

Two options appear possible: 1. Pre-stimulus levels should be analysed for systematic task-related effects; 2. The CNV should be related to an anchor experiment (Lacey and Lacey, 1973).

4.6 Artifact in CNV Recordings

Poor recording technique can result in

considerable artifact from extraneous sources. In particular, muscle activity, mains interference and movement of electrodes can be a problem. In the experiments reported here, these forms of artifact were normally overcome by reapplication of electrodes. Where this was not successful data were rejected.

Eye movement artifact provides a more difficult problem in CNV recording. Because of changes in the orientation of the eye, the corneo-retinal potential can result in the recording of CNV-like artifacts, particularly at frontal sites. Some authors (Girton and Kamiya, 1973) have devised techniques which subtract eye movement potentials from the EEG. Others have concentrated with varying success on encouraging subjects to fixate during the critical S1-S2 interval (Rowland, 1968; Wasman, Morehead, Lee and Rowland 1970; Hillyard and Galambos, 1970).

Three approaches to eye movement artifact were adopted in this research programme. Firstly, the electro-oculogram was recorded from an electrode placed on the midline and 5 cm up from the nasion, referred to the paired mastoids. From the record of eye movements, a decision was made to accept or reject the data. Secondly, subjects were carefully instructed to fixate, particularly during the S1-S2 interval. In the event, instruction proved an effective means of control, although some data were rejected. Since the influence of the corneo retinal potential attenuates with distance from the eye, this problem was not considered as important when analysing recordings from posterior sites.

There is a possible disadvantage in controlling eye movements. Some recent evidence (see Andreassi, 1980 for review) has suggested that eye movements may be causally related to cognitive activities, that is, particular mental processes result in specific deflections of the eye. By controlling eye movement, it is possible that a participant's task strategy may be disrupted.

Issues relating to the appropriate methodology for recording CNVs during cognitive processes have been reviewed. The techniques and equipment used demand compromises in a number of respects and these influence the interpretation of experimental results. Two areas will be highlighted.

When an individual participates in an experiment involving a cognitive task, it is possible that strategies are adopted which reflect the constraints of the experimental situation and not the cognitive task as it would normally be tackled. There is an important consequence of constraining the context enough to satisfy the requirements of experimental method which may militate against the successful elicitation of cognitive processes. The interpretation of experimental results should be carried out in full awareness of these compromises.

4.7 Analysis of the Data

It was decided to adopt a common strategy toward the analysis of the data as far as this is possible. In each experiment a number of specific hypotheses were tested, and these are specified at the end of the introduction to each piece of empircal work. All these contribute to the broader hypothesis that cognitive tasks preferentially activate particular regions of cortex. Localized activation leads to a reduction which is elicited by the association between warning and imperative stimuli in the sample reaction time paradigm. Specifically, this will lead to a correlation between the performance difference between two experimental conditions at different levels of difficulty, and the change in amplitude of the CNV between the same two levels. Furthermore, this correlation is significant at sites which are preferentially activated by the task. Thus generalized activation would be reflected in widespread significant correlations.

The analysis was carried out in a series of stages. Initially the performance data and CNV responses are analysed separately for differences between conditions, and between electrode sites. Then the analysis focuses on the correlation between performance data and the CNV responses which are supposedly indicators of cerebral function.

CHAPTER 5 Simple and Visuo-spatial Response Latency and the CNV

5.1 Introduction

Lacey and Lacey (1973) in discussing the methodological basis of the CNV have suggested that an 'anchor experiment' should be included in any research programme to act as a foundation on which other more complex experimental arrangements can be considered. It is in accepting the general point of the need for an inter-laboratory reference point for the genre that the first experiment has been included. Two other points have also influenced the decision to include this experiment:

1. The comparison with a more complex task enables the appropriate analysis to be developed;
2. Independent evidence suggests that complex performance on the visuo-spatial reaction time (VSRT) depends on mechanisms localized in the posterior quadrant of the right hemisphere.

Human observers normally operate in environments in which the stimulation available far outweighs the capacity to process this information. An important characteristic of the human observer is the ability to select specific aspects of the environment which are relevant to the purposes of the individual and to exclude irrelevant information from conscious processing. If the observer is able to predict accurately where a signal will appear, and know which response must be made to that signal, the task is considerably easier than if any one of a number of signals might appear, and require any one of a similar number of responses. It is reasonably clear that the two tasks described above differ in terms of the difficulty they pose for the observer. The essential feature of the task as it was utilized in this experiment is the localization of a stimulus and the appropriate response, a task demanding the deployment of spatial ability.

A number of neuropsychological investigations (Walsh, 1978; Meier and Thompson, 1983) have suggested that lesions of the posterior right quadrant are related to deficits in spatial performance. A diverse range of symptoms is displayed in these disorders but generally the core problem relates to the location of and orientation to stimuli. Some authors (Benton, 1969) have suggested a distinction between absolute localization, the location of a single stimulus, and relative localization, the spatial relationship between two or more stimuli is an important refinement of the nature of such spatial tasks. De Renzi, Faglioni and Scotti (1971) using a simple rod alignment task found that gross impairment was almost exclusively associated with lesions of the posterior non-dominant hemisphere. A simple task involving the reproduction of stimulus crosses from memory, and measurement of the deviations of responses from the originals was performed significantly worse by a right hemisphere lesioned group, compared with a left hemisphere lesion group (De Renzi and Faglioni, 1967). More complex spatial tasks offer less clear demonstrations of asymmetry, but this may be a consequence of the increasing value of verbal mediation in the performance of more complex tasks. The clinical evidence, therefore, strongly suggests the involvement of the posterior quadrant of the right hemisphere in spatial tasks.

Results on spatial tasks performed by non-brain-damaged subjects are somewhat less clear cut. Kimura (1969) used the lateralised presentation of single dot stimuli and found a left visual field (right hemisphere) superiority in performance on a signal identification task which was more pronounced in male subjects than female subjects. However, attempts to replicate this finding have been equivocal and inconsistent in their results (Pohl, Butters and Goodglass, 1972; Bryden, 1976; Allard and Bryden, 1979; McKeever and Huling, 1970).

In a study of spatial and verbal tasks in which EEG power was measured, Galin and Ornstein (1972) found more power over the right hemisphere especially from parietal leads, and the power ratio of Right to Left hemisphere was consistently higher for verbal tasks than for spatial tasks. Greater power was thought to be indicative of less involvement in the task, and hence the relative involvement of the right hemisphere was greatest in spatial tasks and that of the left hemisphere greatest in verbal tasks. A later study (Doyle, Ornstein and Galin, 1974) found greatest asymmetry in the alpha band and from temporal rather than parietal electrode placements. Galin, Johnstone and Herron (1978) used fourteen block design tasks of graded complexity as a visuo-spatial task and compared this with a writing task. The results suggested greater left hemisphere involvement in the writing task, and, as difficulty on the block design task increased so the left hemisphere involvement increased. An analysis of the data, subject by subject, showed a change in relative hemispheric involvement within individuals as a function of task difficulty suggesting that individual differences in latency are confounded by task difficulty. Unfortunately a similar comparison using concurrent measurements of EEG between the simple reaction time task and the more complex detection of one of a large number of stimuli has not been reported.

The anticipated relationship between RT in both simple and choice RT tasks and the amplitude of the CNV is one of the unfulfilled expectations of CNV research. Rebert and Tecce (1973) review about twenty studies and find a small inverse correlation between RT and CNV amplitude at the vertex. McCallum (1969) had subjects perform an extended series of RT trials, the results of which suggested that the two dependent variables were not associated. However, RT still remains the most common behavioural variable in CNV studies.

In view of the early findings (Kornhuber and Deecke, 1965; Gilden, Vaughan and Costa, 1966) that the readiness potential (RP) over the hemisphere contralateral to the responding hand is of greater amplitude, it could be expected that the size of the correlation between CNV amplitude and RT would vary systematically across the motor strip (Syndulko, 1969). The issue was explored in more detail by Donchin, Kutas and McCarthy (1974), where the asymmetry in RP was related to a voluntary motor response which initiated the trial, and not the CNV preceding a slide to which no response was required. In this example, task demands in the form of a requirement to respond with a specific hand activate the neural system controlling the hand which is localized in the motor strip of the contralateral cortex.

The choice of responding hand raises important issues regarding the appropriate experimental design for testing the functional asymmetry hypothesis. Teuber (1964) argued for the importance of double dissociation for making inferences about localization of function in brain damaged individuals. The principle could also be applied to functional asymmetries in intact participants. Diagrammatically it could be represented as in Figure 5.1 below. Two tasks, Al and A2, are thought to be prepotently controlled by mechanisms in left and right hemispheres respectively. Thus performance on one task is associated with a high level of activation of one hemisphere, and performance on the other task with activation of the opposite hemisphere.

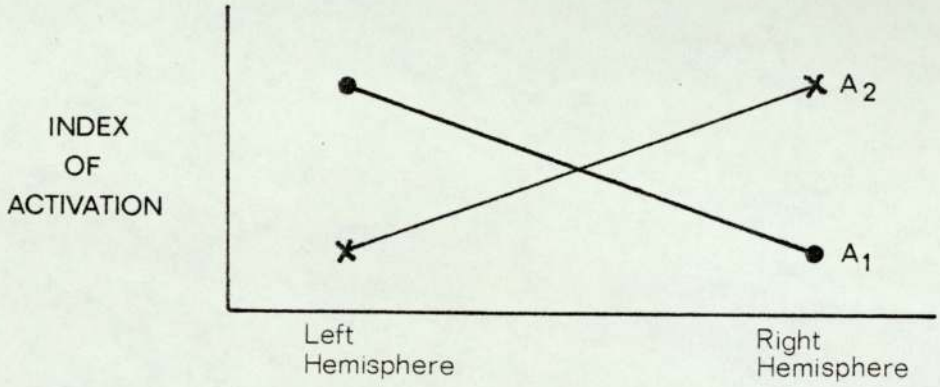


Figure 5.1

Double Dissociation : Idealized Representation of Functions : Asymmetry Al : Left Hemisphere Task; A2 : Right Hemisphere Task

Perhaps the use of different responding hands could be used to illustrate the point since it is known that the part of the motor strip controlling each limb is localized in the contralateral hemisphere. The weakness with this model as an explanation of functional asymmetries relating to the performance of cognitive tasks is the known structural basis for limb control (Bard, 1968).

Furthermore, there also appears to be a weakness in the requirement for double association as it applies to functional aspects of the brain since it seems to imply a strict localizationist model, not recognizing the heirarchical nature of the CNS, the potential for parallel processing at some levels, and the plasticity in the system involved with a particular task.

The hypotheses to be tested in this experiment are as follows:

1. That responses with both dominant and non-dominant hands will be slower on the more difficult Visuo Spatial (VSRT) RT task than the simple RT condition;
2. That the amplitude of the CNV will be lower under the VSRT task conditions than simple RT task conditions at electrode sites over the posterior, right hemisphere;
3. That performance differences between the simple and more difficult tasks will be correlated with amplitude changes in the CNV recorded from electrodes over the posterior right hemisphere.

5.2 Participants

Ten right handed people (five female and five male) took part in the experiment. Their ages ranged from 18-40 years. All received a token remuneration. None were taking medication or had drunk coffee in the past two hours.

5.3 Method

The EEG was recorded with the Elema Schonander Mingograph recorder with amplifiers set to a timeconstant of 3.5 seconds and an upper frequency cut off of 70Hz. Electrodes were placed at F3, F4, C3, C4, P3 and P4 and referred to paired mastoids. Earth electrodes were placed on the midline. Eye movements were recorded from an electrode 5cm above the nasion, on the midline. EEG was sampled every 20 milliseconds in a sweep of 300 sample points in which S1 and S2 were separated by 1.5 seconds.

A running average of the EEG was computed and the result of this after all trials in each condition were completed was plotted. The warning stimulus (S1) was a tone (1000Hz, 80dB) presented for 80 msecs stereophonically through headphones. The stimulus matrix (S2) consisted of a matrix of twenty points (4 rows x 5) which were projected onto a rear projection screen 40cm x 35cm, so that the matrix occupied a space 40cm x 20cm, and individual stimulus locations were separated by 8cm. Responses were made on a panel of microswitches, which formed an equivalent matrix to the stimulus presentation. Each stimulus location had an equivalent microswitch.

5.4 Procedure

Participants were seated in a comfortable chair, 1 metre from the rear projection screen and the response panel was held in the lap. Between trials the responding finger was returned to a standard start point on the panel. Instructions were given as to the nature of the task, and that responses should be made as quickly and as accurately as possible. The order of conditions was counterbalanced across participants, and before each run a practice sequence was conducted so that familiarity with the task could be ensured.

For the simple RT condition, the middle stimulus in the second row was always presented as S2, 1.5 seconds after the warning signal. For the VSRT condition, each of the twenty stimuli was presented at least twice in a predetermined but random order. The experimenter recorded response times and response accuracy from a millisecond timer and an array of light emiting diodes (LED) equivalent to the response panel.

5.5 Results

5.5.1 Reaction Time

Table 5.1 lists the mean reaction times for left and right hand responses for both Simple and

VSRT tasks.

Table 5.1

Mean Reaction Times (milliseconds) for Simple and Visuo-spatial Responses

	Simple RT		Visuo-spatial RT	
Participant	Right Hand Response	Left Hand Response	Right Hand Response	Left Hand Response
1	684	515	974	949
2	941	946	1283	1207
3	199	109	485	472
4	508	533	738	698
5	729	838	1027	1029
6	544	487	1140	1047
7	592	601	629	661
8	859	864	1326	1085
9	282	212	854	903
10	555	574	817	803

The differences between VSRT and simple RT for each participant for each hand are listed in table 5.2. Inspection of this table shows that the VSRT took longer than the simple RT in all cases. This is clearly a highly significant result (F=17.02, df 1,36, p<0.001). There was no significant difference in RT between responding hands.

Table 5.2

Change in RT due to Visuo-spatial Task

Participant	Right Hand Response	Left Hand Response
1	290	434
2	342	261
3	286	363
4	230	175
5	298	191
6	596	560
7	37	60
8	467	221
9	572	691
10	262	229

5.5.2 Contingent Negative Variation

Appendix II lists the change in CNV amplitudes (electrode sites x responding hand x participant) from the simple RT to the VSRT task. Examples of the CNV records from one participant for both tasks are presented in Figure 5.2.

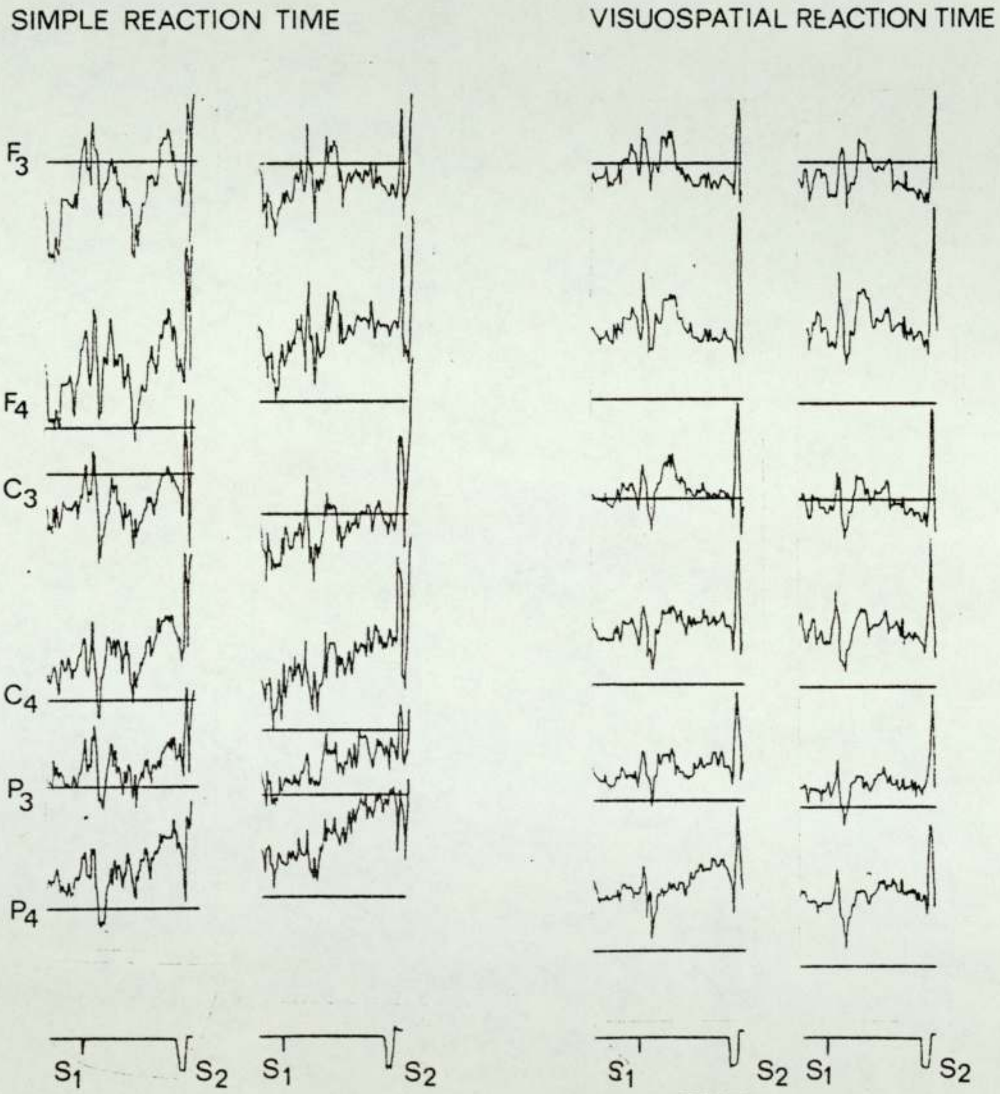


Figure 5.2 Averaged responses – One participant (KD) Simple and Visuospatial RT – Left & Right Hands

The CNV results were subject to analysis by the sign test (Siegel, 1956) which gives an indication, based on the number of differences between conditions of each sign, whether the responses between conditions are significantly different. According to this analysis only the left hand responses recorded from electrode P4 approach significance ($P<0.02$).

5.5.3 Correlations between CNV and Performance

A further analysis based on correlations between change in performance between simple and more difficult task and CNV amplitude differences at each electrode between the two levels of task difficulty was calculated. Table 5.3 presents Spearman's rank order correlation for each responding hand and each electrode site.

Table 5.3

Correlation between Change in CNV Amplitude and Change in RT (Spearman's rank order)

Left hand response		Right hand response	
F3 0.00	F4 -0.14	F3 -0.24	F4 0.14
C3-0.12	C4 0.17	C3 0.20	C4 0.24
P3-0.15	P4 0.16	P3 0.47	P4 0.69 ($p<0.05$)

At the right parietal lead, for a right handed response there is a significant correlation between change in RT and change in CNV amplitude. That is, as the RT gets longer, so the CNV amplitude becomes more positive.

5.6 Discussion

It is useful to speculate for a while on just what a participant does in the interval between warning signal and imperative signal in the two conditions of the experiment reported above. In both conditions the participant is alerted by the same warning signal. The critical difference is that in the one condition the experimental instructions have resulted in a 'set' to expect a particular signal, and make a particular response, while in the other the focus of attention must be considerably broadened to encompass a large number of potential stimuli, and to identify the response button which is appropriate to each of these stimuli. This difference is the basis of the processing demands which are the independent variable in the study.

From previous research on tasks of a similar nature we are led to the tentative conclusion that the independent variable in question is the visuo-spatial characteristic of the more complex task. Furthermore, there seems considerable evidence from a variety of sources that the posterior right quadrant of the cerebral hemispheres is prepotent in the performance of such a visuo-spatial task (Walsh, 1978).

The neural response to the visuo-spatial load provided by the task takes place concurrently with the organization of the motor response. Previous research has suggested that a Readiness Potential precedes a motor response, and the interaction between the response to the cognitive load and the RP must be taken into account. There is some evidence (Donchin, Kutas and McCarthy, 1977) that asymmetries in the amplitude of the RP are related to responding hand, which is controlled by neural mechanisms in the motor strip of the contralateral hemisphere. Amplitude over the hemisphere contralateral to the responding hand is greater than that over the ipsilateral hemisphere.

The? Responding hand, can be utilized as a way of exploring the double dissociation of function. Differences between hemispheres in indices of cerebral function, such as the CNV, which were dependent on the responding hand would lend credibility to the use of a variable such as the CNV in tasks testing the localization hypothesis where cognitive tasks were involved.

On the basis of this one might expect that the difference recorded from P4 between the Simple and VSRT conditions when the right hand is responding would be due to the cognitive load whereas when the left hand is responding this counteracts the effect of the VSRT task and reduces the chance of a significant difference.

To what extent do the results obtained in this experiment support the interpretations developed above ?

The analysis of performance showed that the difference between responding hands was not significant. However, the difference between simple RT and visuospatial RT conditions was highly significant. Interaction effects between responding hand and task demands were not significant. Thus the behavioural results clearly demonstrate the additional cognitive load imposed by the visuo-spatial task.

Cerebral function was monitored by measuring the CNV recorded from six sites distributed over the scalp. If the effect of the task was general activation, involving all the cortex, one would expect a change in amplitude between Simple RT and VSRT conditions at all electrodes, the amplitude of response under visuo-spatial conditions being reduced compared with that for simple RT conditions. If on the other hand localized activation resulted from additional task demands then changes would only be expected at a limited number of electrode sites. On the basis of the evidence reviewed earlier one would predict that activation would occur over the right parietal lobe at electrode P4, and possibly electrodes adjacent to that site. The analysis of differences between conditions in the CNV revealed a significant change at P4 for a left handed response only. On the basis of this result it is possible to reject the suggestion of generalized activation.

To test the localization hypothesis amplitude changes in the CNV were correlated with the changes in the performance variable. One would expect significant correlations at sites which were activated in the performance of the visuospatial task. Again the prediction would be that significant correlations would occur over the right parietal lobe, and possibly in immediately adjacent sites. This hypothesis was well supported by the data for responses with the right hand only. A result which is consistent with the interpretation outlined earlier.

Calculating a large number of correlation coefficients carries the risk of obtaining the occasional spuriously significant result by chance alone. Ultimately, the validity of this finding will depend on replication, ideally in other laboratories. However, on statistical grounds it is reasonable to draw the conclusions outlined above because it was possible to make a priori predictions on the basis of the literature available, as to the sites most likely to be activated by the cognitive load involved in the task.

While the tasks employed in this study provide a useful starting point, because of the base in the traditional CNV recording paradigm it is possible to argue that the exogenous nature of the demands made on the participant devalue the finding as a demonstration of cognitive processes which are more endogenous in character. It is for this reason that an attempt will be made to develop suitable recording paradigms which involve memory tasks emerging from the experimental literature in that area.

5.7 Conclusion

The results of this study are a tentative confirmation of the value of measures such as the CNV derived from the EEG in the investigation of the localization of neural activity subserving cognitive processes. The findings need replication, and extension into other tasks which offer clearer demonstrations of cognitive activity.

CHAPTER 6 Memory and the CNV

6.0 Introduction

The ability to store and retrieve information is crucial for all cognitive processes, and any attempt to investigate the relationship between mental processes and associated electrophysiological events must encompass the models proposed for memory systems. Physiological data may even enable useful tests of some of the models derived from behavioural studies. For example, the localization of the regions of cortex involved in a task might contribute to the refinement of techniques which can elucidate the mechanisms involved. Electrophysiological data also provides a useful tool which can be applied at the conjunction of experimentally based models and the clinical observations of memory impairment in patients with damage or degeneration of the central nervous system to test the hypotheses developed with each of these approaches.

The recent history of research on human memory has passed through a series of phases. Initially, the key concept was consolidation. Human memory was conceptualised as traces imprinted on a neural substrate by the process of consolidation. This theory proved inadequate in the face of experimental findings emerging since the Second World War, and as a consequence, the two store model was developed (Atkinson and Shiffrin, 1968).

This postulated short term and long term stores, each having different functional characteristics, such as capacity, and the codes employed for storage. The emergence of the two store model marked the start of the information processing era. More recently the emphasis has concentrated on the processing involved in encoding of material to be remembered and it is in this context that the levels of processing (LOP) approach (Craik and Lockhart, 1972) has emerged as the progenitor of much recent research. One of the problems with this approach is the lack of an independent measure of level of processing (Baddeley, 1978). Some authors have suggested electrophysiological measures may be valuable in this context (Craik and Blankstein, 1975).

The neuropsychological evidence relating to the amnesic syndrome also supports the conclusion that there is a dissociation between long term memory (LTM) and short term memory (STM). Studies by Warrington and her co-workers (Warrington and Baddeley, 1974; Baddeley and Warrington, 1970; Shallice and Warrington, 1970) suggest that temporal lesions have a potent effect on LTM but lead to a less profound disruption of STM. The basis of long term storage is the semantic coding of stimulus material whereas STM operates on the phonetic or visual characteristics of the stimulus array. In contrast, parietal lesions have been shown to impair short term retention (Shallice and

Warrington, 1970) thus providing an example of the principle of double dissociation.

It is in the context of investigations of encoding strategies that the proposal that impairment of STM might be attributable to a selective deficit in the use of mental imagery have emerged. There are a number of methodological difficulties in attempting to compare verbal and non-verbal coding, such as the differential demands placed on cognitive mechanisms, and the difficulty equating tasks in terms of complexity.

Discussions of various coding strategies, such as verbal and non-verbal, lead to considerations of the localization of mechanisms involved and it is to this question that the research in this chapter is directed.

6.1 Meaning and the CNV in Recognition Memory

It is a well attested finding in memory research that meaningful material is better recalled and recognised than meaningless material. For example, Seymour (1979) reviews a number of studies in which superior recall of words compared with non words has been demonstrated. If 'meaning' is an important variable in recognition memory, then other forms of symbolic representation which can be differentiated by level of meaning are also appropriate to the framework espoused in this chapter.

In this experiment cognitive load was

manipulated by selecting groups of stimuli to differ in 'meaning'. The first experiment was based on two sets of stimuli: (i) a set of 50 words from the Thorndike-Lorge word list (1944) and (ii) a set of non-words constructed by randomizing the letters in each word of the above list. The second set consisted of two groups of 50 stimuli selected from a dictionary of symbols on the basis of the ease with which the symbol could be interpreted. The two groups 'easy to understand' and 'difficult to understand' were later confirmed by independent observers and in post-experimental debriefing of participants. See Appendix III for the stimuli used in each group.

6.1.1 Participants

Nine right handed people, four males and five females, whose ages ranged from 18-25 volunteered to participate. Each was given a token remuneration.

6.1.2 Procedure

The order in which each of the four stimulus groups was presented was counterbalanced across subjects. Half of each stimulus group was presented as a target group by projecting a sequence of slides each containing one stimulus on a screen. A warning signal (80dB, 1000 Hz) presented stereophonically through headphones preceded each stimulus slide by 1.5 seconds. The interval between stimuli varied from 8-12 seconds and was not predictable. Participants were asked to sit comfortably and fixate on a central point in the projection surface while viewing the series. After the presentation of the target group was complete, 30 seconds elapsed and participants were then presented with a sheet of 50 stimuli, in which the 25 stimuli in the target set were randomly interspersed. Participants indicated the stimuli recognised from the target set by marking the sheet.

6.1.3 EEG Recording

The EEG was recorded from 8 sites, F3, F4, C3, C4, P3 and P4 referred to paired mastoids using the Mingograph recorder (TC 3.5 seconds, high frequency cut off 70 Hz). Averages were computed for each site from the 25 trials for each stimulus set.

6.1.4 Results

The percentage correct recognition score for each participant in each stimulus group is presented in Table 6.1. Within each set the percent correct recognition of the more meaningful stimulus group was larger.

Table 6.1

Percentage Correct Recognition Scores

Participant	Words	Non-Words	Meaningful Symbols	Less Meaningful Symbols
1	68	8	96	36
2	72	40	88	24
3	76	28	80	60
4	80	40	92	8
5	76	44	96	96
6	88	36	100	80
7	72	32	96	92
8	80	40	92	80
9	60	52	56	44

In Table 6.2 the differences in percentage correct recognition between groups in each set are presented.

Table 6.2

Differences in Percentage Correct Recognition Within Sets

Participant	Words - Non-Words	Meaningful Symbols - Less Symbols
1	60	60
2	32	64
3	48	20
4	40	8
5	32	0
6	52	20
7	40	4
8	40	12
9	8	12

The difference in CNV amplitude between groups for each set and at each electrode site was derived. Original CNV measurements are included in Appendix IV. The correlation coefficient between the difference in CNV and the difference in percentage correct recognition was computed for each electrode site. These are presented in Table 6.3.

Table 6.3

Correlation Coefficients (rank order) between Differences in Percent Correct Recognition and Differences in CNV Amplitudes between Groups

Words (Words - Non-Words)				Symbols (Meaningful Symbols - Less Meaningful Symbols)			
F3	0.06	F4	-0.59	F3	0.15	F4	0.23
C3	-0.12	C4	-0.22	C3	0.69 $p<0.05$*	C4	0.62 $p<0.05$*
P3	0.40	P4	0.18	P3	-0.31	P4	0.01

6.1.5 Discussion

The manipulation of meaningfulness is clearly effective in influencing recognition memory of the relevant stimuli within the sets. Over the four stimulus groups, meaningful symbols are best recognized and non-words the worst. Since each run consisted of one stimulus group, a participant could quickly adapt the strategy used, and in the case of non-words any attempt to elicit meaning may have been abandoned. In retrospect the word-nonword experiment is a valuable illustration of some of the methodological problems which must be confronted. The randomized sequence of letters is a qualitatively different task to that of word recognition. This distinction may explain the lack of systematic electrophysiological effects on the face of clear behavioural findings. Performance differences between the two symbol groups were smaller than that between words and non-words and this may also be interpreted as support for the view that, effective analysis of stimuli for meaning improves recognition.

In the matrix of correlation coefficients between performance differences and the differences in CNV amplitude significant correlations for the symbol set are observed at two scalp sites which while not directly over the temporal lobe are adjacent to the superior temporal margin. This is consistent with the interpretation of recognition scores presented above. Processing symbols for meaning induces semantic processing involving temporal sites which are apparently involved in long term verbal storage in both hemispheres. In the case of the word set, a better comparison would probably have been made between two groups of words rated for different levels of meaning. In this case the possibility of a qualitatively different approach to the task by the participant could be avoided.

The results of this experiment support the tentative conclusion reached earlier that effort at a task which is the result of different levels of difficulty is correlated with localized changes in slow ERP activity. Because the observation was made with a memory task this gives a clear indication that cognitive activities are amenable to this form of investigation.

6.2 Memory Codes and Memory Strategies

One major controversy in the research on memory concerns the role of imaginal and verbal codes (Paivio, 1971) as opposed to an abstract or propositional code (Anderson, 1980; Pylyshyn, 1973) as a basis for encoding, storage and retrieval. Research in the area has been comprehensively reviewed by Richardson (1980). The initial positive results implicating imagery as a memory code have led to a concern for alternative explanations of the data and the appropriate methodology for testing these hypotheses. Dual-coding theory (Paivio, 1971, 1979) proposes that imagery and verbal processes provide alternate coding systems or modes of representation. The position is specified as follows:

> The theory assumes that cognitive behaviour is mediated by two independant, but highly interconnected symbolic systems which are specialized for encoding, organizing, transforming, storing and retrieving information. One (the image system) is specialised for dealing with perceptual information concerning non-verbal objects and events. The other (the verbal system) is specialized for dealing with linguistic information. The systems differ in the nature of the representational units, the way the units are organized into higher order structures and the way the structures can be reorganized and transformed. (Paivio, 1979)

The most systematic criticism of the dual code model (Pylyshyn, 1973) does not question the existence of imaginal codes, but does challenge the view that this is a fundamental representational system in memory. In effect, this means that, imaginal codes are merely interesting epiphenomena without a direct role in information processing. The difficulty lies in deciding on the nature of the evidence that would satisfactorily resolve the question. In this respect both behavioural evidence, and evidence such as the EEG and ERPs are indirect means of examining the mental processes involved.

The strength of the work of Paivio and his colleagues, and much of the work that followed lies in the operational definition of terms relating to imagery. One of the problems bedeviling research on imagery has been the multiplicity of meanings apparent in the literature. Both the nature of the stimulus material and the individual differences between participants are defined and measured. For example, Paivio, Yuille and Madigan (1968) provided concreteness, imagery and meaningfulness values for 925 English nouns. The validity of these values in the British context was later confirmed by Morris and Reid (1972). Words having high imagery value are better recalled than more abstract words in a number of experimental situations. Also, adopting an imagery strategy in a memory task is effective in improving recognition and recall (Paivio, 1976).

There is an increasing body of clinical evidence which suggests that non-verbal memory deficits are associated with lesions in the right posterior quadrant of the cortex (Meier and Thompson, 1983). Richardson (1982) has drawn attention to the possibility that imagery strategies may provide a useful rehabilitative procedure in cases of cerebral degeneration. The case studies reported by Butters, Samuels, Goodglass and Brady (1970) clearly point to a right parietal involvement in visual memory. Whether this is extended to the ability to use imagery is not clear.

In this experiment it is hypothesised that:

(1) High imagery value words in a target set will be more easily recognized than low imagery words; (2) Adopting an imagery strategy facilitates the recognition of items in target lists of high imagery value; (3) changes in CNV amplitude will be correlated with differences in performance at leads from the right posterior quadrant.

6.2.1 Participants

Participants were 24 right hand people ranging in age from 16-25. They included 9 females and 16 males. None of the participants was taking medication.

6.2.2 Stimuli

Stimuli were selected from the list of 925 nouns for which imagery values have been presented by Paivio et al, (1968). Three lists of words of: (i) low; (ii) medium; and (iii) high imagery values were included. In the high imagery set, values of words were more than one standard deviation above the mean value and those in the low imagery set, more than one standard deviation below the mean and the medium imagery value set within one standard deviation of the mean. Two copies of every word were prepared on photographic slides.

6.2.3 Procedure

Participants were seated comfortably and instructed in the task. They were requested to fixate at the marked centre-point of the screen and view and remember the list of words during the encoding phase. There was no requirement for a motor response during this phase. During the recognition phase participants were requested to respond as accurately and as fast as possible. All participants received a training sequence before carrying out the experiment. Each condition comprised an encoding phase and a recognition phase. In the encoding phase, 20 words in the target set were presented one at a time at the centre of the screen. A presentation consisted of a warning signal (80dB, 1000Hz, stereophonically presented) followed 1.5 seconds later by a slide which was projected for 250 msecs. The interval between presentations ranged from 5-15 seconds and was not predictable.

In the recognition phase a similar presentation was organized except that, participants saw the full set of 40 words and responded by pressing a button with the right index finger, indicating whether the word was in the target set or not. The two response buttons were on a switch panel, which the subject held with the non-responding hand. Between trials the index finger was placed equidistant from each button.

The order of presentation was as follows: (1) training set; (2) low imagery set; (3) high imagery set (a); (4) high imagery set (b). Prior to the fourth presentation, subjects were told the nature of the words and advised of the value of an imagery strategy in remembering the words before viewing the target set. It was suggested that since the words referred to concrete objects, recognition would be enhanced by imagining the object. At this stage, subjects were asked about the strategy they had adopted with the previous set (high imagery (a)).

6.2.4 EEG Recording

EEG was recorded from FZ, CZ, PZ, P3 and P4 referred to paired mastoids. Eye movements were monitored from an electrode 5cm above the nasion referred to paired mastoids. As required by the Elema Schononder Mingograph, two earth electrode were placed on the scalp, in this instance on the midline. Amplifiers were set at a TC of 3.5 secs and a high frequency limit of 70Hz.

6.2.5 Results

Figure 6.1 plots the mean response time for the recognition memory task in each of the stimulus conditions.

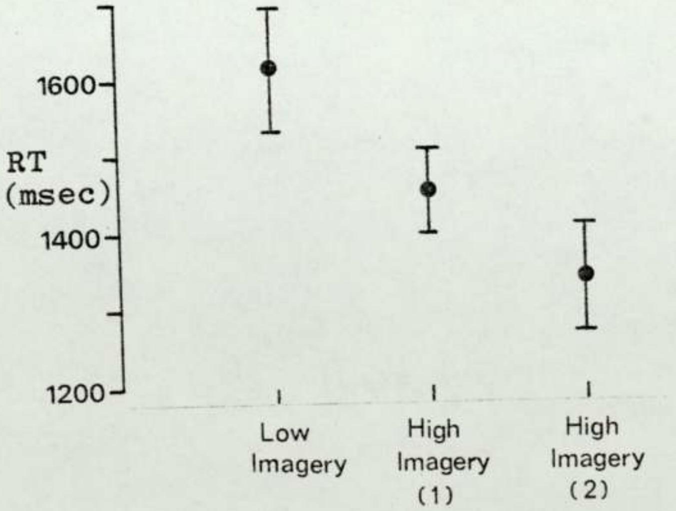


Figure 6.1
Mean RT Recognition Memory

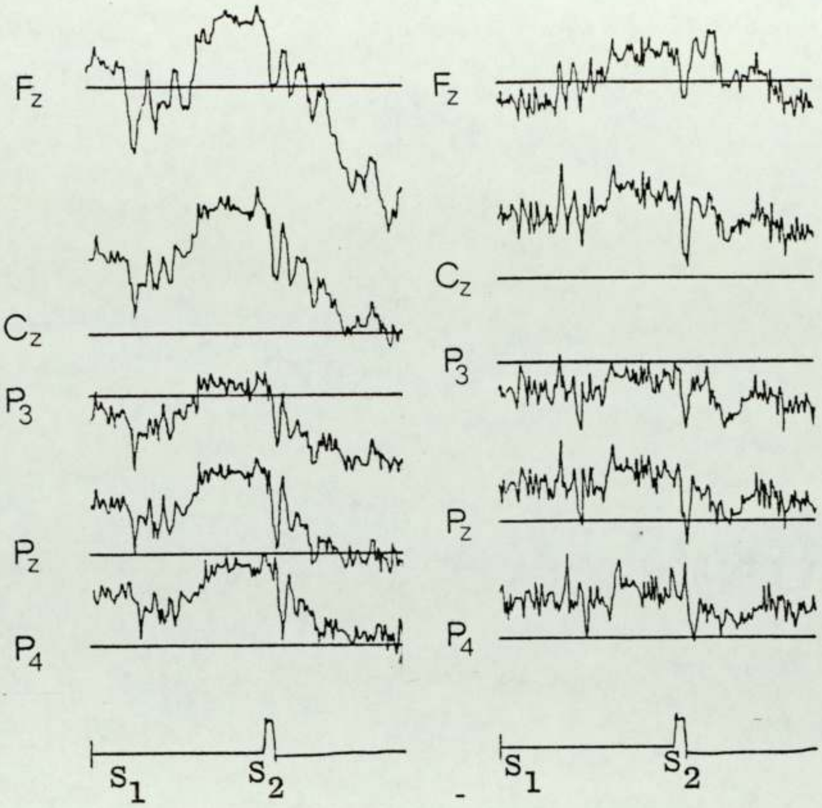


Figure 6.2

Example of CNV from One Participant

Acquisition (left) and Recognition (Right) Phases
High Imagery Stimuli using Imagery Strategy

A two way analysis of variance of response times with respect to conditions (low imagery, high imagery etc) and nature of response (in or out of target set) proved significant. Table 6.4 gives a summary of the analysis.

Table 6.4

Analysis of Variance : Performance Measures, Imagery and Recognition Memory

	df	Sum of squares	Mean square	F Value
Imagery Variable	2	15676584	7838292	11.68**
In or out of target set	1	71881171	8811510	10.71**
Interaction	2	2336177	1168089	1.74
Error	1794	1204216576	671247	
Total	1799	1229417472		

** $p<0.01$

Both the nature of the stimulus material and the adoption of an imagery strategy influence the response time in the expected direction.

In this experiment the transformation procedure for short time constant amplifiers proposed by Elbert and Rockstroh (1981) was applied to the CNV amplitude data. The transformed CNV scores are presented in Appendix V. An example of the average from one participant is presented in Figure 6.2.

In Table 6.5 the correlations coefficients for both acquisition and recognition phases of the experiment between the change in CNV amplitude and the change in response time from low to high imagery stimuli (I) and high imagery value stimuli with and without imagery strategy (II) are presented.

Table 6.5

Correlation Coefficients : Change in CNV Amplitude with Response Latency Change

		Encoding	Recognition
I Low I to High I	Fz	0.0	-0.06
	Cz	-0.15	0.13
	P3	-0.53 $p<0.05$	0.09 $p<0.05$
	PZ	-0.08	0.17
	P4	-0.49	-0.02
II High I (a) to High I (b)	Fz	-0.07	-0.06
	Cz	0.18	0.05
	P3	-0.41 $p<0.05$	-0.02
	PZ	-0.36 $p<0.05$	0.13
	P4	-0.34 $p<0.05$	-0.09

6.2.6 Discussion

The importance of the findings in this experiment is the clear demonstration of a relationship between the utilization of imagery as an encoding strategy and localized changes in the CNV and in the similar changes when stimuli are employed that are likely to evoke an image as opposed to stimuli of low imagery value. This is powerful evidence for the specialization of particular cortical regions for particular methods of processing. Furthermore, the finding that significant effects occur during the encoding phase is consistent with the behavioural evidence suggesting the importance of imagery as a coding strategy. However, the findings do not support the theory of hemispheric specialization for this task, since the response in both left and right posterior quadrants is similar.

The design of the experiment was such that different stimulus variables (high imagery or low imagery words) were the basis of separate experimental runs. A more stringent examination of the tendency to adopt different strategies could be organised if the different stimulus types were included in the one set, and averaging of selected responses which matched particular stimulus types is carried out post hoc. A further experiment could also test the hypothesis that amplitude of response is related to task difficulty by incorporating different levels of complexity. The next two experiments are directed towards these issues.

6.3 Short Term Memory Load and the CNV

Given that highly imageable stimulus words, and imagery strategies influence recognition, it is worth pursuing the question of the mode of operation of imagery a stage further. If the load of high imagery items on short term memory is manipulated does this influence both behavioural and neural variables ? The work of Sternberg (1966, 1969) with target sets of letters and digits suggests that as STM load increases so the time to confirm or disconfirm membership of the target set increases. This conclusion is tested in this experiment using words from the high imagery group as stimuli. It is predicted that:

1. As set size increases, so RT to probe stimulus will increase;
2. That, as set size increased so CNV amplitude would decrease.

Since the results of the previous experiments have indicated the importance of activity in the parietal cortex hemispheric differences at parietal sites will be investigated.

6.3.1 Stimuli

The set of high imagery words selected for the previous experiment were used in lists of 2, 4 and 8 words and prepared on projection slides. Words were placed centrally in a column on the slide. Probe stimuli were single words from the set placed centrally on a slide. At projection words formed an angle of 5 degrees horizontally.

6.3.2 Procedure

The stimulus sequence for a trial consisted of a target set presented for 2.0 seconds followed by an interval of 2.0 seconds and then a probe stimulus presented for 250 milliseconds. Order of presentation was randomised according to set size, and presence or absence of probe in the target set. Participants were presented with two sets of 40 trials. Responding hand differed in each of the two sets and the order was counterbalanced across participants.

6.3.3 EEG Recording

EEG was recorded from PZ, P3 and P4 referred to paired mastoids. Eye movements were monitored from a pair of electrodes, one at the outer canthus of the left eye and the other 5cm above the nasion. The earth electrode was attached to the left earlobe. Amplification was performed by modified Grass 7P511 preamplifiers with a 3.5 second time constant and an upper frequency limit at 30 Hz. Averages were computed on the Altra-50 system for each subject, for each set size, responding hand, and presence or absence of probe in target set. Incorrect responses were not included in the average. Also, baseline averages were computed by using the same sets as stimuli in a simple RT experiment. Thus a participant would interpret a target set as a warning signal, and shortly after would respond to the probe stimulus without any demand for processing of the set of words.

6.3.4 Participants

Five right handed people, three male and two female took part in the experiment. Ages ranged from 20-35 years.

6.3.5 Results

Mean response times for set size and responding hand are depicted in Figure 6.3.

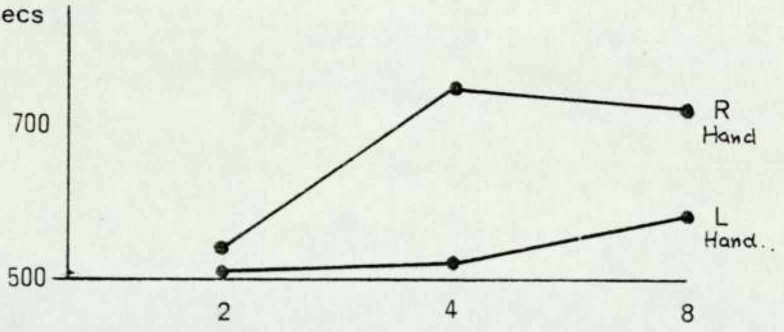


Figure 6.3

Mean Response Time and Set Size

An analysis of variance conducted on these results revealed a significant effect for responding hand but not for size of the target set. Table 6.6 overleaf summarizes the results of the analysis of variance.

Table 6.6

Analysis of Variance, Response Times, Set Size and Responding Hand

Variable	df	Sum of Squares	Mean Square	F Ratio
Set	2,24	101200267	506001334	1.723
Hand	1,24	148966534	148966534	5.07 *
Interaction	2,24	505674665	252837333	0.86

*$p<0.05$

Mean CNV measurements for set size, responding hand and electrode are depicted in Figure 6.4. The notable thing about this graph is the separation of CNV amplitudes according to responding hand.

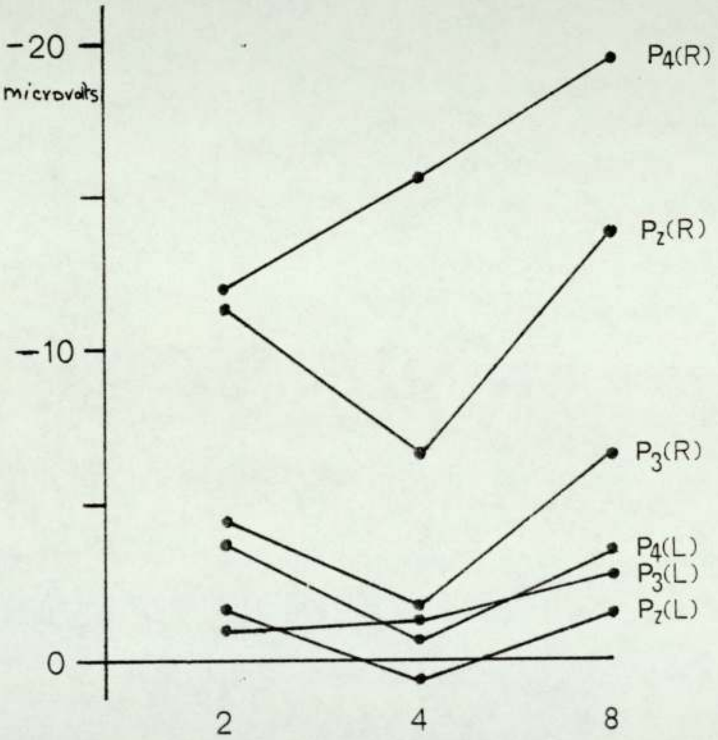


Figure 6.4

Mean CNV Amplitudes for Set Size and Responding Hand at Three Electrode Sites

6.3.6 Discussion

The lack of an effect due to set size may be a consequence of the relatively long exposure time for the target set. Despite this, all participants reported difficulty forming images of all the words in the time allowed, particularly with the larger target set of eight words. The separation of right and left handed responses in the CNV measurements is consistent with the significant effect of hand on response time.

A further experiment, modified to take account of some of the difficulties with this experiment is reported in the next section.

6.4.1 Participants

Five male right handed participants. Ages ranged from 20-25 years.

6.4.2 Stimuli

Three sets of 40 pairs of slides, providing target set sizes of 1, 2 and 4 respectively. Within each set 20 pairs contained low imagery words and the other 20, high imagery words. Order of presentation within the sets was randomised, and the order of presentation of sets counterbalanced. Stimuli were projected by the Kodak Carousel projector onto the wall 1.5m in front of the participant. Presentation times are outlined in Table 6.7.

Table 6.7

Presentation Times (msecs) for Target Set, Probe and Inter Stimulus Interval

Set Size	Prestimulus Baseline	Target Size	ISI	Probe Stimulus
1	1210	250	3000	250
2	960	500	3000	250
3	460	1000	3000	250

6.4.3 Procedure

EEG was recorded from electrodes affixed at F3, F4, P3 and P4 referred to paired mastoids. The earth was placed at the vertex. Amplifiers had a time constant of 10 seconds and a 50 Hz notch filter. The EEG for each trial was stored off-line for later averaging. Averages were calculated for low imagery and high imagery sets at each set size.

The task was explained to the participants, all of whom had taken part in a similar experiment previously. Participants were asked to fixate on the projection area, remember the target set and respond accurately and quickly to the probe stimulus, indicating by depressing the appropriate microswitch whether the probe was in the target set or not.

6.4.4 Results

Mean response times for each participant in each condition are presented in Appendix VI. Figure 6.5 depicts the mean response times for all subjects for each set size and stimulus type.

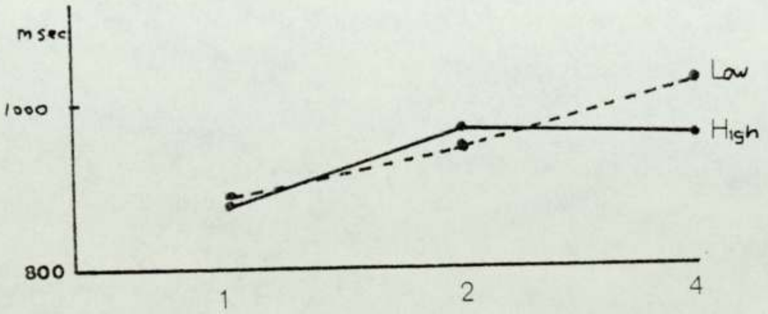


Figure 6.5

Mean Response Times: Low and High Imagery Stimuli; set sizes 1, 2, 4 words

A two way analysis of variance conducted on each participant's mean response time for each condition revealed the significant effect of low versus high imagery stimuli, and a significant interaction between imagery and set size. Table 6.8 gives the results of the analysis of variance.

Table 6.8

Analysis of Variance: Response Times, Set Size and Imagery

	df	Sum of Squares	Mean Square	F Value
Set Size	2,30	89588.1665	44794.0833	0.84
High vs Low Imagery	1,30	3192.24997	3192.24997	6.011*
Interaction	2	8122.16708	4061.08354	7.65 *

*p<0.05

The CNV data are presented in Appendix VII. An example of the record obtained is included in Appendix VIII. Figure 6.6 overleaf depicts the mean amplitudes of CNV's for each condition and electrode site over all participants. The trend appears to be as expected towards decreasing amplitudes of CNV with larger set size. Statistical analysis employing the t test on the differences between low and high imagery sets at electrodes P3 and P4 were not significant at the 5% level.

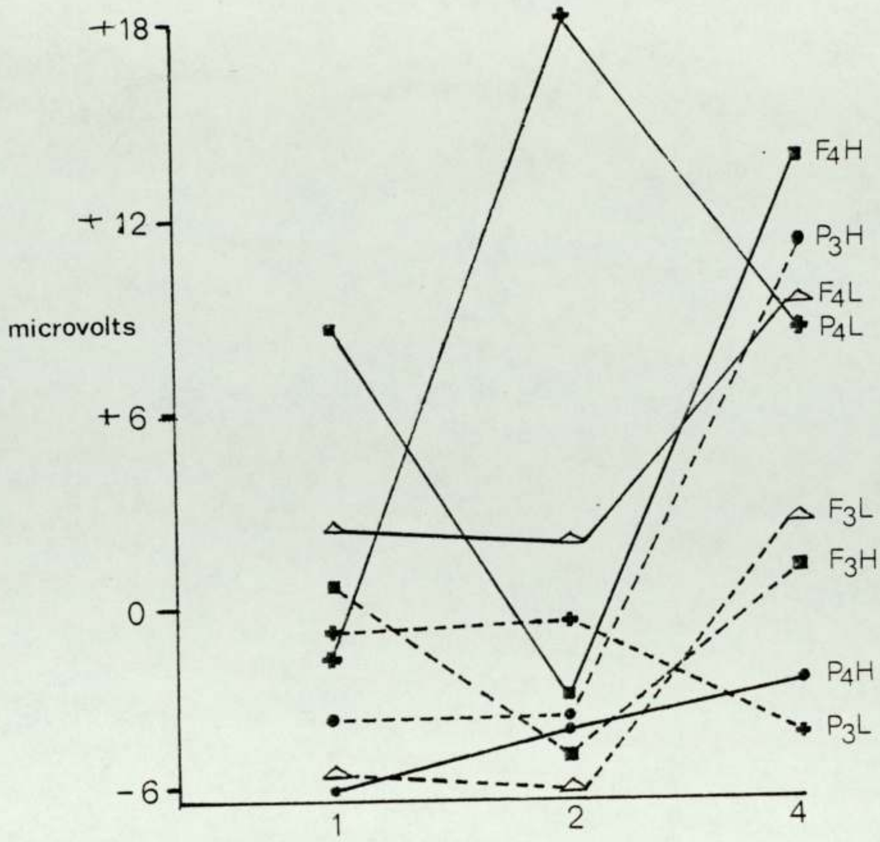


Figure 6.6

Mean CNV Amplitude : Low (L) and High (H) Imagery Stimuli, Electrodes F3, F4, P3, P4

Set Sizes 1, 2, 4 words
Amplitude in microvolts

6.4.5 Discussion

Obviously this experiment could be expanded with advantage. The significant effect of stimulus type on performance is an important observation. The significant interaction between set size and imagery values in the performance measures is consistent with the observation made by all participants at post experimental enquiry that they only bothered to use an imagery strategy at the largest set size. It would also be valuable to incorporate the individual differences in ability to use imagery in a further experiment in this sequence.

6.5 Conclusions and Discussion

The experiments reported in this chapter suggest that where cognitive tasks are carried out, localized activity in the cortex can be identified. In the first experiment, the symbol recognition task, demanding a semantic interpretation of the symbol, activity seemed to be focussed on leads C3 and C4, over temporo-parietal regions. This is consistent with the clinical evidence that the temporal lobes are prepotent for LTM.

In the second experiment the well documented value of imagery in encoding stimuli to be remembered is used as a basis. Significant effects are found for the type of stimulus employed (low vs high imagery words) and the strategy adopted by the participant. After instruction in the use of imagery to remember the lists performance was improved and this improvement was correlated with a decrease in CNV amplitude.

The third and fourth experiments are attempts to develop this finding further by manipulating cognitive load in the form of the size of the set of words to be remembered. The findings from these are inconclusive, but suggest that this line of experimentation is worth pursuing.

CHAPTER 7 Face Recognition and the CNV

7.0 Introduction

The ability to recognise faces is clearly an important attribute of the human information processing system. From the perspective of investigations of the localization of higher mental processes some of the characteristics of the face recognition task are of considerable interest in the search for underlying mechanisms. In particular some workers (Yin, 1969; Walsh, 1978) have interpreted the evidence as suggesting a specific face recognition mechanism, differently localized from the mechanisms utilized in the recognition of other pictorial material. If this is the case and one accepts the assumption that the EEG (and ERPs derived from it) do provide valid indices of cerebral function then it would be reasonable to expect patterns of activity to reflect this localized processing. At this stage the value of the EEG and ERPs as monitors of activity during cognitive processing are still to be demonstrated unequivocally. It is the confluence of these two strands of research that makes the face recognition task such a valuable test. Furthermore, to the extent that verbal cues are unavailable for the solution of face recognition problems, the similarities with tasks demanding the use of imagery in the requirement for visuo-spatial processing may involve some overlap in the mechanisms employed.

Support for the hypothesis of a unique and localized face processing mechanism comes from three areas. Firstly, babies seem to be particularly responsive to facial configurations early in their lives suggesting an innate mechanism (Gibson, 1969). While the importance of face recognition in the development of early patterns of interaction can be appreciated, a number of factors, such as the inability to control for levels of early experience, and the difficulty of controlling all the physical differences between stimuli make the proposition that there is an innate face recognition mechanism difficult to support.

Secondly, the clinical investigation of a number of patients has revealed a pattern of symptomatology labelled prosopagnosia, with specific deficits in face recognition. While patients usually demonstrate a range of associated disturbances, the inability to recognize faces is such a striking deficit that it tends to dominate any other problems. The difficulty for the localization hypothesis is that the clinical literature reports lesions in a range of sites over many areas of the cortex which have been related to prosopognosia. While this is consistent with the notion of distributed processing systems it makes the suggestion of face-specific analysing systems a much more difficult idea to test and sustain. An overview of the clinical neuropsychological investigations and the one review of an extended series of patients (Hecaen and Angelergues, 1962) tends to suggest that the right hemisphere is prepotent for this task.

Inversion of pictorial material leads to problems of recognition in a variety of instances but the effects on face recognition are apparently significantly greater than in the case of other classes of stimulus material (Ellis, 1975). Interestingly the inversion condition has less effect on the performance of patients with brain damage in the right hemisphere than on intact participants in the task (Yin, 1969). Thus the least the inversion condition provides is a useful comparative manipulation, enabling two levels of task difficulty to be investigated.

Recent experimental investigations (Sergent and Bindra, 1981) of the face recognition task have direct implications for the functional hemispheric asymmetry hypothesis. The model of brain function derived from this work tends to stress the similarity between hemispheres as duplicate processors of limited and similar capacities differing only in speed of analysis of stimulus material. The hemispheric differences of response between verbal and visuo-spatial classes of stimulus material are only demonstrated where the task demands of the experiment explicitly manipulate the required speed of analysis. The right hemisphere is supposedly specialized for the fast analysis of low spatial frequencies and the left hemisphere for the analysis of higher spatial frequencies although exactly why this should be the case is unclear. Face recognition, carried out under conditions of brief exposure, emphasises the rapid analysis of lower spatial frequency stimulation, and therefore, preferentially involves the right hemisphere.

Interestingly, this bears directly on one of the issues arising in much of the work which is aimed at the preferential involvement of the right hemisphere, the possibility of verbal mediation in tasks of this type. In analysing the characteristics of the face recognition task Richardson (1980) has drawn attention to the importance of visuo-spatial cues and the limited utility of verbal mediation in a task of this sort, and this is certainly the premise on which the work reported in this chapter was based, however, the possibility that verbal strategies may be utilized should not be ignored.

The hypotheses being tested in the experiments reported in this chapter are therefore:

1. That the face recognition task will preferentially involve the right hemisphere, and that this involvement will be reflected in the amplitude of CNV recorded from electrode P4;

2. That response latencies to decisions in which one member of the stimulus pair is inverted will be significantly longer than those in the upright orientation;
3. That the amplitude of the CNV will be reduced under task demands involving inverted stimuli in responses recorded from P4.

7.1 Face Recognition and the CNV

In the initial experiment in this sequence the relationship between performance and electrophysiological variables will be explored by asking participants to remember a set of unfamiliar faces, and then soon after indicate which of an extended series were included in the target set. Differences between the encoding phase, when participants were presented with the target set and the recognition phase when the target set was later identified later were investigated. On the basis of the literature reviewed, localized effects would be expected to be recorded at the right parietal lead in the encoding phase.

7.1.1 Stimuli

Slides were prepared, each containing a head and shoulders representation of an adult male.

Pictures were originally university identification photographs. Two sets of forty faces were separated and each set subdivided into two groups of twenty.

7.1.2 Participants

The participants were eight females ranging in age from 18-25 years. Seven were right handed.

7.1.3 Procedure

Induction: all participants were instructed in the nature of the task they were undertaking and were given a series of training trials equivalent to the experimental task before participating in the experiment. Instructions were to 'sit quietly with eyes on the projection area', eye movements were to be limited to intertrial periods. During the encoding phase participants were told to 'try and remember the faces they were seeing'. In the recognition phase participants were given the added task of indicating whether the face they were seeing was part of the original target set or not. This they did by pressing one of two microswitches. Responses were to be made as accurately and as quickly as possible.

Encoding Phase: Participants viewed a series of twenty slides in sequence. Each slide was preceded by a warning signal (1000Hz, 80dB) and one second later the stimulus slide which was projected for 500 milliseconds. After projection of a slide, the cassette was automatically moved to the next stimulus. Time between presentations ranged from

4-8 seconds.

Recognition Phase: stimulus presentation in this phase was similarly timed to the acquisition phase. The differences in procedure were:

1. The full set of 40 faces (20 target and 20 non-target) were presented;
2. A response was required of the participant (dominant hand) indicating whether the figure was in or out of the target set;
3. A new trial was initiated after the participant had responded in the previous trial.

7.1.4 EEG Recording

The EEG was recorded from electrodes at P3 and P4 referred to paired mastoids. Eye movements were recorded from an electrode 5cm above the nasion on the midline, and referred to the paired mastoid electrodes. Two earth electrodes were placed on the scalp at the midline. The Elema Schonander Mingograph was used for recording (TC=3.5 seconds, HF cut off 70Hz). The EEG was averaged for each participant for encoding and recognition phases respectively.

7.1.5 Results

In table 7.1 the mean reaction times for responses to the target and non target sets are presented.

Table 7.1

Mean Reaction Times to Faces in Target and Non Target Sets

Participant	Target Set	Non Target Set
1	1080	1013
2	841	1142
3	862	808
4	1097	1195
5	1108	1312
6	1602	2064
7	995	2064
8	1169	1157

A t test was performed on the RT data and the difference between responses to target and non target sets was not significant (t=1.56, df=7, p>0.05).

In table 7.2 CNV amplitudes for all participants are presented. A sample of the ERPs from one participant are included in Appendix IX. Differences in CNV amplitudes between electrode sites and phases were not significant.

Table 7.2

CNV Values for Encoding and Recognition of Faces

		Electrode Site	
		P3	P4
Encoding	1	4.79	2.21
	2	3.36	1.54
	3	3.24	3.14
	4	6.94	5.96
	5	7.19	6.66
	6	5.48	10.91
	7	4.60	7.71
	8	9.14	7.15
Recognition	1	6.08	8.90
	2	7.63	10.61
	3	5.35	5.35
	4	11.35	8.13
	5	4.17	3.27
	6	4.30	5.90
	7	5.40	5.05
	8	3.28	2.10

A correlation coefficient (Spearman's rank order) was calculated for the CNV amplitudes at each electrode during each phase with the mean response time for all responses. The results of this are presented in Table 7.3 which shows a significant correlation at lead P4 during the encoding phase.

Table 7.3

Spearman's Rank Order Correlations between CNV amplitude and mean RT

		Electrode	
		P3	P4
Phase	Encoding	0.52	-0.91 $p<0.001$
	Recognition	0.43	-0.45

7.1.6 Discussion

The results of this experiment indicate the involvement of mechanisms in the right parietal lobe in the encoding phase of a face recognition task. This is shown by the significant correlation between the amplitude of the CNV during encoding and the RT to stimuli in the target set during recognition. Differences between reaction times to target and non target sets, and amplitude differences in the CNV between electrode sites and phase were not significant. The face recognition task has been shown to be suitably adapted for recording ERPs and the result obtained supports the evidence from other sources for the involvement of mechanisms in the right parietal lobe. The task is clearly worthy of further investigation, and the inclusion of upright and inverted task conditions enables a comparison of different levels of task difficulty.

7.2 The CNV and Face Recognition in Upright and Inverted Orientation (1)

One finding emerging in the literature on face recognition is that inversion of the face to be recognised significantly enhances the difficulty of the task for normal subjects (Galper, 1967; Yin, 1970; Ellis, 1975). Apparently individuals suffering from brain damage in the posterior right quadrant of the cortex find little additional difficulty with the inverted stimulus compared with the upright (Yin, 1970): a finding which has been interpreted as supporting the notion of a face specific processing mechanism in the right parietal lobe.

For the purposes of this programme of research inversion of the probe stimulus provides a convenient increment in task difficulty by which to test the localisation and effort hypotheses which have directed the work. The face recognition task was therefore adapted to the CNV recording paradigm. Specifically, it is hypothesised that:

1. Recognition of the inverted face will take significantly longer than faces in the upright orientation;

2. CNV recordings from the right parietal lead in the inverted condition will be significantly smaller than those in the upright condition.

7.2.1 Stimuli

Sets of pairs of projection slides of faces prepared for the previous experiment was were used. Two groups of forty pairs were selected, one which became the upright group, the other the inverted. Within each group half of the probe stimuli were the same face and half of different faces. Order of presentation within each group was randomised.

7.2.2 Procedure

A trial consisted of a pair of slides, each presented for 250 milliseconds and separated by 4.0 seconds. In the upright condition every slide was right side up and in the inverted condition every second slide of a pair was upside down.

Participants were seated in a comfortable chair and responded with the dominant hand while holding the response box in the non-responding hand. Stimuli were projected onto a grey wall 1.5m from the participant at eye height. Stimuli subtended a visual angle of approximately 5 degrees.

7.2.3 Participants

Five people took part in the experiment. Ages ranged from 20-35 years. Three were male and two female. All were right handed. None was receiving pharmacologicaal medication.

7.2.4 EEG Recording

EEG was recorded from P3, PZ and P4 referred to paired mastoid electrodes. Eye movements were recorded from a pair of electrodes, one at the outer canthus of the left eye, the other at a point 5cm above the nasion. The earth electrode was connected to the left earlobe. Time constant of the Grass 7P511 amplifier was 3.5 seconds and high frequency cut off was at 30Hz. The EEG from each trial was digitized and stored on disc in the Altra-50 system. Separate averages were computed for the following conditions: (i) stimulus pairs the same; (ii) stimulus pairs different; (iii) stimulus pairs upright and (iv) probe stimulus inverted, for each participant separately.

7.2.5 Results

The mean response times for each condition are presented in Table 7.4.

Table 7.4

Response Times in Face Recognition task including Upright and Inverted Conditions

	Upright	Inverted
Same	800	1105
	733	730
	805	1121
	1003	1113
	1082	1295
Different	1004	1037
	867	890
	922	1095
	1068	1091
	1025	1220

Inversion of the probe stimulus results in a longer response time for all participants which is clearly significant (F=19.92, df=,16, p<0.001). The difference between 'same' and 'different' responses is not significant.

Measurements of the CNV with respect to a pre-stimulus baseline are presented in an Appendix X. An example of the averages from one participant are included in Appendix XI.

The mean CNV values at electrodes P3, Pz, P4 are depicted in Figure 7.1.

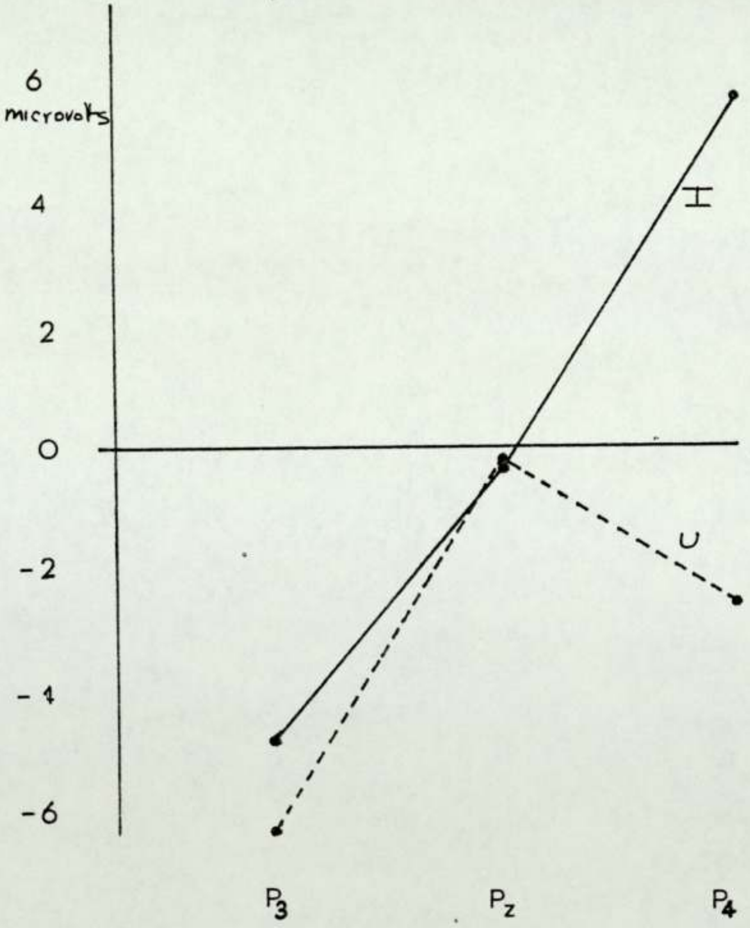


Figure 7.1

Mean CNV Amplitudes for Upright and Inverted Conditions Face Recognition Task

A t test to determine the significance of the difference between the responses for upright and inverted conditions recorded from lead P4 was highly significant (t = 33.4, df = 4, $p<0.001$).

7.2.6 Discussion

Considering the small sample utilized it is very interesting to find such a clear cut result. Until the finding is replicated it must, however, be treated with some caution. Clearly the demand for a comparative decision to an inverted face leads to an increased response time suggesting the additional processing demands that the inverted condition entails compared with the upright condition. The experiment also provides some support for the findings from experiment 7.1 that the posterior right quadrant of the cortex appears actively involved in the task of face recognition since the CNV amplitude recorded from P4 is lower in the inverted condition than the upright.

At post experimental enquiry all of the participants in this experiment indicated a tendency to try and reorient the inverted probe stimulus to the upright position in solving the problem. This would involve manipulation of the image just perceived since the stimulus was only presented for 250 milliseconds and it was this observation, and the availability of a better amplification system which prompted the redesigned experiment to be reported next.

The opportunity was also taken to correct two further shortcomings in this experiment, the limited range of electrode sites and the grouping together of all trials in a particular condition.

7.3 The CNV and Face Recognition in Upright and Inverted Orientation (2)

This experiment is designed to examine further the results obtained in the last two experiments which lead to the conclusion that mechanisms in the right posterior quadrant of the cerebral hemispheres are prepotent in responding to the demands of a face recognition task, particularly where a condition based on the inversion of the probe stimulus is included. In this instance three main modifications to the experiment are included:

1. The trials under upright and inverted conditions are now run in the same set but in a randomised order within that sequence and the averages are calculated off line;
2. The inverted stimulus is now the first of the pair in the inverted trials;
3. New amplifiers have been constructed, giving a longer time constant (10 seconds) and a notch filter at 50 c.p.s.;
4. EEG recordings are made from four sites, F3, F4, P3 and P4.

Once again the hypotheses being tested are:

1. That responses to inverted trials will be significantly longer than those to upright trials;
2. That the CNV amplitude for inverted trials will be lower (more positive) than for upright trials in the recordings from P4, the right parietal lead.

7.3.1 Stimuli

The same set of stimuli as employed in the two earlier experiments in this set were utilized. In this case the stimuli were modified by blanking out external features such as hairline, shoulder and neckline thus forcing the respondent to concentrate on internal cues and, therefore, reduce the possibility of verbal mediation.

The stimuli were arranged in a set of 40 pairs, 20 upright and 20 inverted. Within each of the inverted and upright subsets, 10 responses were the 'same' and 10 'different'. The order of stimulus pairs was randomised. Presentation was controlled by a programme written for the BBC Model B microcomputer. This allowed the presentation times and intervals between stimuli to be set, and also triggered the A-D converter to sample the EEG. The projection of stimuli was by Kodak carousel projector with a tachistoscope shutter.

Each stimulus was presented for 400 milliseconds and the inter stimulus interval was 2.5 seconds. Intervals between trials ranged from 8.5 seconds to 12.5 seconds and varied in an unpredictable sequence.

7.3.2 Procedure

Electrodes were fixed at F3, F4, P3 and P4 and all were referred to paired electrodes on the mastoid processes. The earth was placed at the vertex. The amplifiers utilized had a time constant of 10 seconds, and a notch filter at 50 Hz.

The experiment was explained to each participant and a short training sequence conducted prior to running the experiment proper. Each participant expected some trials which would start with an upright stimulus and others with an inverted stimulus. In the case of an inverted stimulus, encouragement was given to 'rotate the image of the face in the interval before the stimulus is projected'. Instructions were to respond as accurately and also as fast as possible.

Response latencies were measured from the onset of the second slide in the sequence with a sensitivity of millisecond.

Averages of the selected EEG trials were computed off line.

7.3.3 Participants

The participants were eight right handed males ranging from 20-37 years of age. None were taking medication.

7.3.4 Results

The response times recorded were analysed using a three way analysis of variance (S.P.S.S. package, 2nd edition, 1982). Factors tested were the face (whether the probe was the same or different), the orientation (upright or inverted) and the participant. The result of the analysis of variance is presented in Table 7.5 below.

Table 7.5

Analysis of Variance : Face Recognition in Upright and Inverted Orientations

Performance Data

Source of Variation	Sum of Squares	df	Mean Square	F	Significance F
Main Effects	52268032.000	9	5807559.000	30.120	***
Face	6733841.000	1	6733841.000	34.924	***
Orient	718253.875	1	718253.875	3.725	*
Subject	44843768.000	7	6406252.000	33.225	***
2-way Interactions	12472128.000	15	831475.125	4.312	***
Face Orient	411392.625	1	411392.625	2.134	NS
Face Subject	7532564.000	7	1076080.500	5.581	***
Orient Subject	4525215.000	7	646459.250	3.353	**
3-way Interactions	624320.000	7	89188.563	0.463	NS
Face Orient Subject	624315.875	7	89187.969	0.463	NS
Explained	65364480.000	31	2108531.500	10.935	***
Residual	55338320.000	287	192816.438		
Total	120702800.000	318	379568.500		

* $p<0.05$
** $p<0.01$
*** $p<0.001$

The three main variables manipulated in this experiment, the match between target and probe stimulus, the orientation of the target stimulus and the individual differences between participants all had a significant influence on the performance of the task. Furthermore, the individual differences between participants interacted with both the orientation and the match between target and probe, suggesting that an important variable which must be identified probably relates to individual abilities to adopt a particular strategy toward the task. The mean response times for each participant in each condition are included in Appendix XII.

Event related potentials were also subject to an Analysis of Variance. The outcome of this analysis is presented in Table 7.6 overleaf. It shows that the site of electrode, the orientation of the stimulus and differences between participants all had a significant effect on the amplitude of the CNV, and also there was a significant interaction between participants and the orientation of the target stimulus.

Table 7.6

Analysis of Variances : Face Recognition in Upright and Inverted Orientations

Performance Data

Source of Variation	Sum of Squares	df	Mean Square	F	Significance F
Main Effects					
Electrode Site	276937.58594	3	92312.52865	6.67	**
Orientation	1297459.13281	1	1297459.13281	93.75	***
Face	6947.25781	1	6947.25781	0.50	NS
Participant	4756833.05469	7	679547.57924	49.10	***
Two Way Interactions					
Site by Orientation	68967.83594	3	22989.27865	1.66	NS
Site by Face	27974.33594	3	9324.77865	0.67	NS
Site by Participant	320486.35156	21	15261.25484	1.10	NS
Orientation by Face	13020.94531	1	13020.94531	0.94	NS
Orientation by Participant	5081273.67969	7	725896.23996	52.45	***
Face by Participant	178612.05469	7	25516.00781	1.84	NS
Three Way Interactions					
Orientation by Face by Participant	58203.86719	7	8314.83817	0.60	NS
Site by Face by Participant	179058.10156	21	8526.57626	0.62	NS
Site by Orientation by Participant	605756.10156	21	28845.52865	2.08	*
Site by Orientation by Face	130885.77344	3	43628.59115	3.15	*
Residual	290632.16406	21	13839.62886		

* $p<0.05$
** $p<0.01$
*** $p<0.001$

The significant differences between electrode sites were subject to further analysis to determine if the effect was due to an asymmetry across hemispheres or a differences between frontal and posterior sites. This analysis was performed by t tests on the responses from the relevant pairs of electrodes. The results are presented in Table 7.7.

Table 7.7

CNV : Face Recognition : Upright and Inverted Conditions : t tests : Selected Pairs of Electodes

Condition	Electrode Pair	t		
Upright	F3 P3	4.61	p<0.001	Frontal to Parietal
Upright	F4 P4	0.46	NS	
Inverted	F3 P3	10.55	p<0.001	
Inverted	F4 P4	3.95	p<0.001	
Upright	F3 F4	0.68	NS	Left to Right
Upright	P3 P4	2.91	p<0.02	
Inverted	F3 F4	4.64	p<0.001	
Inverted	P3 P4	1.93	NS	

Of the four results focusing on fronto-parietal differences, three are significant and all indicate greater amplitude CNV from posterior leads. The four results referring to hemispheric asymmetries tend to show smaller amplitude CNVs from right hemisphere leads. In two cases the difference is significant, in one other approaching significance, and the other result shows very similar amplitudes over both hemispheres. These results suggest right hemisphere involvement in the face recognition task.

Having clearly shown that the orientation has a significant effect on both performance and event related potentials, it is of interest to develop the analysis further in an attempt to localize the prepotent cerebral areas for performance on this task. To do this the strategy developed in previous chapters, the computation of correlation coefficients between the change in performance from upright to inverted orientation, and the change in the amplitude of the CNV response from one condition to the other is calculated. In previous experiments this has commonly resulted in a significant correlation at a limited number of sites, predicted on the basis of the relevant neuropsychological and behavioural literature. The data on which the correlations are based is included in Appendix XIII. The resultant correlation coefficients are presented in Table 7.8.

Table 7.8

Correlation Coefficients between Change in Performance and Change in CNV Amplitude from Upright to Inverted Orientation of Target Stimulus

F3	F4
0.358 NS	0.150 NS
P3	P4
0.116 NS	0.223 NS

Clearly it is not possible to identify a quadrant of the cortex which is prepotent in the task as operationalised in this experiment using the method we have successfully employed in earlier studies. In the light of the significant results obtained in the earlier analyses further exploration of the problem is warranted.

A graph (Figure 7.2) depicting the mean CNV values of each electrode site for each condition is revealing. This shows that the effect of the inverted condition compared with the upright was significant at all sites. That is the additional task demands of the inverted condition lead to a decrease in CNV amplitude at all electrode sites.

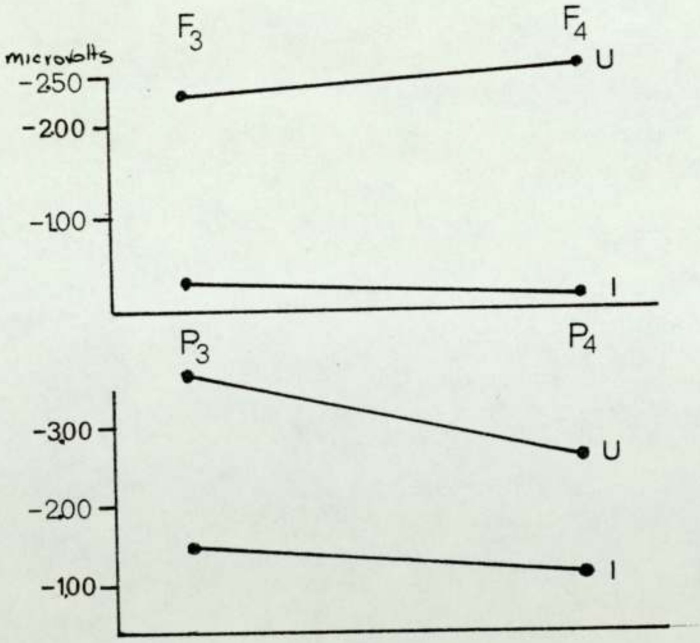


Figure 7.2

CNV Values : Face Recognition Task; Upright and Inverted Conditions

7.3.5 Discussion

In this experiment the two conditions, upright and inverted stimuli, have been shown to differ in level of difficulty on the basis of the performance measures. Furthermore, there is a clear difference between conditions in CNV amplitude, the more difficult inverted condition having a lower amplitude. These findings offer clear support for the inverse relationship between task difficulty and amplitude of the CNV. However, it has not been possible to identify prepotent areas for processing faces, and this has been because of the general effect of task difficulty on CNV amplitude at all electrode sites. Under these experimental conditions, the inverted task may have proved so difficult in comparison with the upright that cortical activation was extensive.

7.3.6 Conclusions

The objective of this chapter was to investigate a task which, on the basis of the literature available one would expect to be associated with activity in the posterior right hemisphere. In general the findings support this hypothesis. Also, there is support for the hypothesis that as tasks increase in difficulty, the amplitude of the CNV decreases. In all cases where one of the stimuli in a trial was inverted, this manipulation was reflected in slower performance of the task as well as decreased amplitude of the CNV. In the first experiment the relationship between performance and amplitude of the CNV was shown to be in the encoding phase, rather than during recognition. In the second experiment of the sequence the relationship between change in performance and change in amplitude of the CNV was significant at the electrode over the right hemisphere. However, in the last experiment, in which the independent variable was the orientation of the target face the relationship between performance and CNV change could not be localized to a particular site, and this was thought to be a consequence of generalised activation at all sites.

In this experiment the participants were asked to rotate the target stimulus to the upright orientation during the interstimulus interval, so that a comparison between target and probe could be made at the termination of that interval. At post experimental enquiry all participants indicated they had attempted to mentally rotate the face but had adopted a strategy whereby particular internal features, such as the eyebrows, were analysed in detail and this was used as the basis of the decision at the end of the trial. The finding that decisions are made on the basis of manipulation of an image of the face is worthy of further investigation. The idea of rotation of a mental image as the basis for exercises in spatial problem solving has recently been investigated extensively and considerable data has been accumulated on the performance of this task. In the next chapter mental rotation will be investigated further.

CHAPTER 8 Mental Rotation and the CNV

8.1 Introduction

The ability to solve problems based on the mental reorientation of objects has emerged as an important aspect of visuo-spatial skills from both psychometric investigations employing factor analytic techniques and experimental investigations of the relevant behaviour. It is the active nature of the manipulative process to which the explanations of these findings refer which suggests that, if it can be constrained to a recording paradigm suitable for the CNV, then a powerful tool for the investigation of brain behaviour relationships will be available.

In experiments conducted in this area (Cooper, 1975, 1976; Cooper and Shepherd, 1973; Shepherd and Metzler, 1971) the participant is usually asked to imagine the manipulation of objects which are supposedly not easily described verbally. For example, a pair of two dimensional perspective line representations of three dimensional objects might be presented and participants asked to indicate whether the objects are the same or different (Cooper, 1975). The angle of orientation separating the stimuli is the independent variable, and apparently a mental process analogous to the physical manipulation of the objects is employed in making the decision. The time to solve the spatial problem is proportional to the reorientation necessary to make a direct comparison. Most participants report that both visual and kinaesthetic imagery are employed in carrying out the task.

Shepherd and Podgorny (1978) review a number of the relevant studies exploring the phenomenon and identify three important characteristics, the correspondence between the results obtained with both mental and physical processes of reorientation, the equivalence of the processes whether the original object is present or not, and the analogies between the underlying processes whether imagined or perceptual. The claim is that comparisons of the shapes of two objects of similar appearance but in different orientations is carried out by mental movement through internal states which bear a one to one relationship to the physical state that the object would pass through if physically rotated. It is suggestive of an internalized framework representing the spatial relationship of the body to the rest of the world which is utilized in devising solutions to spatial problems and remembering spatial relationships. The functional characteristics of this mental framework bear a striking similarity to the features commonly ascribed to the use of mental imagery in problem solving.

Considering the extensive literature on hemispheric asymmetries in the performance of visuo-spatial tasks it is surprising that mental rotation has not been more widely used as a model. Hayashi and Hatta (1978) found that with lateralized presentation of Japanese ideographs in different orientations there was a left visual field superiority in performance on a comparison task. Cohen (1977) found a left visual field advantage on a mental rotation task similar to that employed by Shepherd and Metzler (1971) while Kroll and Madden (1978) were only able to identify this preferential activation of the right hemisphere in a subset of their group.

Some preliminary attempts have been made to investigate the phenomenon using paradigms which enable the collection of EEG data. Ornstein, Johnstone, Herron and Swencionis (1980) compared the integrated alpha measurements at central and parietal sites for 10 female and 10 male subjects performing six spatial and one verbal task. The tasks were designed to take approximately three minutes each and there were attempts to control for gross motor activity and stimulus characteristics. Oculo-motor activity, level of difficulty of the task, and effort expended by the participant remained confounding variables. Most task-associated changes in the EEG occurred over the right hemisphere, but the mental rotation task was least effective at activating both hemispheres suggesting perhaps that less effort was expended on this task.

Gevins, Zeitlin and Doyle (1979) attempted to improve the controls over factors other than the cognitive variables in their experiments by selecting sections of trials not contaminated by changes in some of the confounding variables, eliminating the need for limb movements and by pretesting participants so that tasks could be equated for level of difficulty. Compared with a base line passive visual fixation condition all tasks activated the cortex but it was not possible to distinguish between tasks in terms of patterns of activation. The mental rotation task, which was the only supposedly right hemisphere task could not be differentiated from the analytic left hemisphere tasks on the basis of the topography of EEG changes.

The limited evidence available in which EEG measures were employed only serves to emphasise the difficulty devising experimental arrangements which can satisfy the many technical demands identified if a valid test of the localization hypothesis is to be carried out. No studies measuring ERPs with mental rotation tasks have been located.

The relationship between lesions of the posterior right quadrant of the cerebral hemispheres and performance on visuospatial tasks has been well documented (Davidoff, 1982; Meier and Thompson, 1983). Recently this has been investigated using a variant of the mental rotation task originally devised by Benson and Gedye (1963) in which the stimuli are front and back views of a mannikin holding two circular flags, one in either hand (Ratcliff, 1979). One flag is shaded and the other not (see Figure 8.1). Patients with unilateral brain damage confined to either the posterior or anterior quadrants were examined in a task requiring comparative judgements of two mannikins in different orientations. Those with posterior right hemisphere lesions performed significantly worse on the task than all other groups. The implication is that the mental rotation necessary for this judgement is dependent on the functional integrity of the posterior right hemisphere. If this is the case, it may be possible to identify functional differences in non clinical groups in indices of cerebral function such as ERP.

The review of studies on the mental rotation phenomenon by Shepherd and Podgorny (1978) makes explicit references to the importance of imagery in understanding the processes involved. In particular transformations in the prescence or absence of relevant stimulus objects have been shown to be equivalent in a number of respects and the use of imagery provides a parsimonious explanation for this finding. The experiments in this chapter examine the use of imagery in solving mental rotation problems and correlate these findings with measurements of cerebral function employing the CNV. The hypotheses to be tested are as follows:

1. (a) That the utilization of imaginal or verbal strategies in performance of a mental rotation task has systematic consequences for the amplitude of the CNV;

   (b) That different solution strategies lead to systematic variations in response latencies;

   (c) That performance changes are correlated with changes in the amplitude of the CNV at electrodes over the posterior right quadrant of the cortex, or those immediately adjacent to this area;

2. (a) That the complexity of the rotation task systematically influences solution latencies;

   (b) That there will be a difference between hemispheres in CNV amplitude, the right hemisphere amplitude being smaller than the left for tasks requiring greater reorientation of the target stimulus.

8.2 Imagery Strategy, Mental Rotation and the CNV

A consideration of the experimental results, and the protocols collected from individuals performing mental rotation tasks suggests that imagery is commonly utilized as a strategy for solving problems. In this experiment performance after instructions designed to induce an imaginal set is compared with the effects of use of a verbal set.

8.2.1 Stimuli

The mannikin stimuli used by Ratcliff (1979) were prepared as slides for projection. The four permutations possible are depicted in Figure 8.1 overleaf. Pairs of these stimuli were selected so that equal numbers of 'same' and 'different' judgements were included in each sequence of trials which made one condition.

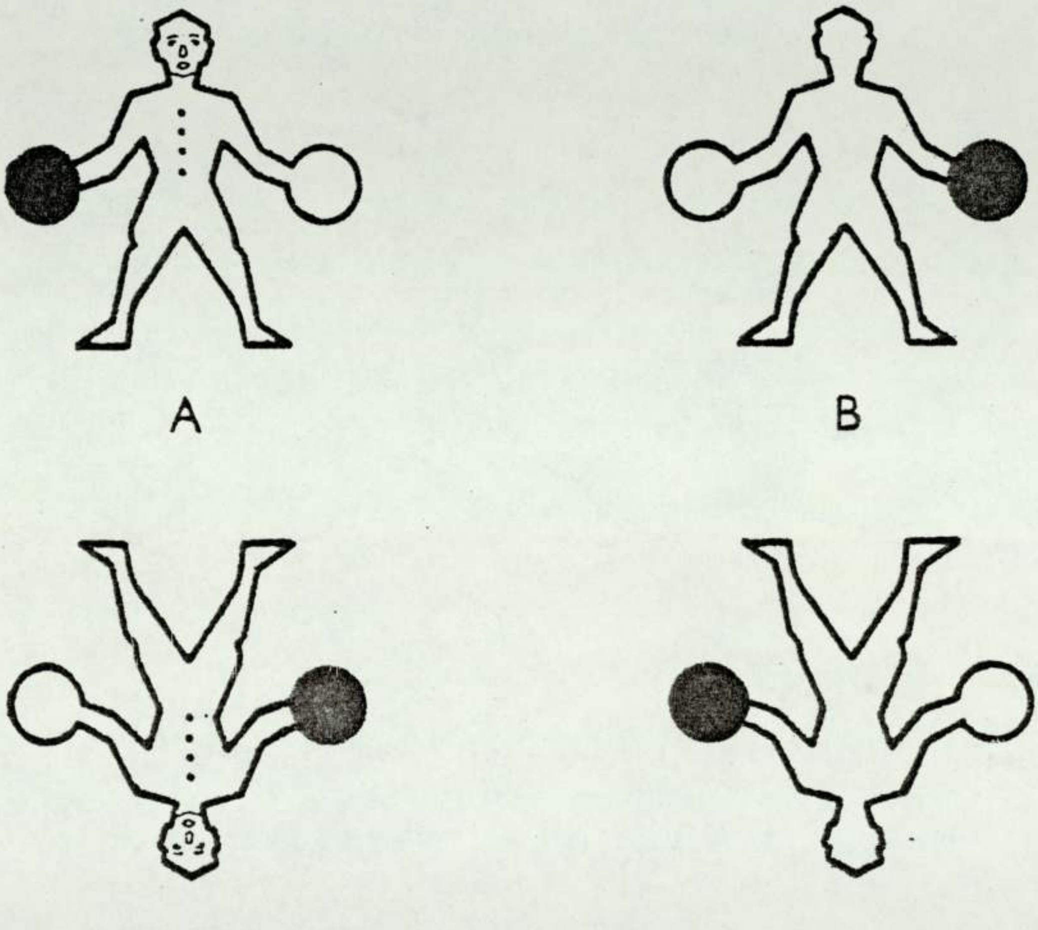


Figure 8.1

Mannikin Stimuli, Mental Rotation (Ratcliff, 1979)

Experiments 8.1 and 8.2

8.2.2 Procedure

A trial consisted of the presentation of a pair of the stimuli. Each of the four possible stimuli (Figure 8.1) represented the initial stimulus an equal number of times The second stimulus was either a rotated version of the first or an alternative. On half the trials a decision that the initial and subsequent stimuli were the same was correct. All combinations appeared equiprobably in each sequence which formed one condition in a randomised order. Stimuli were presented for 250 milliseconds and were separated by 3.0 seconds. Sixteen trials were included in each sequence.

In the imagery condition participants were asked to imagine the mannikin rotating, and then on viewing the second slide decide if this was the same stimulus. Considerable care was taken in inducing the imaginal set. A short training sequence of ten pairs was used to familiarise participants prior to each of the imagery and verbal sequences. Response times were measured from the onset of the first slide. Each participant completed three sequences of 16 trials. In the first two the imagery strategy was encouraged. In the third, the verbal strategy was introduced. By identifying which hand held the shaded flag (left or right) and making the appropriate correspondence with the second stimulus, it was possible to avoid the use of the imagery strategy and thus alter the cognitive demands during the S1-S2 interval.

8.2.3 Participants

Participants were eighteen volunteers ranging from 18-38 years of age. Eleven were female, seven male and all were right handed. None were receiving medication.

8.2.4 EEG Recording

The EEG was recorded from F3, F4, C3, C4, P3 and P4 using the Elema Schonander Mingograph with amplifiers at a time constant of 3.5 seconds and high frequency cut off at 70Hz. Averages were computed for each participant for each of the three sequences, at each electrode site.

8.2.5 Results

Figure 8.2 depicts the mean response time for each condition. The difference in response time between the second imagery sequence and the verbal sequence proved significant ($t=2.34$, $df=17$, $p<0.05$). Thus the verbal strategy proved more effective in reducing response times than an imagery strategy.

The CNV measurements are presented in Appendix XIV. Figure 8.3 depicts the mean CNV amplitude at each electrode site for each condition. A general decrease in amplitude occurs from condition 1 to 2, presumably the result of more effective utilization of the imagery strategy, and an increase in amplitude from condition 2 to 3. Two observations of the CNV data are worth noting. Under the imagery set the electrode over the left hemisphere at each of the frontal, central and parietal sites always records the higher amplitude CNV. This pattern is reversed in all but the parietal sites under the verbal strategy. Secondly, the greatest changes in CNV amplitude occur at the parietal sites, both between the two imagery sequences, and from the second imagery to the verbal strategy.

Correlations between the change in response time from condition 2 to condition 3 and change in CNV amplitude between these two conditions were computed, and these are presented in Table 8.1. These suggest a localized relationship between performance change and CNV amplitude change which is centred on the right parietal lobe.

Table 8.1

Correlation (Spearman Rank Order) between Change in Response Time (Imagery to Verbal) and Change in CNV Amplitude

F3 -0.38	F4 -0.46
C3 -0.29	C4 -0.52 ($p<0.05$)
P3 -0.57 ($p<0.05$)	P4 -0.54 ($p<0.05$)

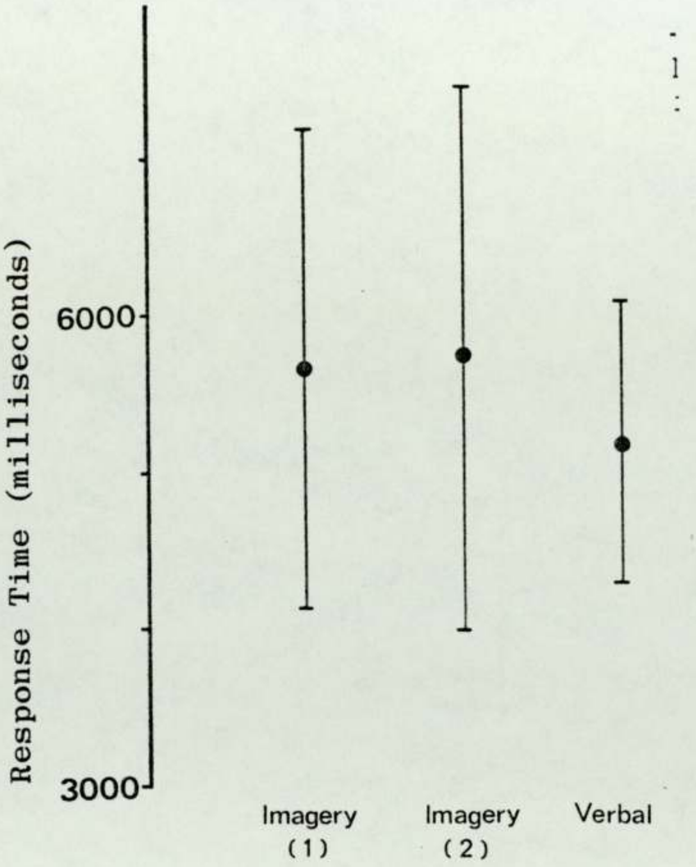


Figure 8.2
Mean Response Times for Each Condition,
Imagery 1, Imagery 2, Verbal

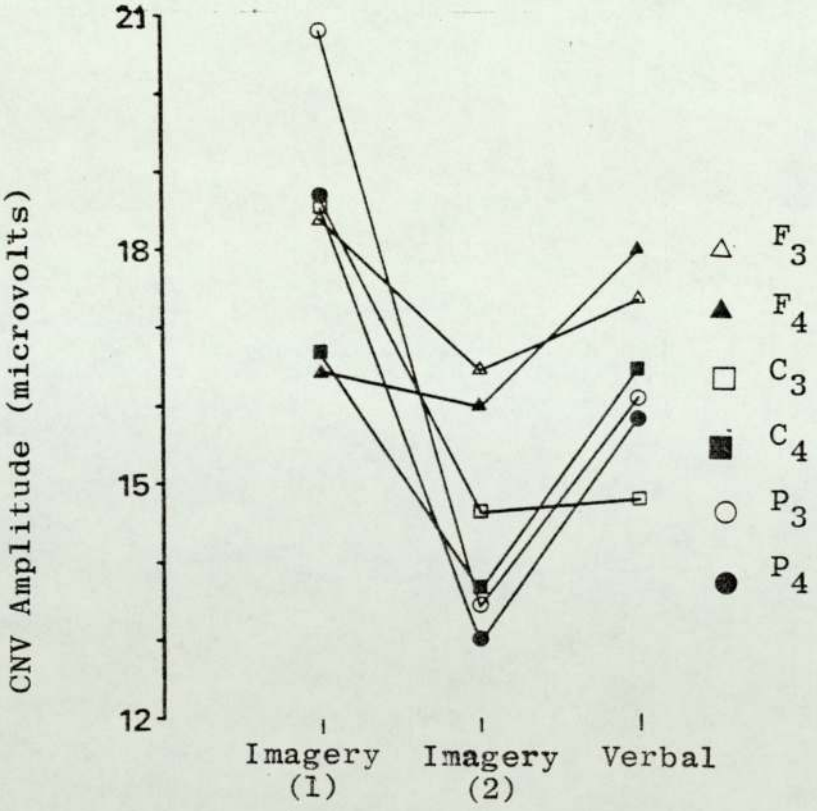


Figure 8.3
Mean CNV Amplitudes : Mental Rotation Task
(Experiment 8.1)

8.2.6 Discussion

One of the difficulties in this experiment is to obtain confirmation that participants utilized the strategy suggested. At post experimental enquiry all participants claimed to have used the imagery strategy, however they experienced varying levels of difficulty with this technique. None admitted to thinking of the verbal strategy without prompting by the experimenter.

The results suggest that the task is much more complicated than originally envisaged. The improvement in response time from the first to second imagery sequence is minimal, but this is accompanied by a considerable change in CNV amplitude, suggesting that a systematic examination of the effects of training in the use of imagery strategies might prove fruitful. The significant decrease in response time from the second imagery sequence to the sequence using the verbal strategy was accompanied by an increase in CNV amplitude (more negative) at all electrode sites. The correlation matrix (performance with CNV amplitude) for all sites shows significant relationships at both parietal sites and C4. In this instance, the inverse correlation signifies a relationship between a decrease in response time and an increase in CNV amplitude. The design employed in this study would have been more symmetrical if two runs of both the imagery and the verbal conditions had been conducted, and in that event comparisons between the second run in each condition may have provided clearer indicators of the localization of processing. The change in amplitude of the response at all electrode sites with the change from an imagery to a verbal strategy is a clear demonstration of the relationship between the electrophysiological variable and cognitive processes being employed in the solution of problems. One direction in which this finding might be explored further is in the effects of task complexity on both performance and CNV amplitude. The next study is designed with this objective in mind.

8.3 Complexity of Mental Rotation Task and CNV

The results of the experiment reported above suggest that the pattern of activation across the scalp is influenced by the strategies adopted to accomplish a mental rotation task and that the records from parietal electrodes seem to be the most responsive to demands of these tasks. One factor which makes for problems in interpreting the results of these studies is the level of difficulty of the task and the effort expended on solution by the participant. It is not possible to equate the difficulty of tasks across participants, just as it is impossible to equate the level of effort a participant will expend on a task. This experiment is designed to explore the effects of task difficulty on performance and patterns of cerebral activity. The hypotheses tested, as indicated previously are:

1. That the complexity of the rotation task systematically influences solution latencies, more complex reorientations leading to longer latencies;
2. That there will be difference in CNV amplitude at parietal electrodes, the amplitude over the right hemisphere being smaller as task complexity increases;
3. That there will be a hemispheric difference in amplitude of CNV, the amplitude over the right hemisphere being smaller than that over the left at any one level of task complexity.

8.3.1 Stimuli

In this experiment, the same stimuli were used as in the first experiment . Four sets of sixteen pairs of mannikins were selected, one set for each condition. Stimuli were arranged so that equal numbers of same and different responses were required in each set.

The selection of stimuli was based on the manipulations asked of the participants which were as follows: (i) no reorientation, (ii) 180 degree reorientation in horizontal plane, no reorienation in vertical plane, (iii) no reorientation in horizontal plane, 180 degree reorientation in vertical plane and, (iv) 180 reorientation in both horizontal and vertical planes. The order of presentation of each of the conditions requiring manipulation of the image was counterbalanced.

8.3.2 Procedure

Participants were instructed in the use of the imagery strategy and given a series of training trials. The instructions included a demonstration of stimulus pairs as the participant went through the manipulations necessary to carry out the task. Participants were asked to respond as accurately and as speedily as possible. Training trials immediately preceded the experimental trials for each condition. A trial consisted of the presentation of a pair of the stimuli. Each of the four possible stimuli (Figure 8.1) represented the initial stimulus an equal number of times. The second stimulus was either a related version of the first or an alternative. On half the trials the decision that stimuli were the same was correct. All combinations appeared equiprobably in a sequence which formed one condition in a randomised order. Stimuli were presented for 250 milliseconds and were separated by 3.0 seconds. Sixteen trials were included in each sequence. Apart from recording four sequences, one for each complexity level, instead of three, the procedure adopted was the same as for experiment 8.2.

8.3.3 Participants

Nine volunteers who had not taken part in an experiment on mental rotation before took part. All were right handed and ages ranged from 19-25 years. Six were female and three male. No participant was receiving pharmacological medication.

8.3.4 EEG Recording

The EEG was recorded from electrode sites P3 and P4 using the same recording equipment as in experiment 8.2. Averages were computed for each condition, for each electrode site for each participant. The decision to limit the sites from which the EEG was recorded was taken on the basis of the results in the earlier experiment which indicated activity at parietal sites was related to performance on mental rotation tasks.

8.3.5 Results

The average response time for the nine participants for each condition are presented in Table 8.2. The difference in response time between each of conditions (ii), (iii) and (iv) and the baseline condition (i) is listed in brackets behind each average response. Figure 8.4 depicts the mean response over all participants for each condition.

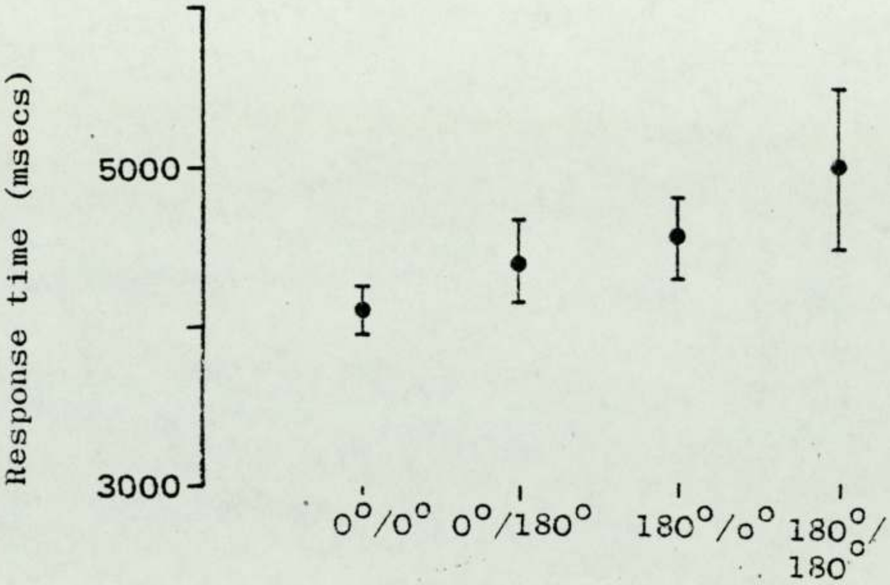


Figure 8.4

Mental Rotation : Mean Response Times : Four Levels of Task Difficulty

Table 8.2

Response Times for Mental Rotation Tasks Varying in Complexity

	(i) Baseline No reorientation	(ii) 180 reorientation in horizontal plane	(iii) 180 reorientation in vertical plane	(iv) 180 reorientation in both vertical and horizontal planes
1	4291	4445 (154)	4902 (611)	5571 (1280)
2	4152	4686 (534)	4358 (206)	4891 (739)
3	4598	5168 (570)	5594 (995)	7038 (2440)
4	3760	5172 (1412)	4827 (1067)	4800 (1040)
5	3956	4245 (289)	4419 (463)	4022 (66)
6	3690	3773 (83)	4150 (460)	4433 (743)
7	4147	4040 (107)	3940 (207)	4507 (360)
8	4054	4108 (54)	4403 (349)	3930 (-124)
9	4266	3987 (279)	4283 (19)	8023 (3759)
Mean	4102	4403	4542	4979
Standard Deviation			496	973

Mean differences in reaction time between each of conditions (ii), (iii) and (iv) and the baseline were all significant ($p<0.05$).

Amplitudes of the CNV recorded from P3 and P4 are listed in Appendix XV. These are depicted in Figure 8.5 which represents the mean CNV amplitude for each condition at electrode sites P3 and P4. Separate statistical analyses of the differences in CNV amplitude between each of conditions (ii), (iii) and (iv) and the baseline using the Wilcoxon Signed-ranks test only revealed significant finding for electrode P3 on condition (ii). CNV amplitude in all other conditions did not differ significantly from the base line. Correlations were also calculated between the CNV amplitude change for each of conditions (ii), (iii) and (iv) from the baseline and the equivalent changes in reaction time. The correlation between amplitude change due to condition (iii) at electrode P3 with the change in response latency from condition (i) to condition (iii) was significant. There was also a significant correlation between the change in CNV amplitude at P4, and the change in response latency for condition (iii). It is interesting to note that in Figure 8.5 condition (ii), the mirror image reversal, has resulted in CNV amplitudes which differ in the opposite direction from the baseline condition to the two other experimental conditions. The differences in amplitude between baseline and complexity of manipulation are presented in Table 8.3.

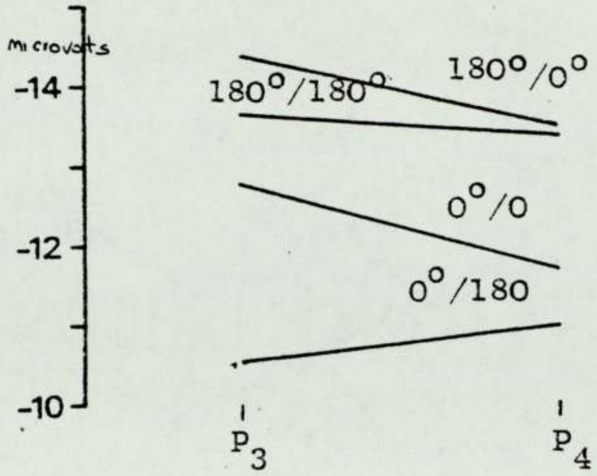


Figure 8.5

Mental Rotation : Mean CNV Amplitude for Four Levels of Task Complexity

Table 8.3

Difference in Amplitude of CNV at P3 and P4 for each Experimental Condition compared with Baseline

	(ii)		(iii)		(iv)	
	P3	P4	P3	P4	P3	P4
1	0.54	- 3.56	1.18	- 0.17	3.91	2.86
2	3.43	- 2.59	- 2.22	- 2.92	- 9.35	- 9.54
3	3.74	0.52	- 1.79	- 5.26	- 0.44	- 4.80
4	3.59	5.75	- 3.35	- 1.24	- 0.95	2.35
5	- 6.55	- 3.89	- 3.75	- 0.35	- 6.55	- 2.77
6	7.33	2.62	5.02	- 3.40	3.92	- 5.25
7	-10.56	- 8.45	-24.01	-12.80	- 2.93	1.16
8	0.23	3.23	3.77	0.88	- 5.77	-10.79
9	18.11	12.77	7.58	9.26	10.18	11.44

An analysis of amplitude differences at electrode P3 and P4 between (ii) and (iii) and (ii) and (iv) respectively revealed differences that were significant for electrode P3 for both comparisons, and electrode P4 for the comparison between conditions (ii) and (iii). These results are presented in Table 8.4.

Table 8.4

Statistical Analysis of CNV Amplitude Differences between Conditions (ii) and (iii) and (ii) and (iv) at Electrodes P3 and P4

		Probability	
P3	(ii) to (iii)	1.83	$p<0.05$
	(ii) to (iv)	1.53	$p<0.05$
P4	(ii) to (iii)	1.89	$p<0.05$
	(ii) to (iv)	0.98	$p>0.05$

8.4 Individual Differences in Imagery Ability

Participants in both experiments 8.2 and 8.3 completed the shortened version of the Bett's Vividness of Imagery questionnaire (Sheehan, 1967) and carried out the Necker cube reversal test (Richardson, 1972) to evaluate control of imagery. The correlation between scores on both these aspects of imagery for all participants was calculated, and found to be non significant. It was, therefore, concluded that different aspects of the ability to use imagery were being measured. It was hypothesised that control of imagery would be the most appropriate ability for performance on the mental rotation task and therefore, a t test on the performance of two groups of eight participants selected on the basis of high and low scores on the

Necker cube test was conducted. The difference in performance was significant ($t = 2.645$, $df = 8$, $p<0.01$). A similar analysis of the differences in amplitude of the CNV at P3 and P4 was not significant. In a number of the experiments reported in this dissertation the participant has interacted with the difficulty of the task suggesting the importance of individual differences in imagery ability in performance on these tasks. A systematic exploration of individual differences would require the selection of participants on the basis of scores on vividness and control of imagery and then conducting experiments based on the tasks which have been utilized in this dissertation. Clearly individual differences in the ability to use imagery are an important variable, and one which should form the basis of a future line of investigation.

8.5 Discussion and Conclusions

The mental rotation task was chosen for two main reasons, the neuropsychological evidence suggesting the prepotency of the right parietal quadrant in performance of this task, and extensive behavioural evidence which has been interpreted as suggesting that a mental process analogous to the physical manipulation and reorientation of objects takes place when an individual carries out the task.

Verbal protocols collected from individuals performing the task indicate a level of active involvement by particpants which, when incorporated into the CNV recording paradigm is a valuable development in the control of in the inter-stimulus interval. A further attractive feature of the task is the apparent utility of imagery as a strategy in performing the task.

The hypotheses tested were designed to identify systematic effects, behavioural or electrophysiological, as a result of the employment of verbal and imaginal strategies and to identify cortical areas which are prepotent in performance of the task. The relationships between performance and electrophysiological changes provided and additional focus for these studies.

The experiments reported are clearly successful in advancing our understanding of the relationship between ERP and mental processes. In experiment 8.1 the induction of an imagery strategy in performing the mental rotation task was apparently successful. Performance on the task improved significantly from the first to the second imagery sequence. At post experimental enquiry all participants reported success in adopting an imagery strategy. Furthermore, there was a clear discontinuity in the performance when a change to the verbal strategy was required by special instructions at the start of the third sequence of trials. On enquiry during the introduction of this strategy all participants reported that the verbal strategy had not been apparent to them during the two earlier sequences.

The strategy utilized had a significant influence on the amplitude of the CNV ($F = 16.3$, df 2, 32, $p<0.001$). The change from the visual imagery sequence to the verbal sequence was reflected in a change in amplitude of the CNV which was correlated with the change in response time over the same conditions at electrode P4. A similar significant relationship was also recorded at electrodes C4 and P3, adjacent to the posterior right hemisphere quadrant. The result reported above is an indication of the value of ERPs in the investigation of the localization of the processes involved in mental rotation.

Two design features of the above study could be usefully modified in any attempted replication. The first has to do with the order of conditions in the experiment. In the experiment reported above the imagery condition always preceded the verbal condition. It would be valuable if any replication counterbalanced the order of these variables. Secondly, the design would be more symmetrical if two runs of both the verbal and the imaginal conditions were included.

There is a clear limitation in any psychophysiological study attempting to relate performance and physiological variables in which data cannot be selected data for analysis on trial by trial basis. The continuous average thus has definite limitations which must be taken into account in the evaluation of this work. A further major insecurity relates to the effectiveness of the imagery induction procedure. All the evidence suggests that the use of imagery is widespread if not universal, but doubts as to the efficacy of induction procedures must always be of concern with investigations in this area.

The results reported above focused on the localization of activity in the change from one strategy to another. A more stringent examination of the involvement of a particular region in the task when an imagery strategy is employed can be conducted by examining a number of levels of complexity of the task. The second experiment in this sequence is just such an attempt. Limiting the task to the imagery strategy only means that the electophysiological changes correlated with changes in strategy are not identifiable, however, this does provide a more sensitive test of the relationship between performance and electrophysiological changes. Under these circumstances it was thought legitimate to confine the electrophysiological recording to the two electrode sites over the parietal lobes since the evidence of the earlier experiment indicated the responsiveness of these sites under these conditions.

The results of this experiment were analysed with reference to a baseline condition in which no mental manipulation was required. That is the differences, which formed the basis of the correlations between peformance and CNV amplitude all referred to the same active baseline. On this basis the performance variables clearly showed a significant increase from conditions (i) through to (iv). Once the analysis was directed toward the CNV data the picture became much more complex. While the mean amplitudes at each electrode (depicted in Figure 8.4) illustrate differences between conditions, none of the differences from the baseline condition are significant. This is due to the range of the results within each condition. However, a further analysis revealed significant differences between condition (ii), the mirror image reversal, and both conditions (iii) and (iv) at electrode P3, and between condition (ii) and (iii) at electrode P4. Thus different experimental conditions did lead to significant differences between the amplitude of the CNV. It would, therefore, seem valuable to explore the effects of complexity of manipulation further, particularly with a view to reducing variability within each condition. A larger group of participants would help in this regard, and the ability to select trials on the basis of performance criteria, and average these separately would prove particularly advantageous in this respect.

The experiments reported in this chapter are both an endpoint and a beginning. They are the end of a sequence which started with the classical warned reaction time paradigm and progressed through a number of apparently disparate experimental situations, all of which were attempts to involve the participant in tasks demanding higher mental processes. Ultimately participants were expected to actively manipulate mental images of to solve simple problems. These experiments are a beginning because more questions have been raised than have been answered. In the next chapter an overview of all the work in this programme of research will be presented and the questions which will form the basis of future work will be identified.

Chapter 9 Conclusions

9.1 The Context

Any programme of research must be evaluated in context. The starting points for investigations may vary widely in terms of theoretical and empirical development and the point of entry on this continuum of development influences the course of the research. Where the conceptual underpinning and theoretical accounts available are less well developed and the choice of variables is at least the subject of some discussion, progress can be measured by the clearer conception of the issues which accompanies empirical investigation. The research reported in this dissertation increases the understanding of relationships between variables representing brain function from both electrophysiological and behavioural perspectives and also identifies a number of key issues in the relationships between brain function and behaviour. The choice of the contingent negative variation as an electrophysiological dependent variable reflecting brain function was based on its sensitivity to the manipulation of independent variables related to higher mental processes, rather than simply to the physical characteristics of the stimulus.

The strategy chosen to tackle these issues was to start from an experimental base which involved the CNV in its traditional context, the simple warned reaction time paradigm, and from that to develop a framework for the investigation of cognitive processes by requiring individuals to perform specific information processing tasks during the interval between the warning and imperative signals.

The investigation of the behavioural and electrophysiological correlates of cognitive processes requires consideration of the question of localisation of function in the nervous system. Accounts which focus on hemispheric differences in the organization of brain function commonly ascribe visuo-spatial tasks to the right hemisphere whereas verbal processes are localised in the left hemisphere. The localisation of visuo-spatial function subsumes the imaginal representation of information. In practice it is commonly impossible to arrange tasks which involve one or other hemisphere exclusively and it is probably misleading to conceive of the information processing system organised in this way. In particular it is difficult to control for the possibility of verbal mediation in cognitive tasks which have been designed to involve preferentially the right hemisphere. The tasks employed involved the active manipulation of images in the inter-stimulus interval as a basis for the behavioural response. In addition tasks selected were suitable for concurrent CNV recording.

The localization of function hypothesis

concerned with the organisation of brain function subserving higher mental processes has been explored throughout the programme of research. In each experiment a hypothesis derived from neuropsychological and behavioural evidence predicting the locus of involved cortical regions was tested by examining the patterns of CNV amplitude of different scalp sites and different levels of task difficulty. An additional hypothesis based on the observation (Tecce et al., 1979) that distractor tasks reduced the amplitude of the CNV was tested. The essential idea directing this aspect of the work was that the amplitude of the CNV at sites involved in a particular task would be reduced compared with a task placing less demand on these cognitive systems.

The value of physiologizing about mental events is often questioned. The radical behaviourist movement not only expunged all reference to mentalistic concepts from the vocabulary of psychology, but also tended to regard the brain as the exclusive province of the physiologist, referring to it as a component of a system defined merely by its input-output characteristics. On the other hand, the artificial intelligence movement tends to regard the specific physical manifestation of the information processing system as trivial in relation to the functional properties. To the extent that one believes that biological mechanisms are necessary for mental life any account which does not include an explanation of the mechanisms involved will be inadequate. This view is by no means universal, even among professional psychologists. The requirement for an explanation of the biological mechanisms raises particular difficulties. For obvious reasons people have reservations about active intervention in their brains for experimental purposes and this results in a clear requirement for non-invasive techniques, particularly in the investigation of so-called normal individuals. The limited range of techniques available in this category puts additional demands on the measures used.

The account of mental processes derived from analyses of the function of the nervous system by EEG and behavioural methods complements accounts developed mainly from clinical investigations of the disruptions of behaviour as a consequence of damage or degeneration of any part of the system. To develop the understanding of any mechanism by removal of various sub-components is fraught with logical difficulties and nowhere is this more evident than in investigations of brain function. To complement the account of brain function derived from lesion studies with a coherent picture of functional changes while tasks similar to those affected in clinical cases are performed adds strength to any theory derived from either one of these approaches.

The outcome of these investigations may have practical implications. Recovery from brain damage is not impossible, and if the electrophysiological changes accompanying natural recovery can be monitored it is possible that the encouragement of these processes might form the basis of a rehabilitiative technique.

9.2 Measurement of Cerebral Function and Task Performance

Considering the complexity of the dynamics of information processing involved in cognitive tasks and the range of EEG changes which could be monitored the dependence on any one phenomenon puts particular onus on that measure. Significant relationships between performance and the chosen electrophysiological measure, particularly when replicated in different experiments involving different tasks are, therefore, likely to reflect pervasive effects.

Since the first report of the CNV (Walter et al., 1964) considerable attention has been devoted to the phenomenon and its relationship to both cerebral function and mental processes. At least four conferences (Donchin and Lindsley, 1969; McCallum and Knott, 1973; 1976; Callaway, Teuting and Koslow, 1978) have devoted a major part of the proceedings to a consideration of these issues. From an early concern with the appropriate recording methodology a more recent trend which addresses the issue of an appropriate theoretical framework can be discerned (Donchin, Ritter and McCallum, 1978).

Much of the early research has been influenced by a view of the CNV which now requires modification. Firstly, it is apparent that the CNV is not a unitary phenomenon, but rather a composite of a number of components derived from separate cortical generators. Secondly, the characteristics of the response vary with the site of electrodes on the scalp and the nature of the task. The pattern of changes at various sites and with different tasks is the focus of the research reported here.

Consider the behaviour of an individual performing a simple warned reaction time experiment. During the interval between warning and imperative signals, activity is inhibited in anticipation of the response and the amplitude of the CNV reflects the inhibition of widely dispersed systems. When the participant performs a task in the inter-stimulus interval the reduction in amplitude in specific areas compared with the simple control condition reflects the activation of specific neural systems involved in the task. The distraction hypothesis (Teece et al., 1972) proposes that stimuli processed during the inter-stimulus interval reduce CNV amplitude non specifically with a control condition. Thus it is suggested that patterns of activation of the cortex related to the demands of a specific task are reflected in differences in amplitude of slow potential changes between recording sites, the more positive the amplitude the more involved the region in the task.

A problem with a phenomenon such as the CNV is the choice of an appropriate baseline. Traditionally it has been accepted that a brief interval prior to the warning signal is adequate to provide a baseline.

In a sequence of trials in which it is possible for a participant to adopt and maintain a strategy it is unwise to assume that the anticipatory interval begins with the warning signal. To the extent that systems involved in a particular task are activated prior to the receipt of a warning stimulus the baseline measures incorporate a confounding variable. This point was not systematically investigated and is worthy of detailed consideration in later studies.

Response latency has a lengthy history as an indicator of differences in processing time between individuals and tasks. The experiments reported here are based on the assumption that time spent in the sensory and motor phases of the tasks are equivalent between conditions and that differences in response latency indicate differences in central processing. This simple linear model has been challenged by heirarchical and parallel processing models which assume some overlap of processing stages (Posner, 1978). It is probably useful to distinguish two bases for the interpretation of response latency. In one, a clear change of strategy has been required in performing the tasks (with presumably a similar change in distribution of the CNV), and in the other, the task strategy is maintained across different levels of complexity (involving the same system). In the first instance differences in response latency between conditions can reflect the use of different cognitive systems. In the latter, differences in response time between conditions reflect extended processing but in the same subset of systems. The importance of this is that both behavioural and electrophysiological measures of brain function can reflect differing underlying patterns of mental activity. Having considered the two variables chosen to reflect brain function from different perspectives it is now worthwhile considering the technical limitations.

9.3 Technical Criteria

9.3.1 Stimulus Presentation and Measurement of Response Latency

The system employed to present stimuli consisted of a control system and a projection system. The projection system was based on the Kodak Carousel projector with the modification for tachistoscopic presentation. The main weakness related to the noise and inconvenience of the system. The noise was always somewhat distracting and the preparation of slides was very time consuming and was not conducive to experiments using a range of different stimulus materials. Since this part of the system remained essentially the same throughout the experimental work one would not expect it to result in differential effects on the results.

The control sytem was modified during the research programme. Initially a system based on separate modules controlling the stimulus presentation equipment and the inter-stimulus intervals was constructed. The times were checked prior to each experiment and were set to a sensitivity of a millisecond. In the later experiments (7.3, 6.4) a program operating on a BBC Model B microcomputer was devised which allowed the setting of various exposure times and intervals, and also triggered the A/D converter. The latter system had advantages in terms of compactness and flexibility but both worked well throughout the research programme and few data were lost due to unreliable stimulus presentation.

Response latency was measured to a sensitivity of a millisecond using a digital timer which was initiated by a trigger pulse from the control system and stopped by a response on a microswitch. This system was adequately sensitive and very reliable.

9.3.2 EEG Recording and Analysis

Often the novice experimenter is tempted to wait just that little bit longer for the ideal piece of equipment which is technically feasible but as yet unavailable. Conducting a research programme seems to involve making do with what is available while still being aware of the technical developments which can be incorporated, and the implications of these for the data collected.

At the outset the problem was to devise a recording system which would enable the spatio-temporal patterns of the EEG, and the slow potential changes particularly, to be measured while participants perform various tasks and displayed in an interpretable way. Technical limitations to the recording systems employed are commonplace and an important part of the work involves an evaluation of the systems employed in the context of the technical demands of the ideal system.

Satisfactory coverage of all the cortex with electrodes at inter-electrode distances enabling sensitive recording of localized modulation of activity, would require many more electrodes than utilized in these studies. Probably something of the order of twenty electrodes would provide a suitable coverage. The resultant data would provide a considerable problem for analysis, and even comprehension. The system employed in this set of experiments is clearly limited with respect to the spatial resolution of activity. The amplitude differences between electrodes and conditions are very small and therefore it is necessary to have a system which will enable discriminations down to a tenth of a microvolt. While the amplifiers and A/D converters used are quite capable of resolutions at these levels it is doubtful whether the electrodes employed are consistent enough for recording at sensitivities of this order. A consideration of electrode arrangements, which are probably the weak link in the system, would probably repay the effort.

The sampling rates used were well within the capabilities of the system, and are limited by problems of storage capacity for the off line analysis of selected trials. This proved a relatively simple computational problem once the necessary hardware was available, and clearly enhances the capacity of the system to answer relevant experimental questions.

The EEG recording systems used were developed considerably during the course of the research programme. Perhaps the weakest link in the system remains the electrode, and its location in relation to underlying specific brain structures and the undoubted intra-individual variation in both bony landmarks and cortical structure.

Considering the quantity of data assessed during the experiments the choice of CNV amplitude as a dependent variable seems to provide a rather poor return. The choice was intentional. Firstly the most common measure reported is the amplitude difference between a prestimulus baseline and the response just prior to the imperative stimulus; and secondly, in the context of the available range of measurements it provides a very conservative indicator of the CNV. A comparative examination of different methods of measuring the CNV would be productive.

9.3.3 Task Induction

The effectiveness of the research programme depended on participants carrying out complex mental activities in a particular style. The veracity of their performance could only be checked by verbal report. Care was taken in the training of participants and the initiation of them to the task. Practice trials were always incorporated into the preparation for an experimental run.

After an experimental run was completed all participants were debriefed in an attempt to confirm the approach they had utilized for the task. It is difficult to evaluate this aspect of the experimental work but the indications are that an effective rapport with participants was rapidly achieved and that the range of difficulties reported with the tasks utilized was what could be expected.

In most of the experiments the stimuli and responses were designed to elicit the mental processes under investigation. For example, while it is not difficult to imagine a verbal strategy in Experiment 5.1, the visuo-spatial reaction time task, none of the participants reported this when debriefed. Since the behavioural results of most of the experiments confirmed the predictions with respect to response time this would also suggest that the choice of levels of complexity of tasks was effective.

The examples that appear particularly contentious are the mental rotation task and the use of an imagery strategy in memory tasks. Participants reported considerable variation in the ease with which an image could be formed and manipulated. This aspect of the problem appears worthy of further investigation. A more detailed investigation of different levels of performance within an individual may reveal patterns of slow potential activity correlated with ease of use of imagery. Because confirmation of the cognitive processes employed depends on access to the private aspects of mental activity this will remain an important issue in any future studies.

9.4 The Results

It is worth reiterating the objectives of this programme of research prior to an attempt to summarize the results obtained. This can be done most effectively by imagining a hierarchy, at the peak of which is the most general hypothesis that there is a relationship between mental processes and brain function. At the base of the hierarchy are a series of specific hypotheses relating to the particular experiments conducted. The most general question was addressed through two hypotheses at an intermediate level on the hierarchy:

1. That specific mental processes are correlated with localized activity in the cortex; a subsidiary version of this hypothesis would predict hemispheric asymmetry in activity;
2. That different levels of task difficulty, and presumably effort on the part of participants result in correlated changes in performance, and in electrophysiological indices of brain function.

The contingent negative variation, recorded from a number of scalp sites provided the indices of brain function. Task performance was monitored by measurement of reaction time. The research can, therefore, be seen also as an evaluation of the CNV as a dependent variable in the exploration of relationships between brain and behaviour.

The findings from apparently disparate tasks are not only linked by the theoretical issues in 1.

and 2. above. The choice of tasks was also influenced by how well they illustrate the typical features of cognitive activity. It is in this context that visuo-spatial activity emerged as a central theme in the work. Other investigations of visuo-spatial activity suggest that the parietal lobe of the right hemisphere is prepotent for these tasks. Throughout the research programme there is an increasing demand for active processing during the inter-stimulus interval as an increasing constraint on the mental activities which may influence the measures of brain function and performance. Table 9.1 is an attempt to summarize the findings of all the experimental work in relation to the localization and effort hypotheses.

Table 9.1
Overview of Experimental Findings

Experiment Number	Task	Findings
5.1	Simple RT and visuo-spatial RT.	VSRT task resulted in consistently longer response times. Correlations between change in RT, and change in CNV amplitude suggest localized activity at right parietal sites for right handed response.
6.1	Memory for meaning word/non word; symbols.	Less meaningful stimulus material resulted in poorer % recognition in both categories. Correlation between performance change and amplitude change in CNV for symbols only, suggests activity during encoding localized at left and right rolandic sites.

Experiment Number	Task	Findings
6.2	Memory : Value of imagery strategy and nature of stimulus material.	Use of imagery and nature of stimulus words had significant effect on performance. Correlations between change in CNV amplitude and change in performance for (i) Low to High imagery stimuli (ii) use of imagery strategy, significant at left and right parietal sites during encoding phase.
6.3	Memory, high imagery value words; set sizes 2,4,8 words.	No significant effect of set size on response time or CNV amplitude. Responding hand significant.
6.4	Memory; high and low imagery words, different set sizes, 1,2 & 4 words.	Set size did not have significant affect on performance. Interaction of set size and imagery value of stimuli significant. Set size 4, showed difference in response between high and low imagery stimuli.
7.1	Face recognition, encoding & recognition phases.	Significant correlation between recognition latencies and CNV amplitude at right parietal site during encoding.
7.2	Face recognition, upright and inverted stimuli.	Inversion had significant effect on performance; also CNV amplitude significantly different between conditions. Effect on CNV amplitude localized to right parietal site.
7.3	Face recognition, upright and inverted stimuli.	Significant decrease in CNV amplitude at all electrode sites from upright to inverted condition.

Experiment Number	Task	Findings
8.2	Mental rotation. Imagery or verbal strategy.	Significant effect on performance between imagery or verbal condition. Localized significant change in CNV amplitude at left and right parietal and right rolandic sites.
8.3	Mental rotation. Complexity of rotation.	Significant change in performance between levels of complexity of rotation. No significant changes in CNV amplitude from baseline task. Significant effects at left and right parietal sites between mirror image reorientations.

9.4.1 Review of Experimental Results

The main substantive finding in this research programme is that with a number of distinct cognitive tasks a significant relationship between change in amplitude of the CNV and change in the behavioural response (Response latency) was demonstrated for different levels of task difficulty. Furthermore, the relationship was commonly localized to relatively circumscribed areas of the cortex, which were predictable on the basis of independent evidence, suggesting that specific cortical systems were prepotent in those activities. Because the measure of brain function used as a dependant variable is relatively conservative, this finding is all the more striking.

In experiment 5.1 the imposition of a visuo-spatial load resulted in a significant relationship between performance and the CNV only when the right hand was used. Response with the non-dominant hand involves the motor systems in the right hemisphere and this it is suggested reduces the amplitude of the CNV over that hemisphere. Furthermore, this reduces the chances of identifying a significant correlation of performance differences between conditions and change in CNV amplitude.

In two memory tasks (experiments 6.1 and 6.2) significant relationships were found during the intial encoding of the target and not the recognition process. In the one case (experiment 6.1) which required analysis of symbols for meaning, the relationship was found with records from central sites (C3 and C4) which are commonly implicated in long term memory based on semantic processes (Geschwind, 1972). In the other case (experiment 6.2) the nature of the stimuli and the strategy adopted were chosen to involve mental imagery (Paivio, 1971) and performance changes were significantly correlated with change in amplitude of the CNV at leads in the posterior part of the cortex with manipulations involving a change from low to high imagery stimuli and a change to an imagery strategy.

In an attempt to manipulate task difficulty in a memory task based on the work of Sternberg (1969) sets of 2, 4 and 8 high imagery value words were employed. Participants either responded with right or left hands to indicate whether a probe stimulus had appeared in a target set. Set size did not have a significant affect on performance or amplitude of the CNV but Figures 6.3. and 6.4 do suggest consistent trends in the predicted direction which could be pursued in a redesigned experiment. It is an important observation that the confounding effect of responding hand is reflected in the mean CNV amplitudes (Figure 6.4).

In a further experiment designed to take account of some of the weaknesses of the previous study a significant effect on performance at the largest set size between low and high imagery stimuli was found. This was accompanied by a significant effect on CNV amplitude at parietal sites between high and low imagery stimuli. This result was all the more interesting because of the opposite effect of imagery value on CNV amplitude at posterior sites (Figure 6.6). From the left parietal lead, amplitude of the CNV was lower for low imagery than high imagery stimuli; whereas, at the right parietal lead low imagery stimuli resulted in higher amplitude CNVs. This finding is worthy of further investigation.

The investigation of imagery strategies was further developed in the experiments involving a mental rotation task (experiment 8.1 and 8.2). In this instance the imagery strategy proved less effective than a verbal strategy in terms of response latency and performance is correlated with reduction in CNV amplitude from leads recording from the posterior quadrants of the cortex. The mental rotation task appears to provide a very useful basis for further work. The stimuli enabled the easy adoption of verbal strategies but this could be controlled by stimuli such as irregular shapes.

Increased task complexity in mental rotation resulted in systematic effects on performance but the relationship to changes in CNV amplitude is more difficult to interpret. At the two parietal leads the task requiring comparison of a mirror image stimulus with the anchor task results in lower amplitude CNVs. This effect is in contrast to the other two levels of task complexity, both of which result in higher amplitude CNVs. The attempt to manipulate task complexity while one strategy is employed has provided results which do not fit an ordinal scale of complexity. This would suggest that the investigation of the particular task of mirror image reorientation of stimuli would prove rewarding.

Inversion of the stimulus was also used as one level of task difficulty in the face recognition task (experiments 7.2 and 7.3). Correct responses were sorted on the basis of the decision (same or different) and the condition (upright or inverted) and averaged separately. In the first of these experiments only five participants were involved but the imposition of the more complex task requiring an inverted face to be compared with the target resulted in more positive CNV amplitudes from parietal lead P4 and this is consistent with the proposed relationship to complexity. In the second of these experiments the reduction of CNV amplitude for the task requiring inversion of the face was further supported, in this instance the effect was found at both frontal and parietal sites.

The face recognition task was intially explored in this research programme in experiment 7.1, the results of which indicate that the right parietal lobe was prepotent in encoding these stimuli, and it was this that influenced performance on the recognition task suggesting localization of function.

9.5 The Significance of the Results of Empirical Investigations of the CNV in Cognitive Tasks

The results of the empirical work conducted in this programme of research support the concept that there is a relationship between brain function and mental processes, and furthermore the CNV, or similar slow potential changes can be effectively used as an indicator of regional activation in support of various cognitive tasks.

A reformulation of the theory relating CNV to behaviour seems necessary on the basis of the work reported here. Perhaps the specific emphasis on the CNV as the crucial phenomenon of slow potentials is misplaced. The CNV may be a consequence of the special features of the simple RT task and perhaps a return to the investigation of regional variations in more general slow potential changes under conditions of different task demands is more appropriate. The finding that performance at different levels of task difficulty relate to the CNV as an example of slow positive potential change would certainly suggest that the CNV does reflect the topography of brain activation as a result of specific tasks.

To an extent this has been recognised in recent theoretical formulations (Pribram, 1971; Donchin and McCarthy, 1978; Cooper et al., 1979). Early formulations of the relationship between the CNV and psychological processes suffered because the range of variation in the CNV from site to site was not fully recognised and the range of psychological correlates was limited. Recent formulations appear to recognize that the CNV at a specific site reflects the involvement of cortical systems in that region in the task, and as the task is made more complex, so the level of involvement changes. Donchin and McCarthy discuss this in terms of the "terrain hypothesis" in which the differences in the CNV represents the adjustment of the system to achieve a fixed behavioural output in the face of changing external conditions. The importance of a fixed behavioural output, as opposed to an output satisfying certain individual criteria needs further consideration. Clearly, this formulation attempts to take account of the effort expended in the task. This important distinction also forms the basis of the theory of Cooper et al. (1979) which identifies two forms of processing - the "scopeutic" in which intentions lead to the selective involvement of various systems and the focus of attention on particular aspects of the world, and the "categoric" in which tasks are performed relatively automatically and do not involve the same degree of conscious involvement of the individual. During categoric processes slow wave activity such as the CNV develop, whereas in scopeutic activity the CNV does not emerge. While the results reported here are consistent with the general features of these theories, a finer grained analysis of the relationship between performance and slow potentials will be necessary for a thorough test of these ideas.

The findings reported offer support of the localizationist hypothesis that limited cortical regions are prepotent for the performance of particular cognitive tasks. The limitation of this support is a consequence of the difficulty in finding differential patterns of activity related to performance for different levels of task difficulty. As the tasks employed are developed further, and the relevant controls are incorporated into future experiments, it is likely that further patterns of activity relating to task complexity will be observed. The localizationist hypothesis is strongly supported in studies where there is a clear requirement for a change of strategy in the performance of a task. The specific version of the localizationist hypothesis, that there are functional differences on a purely hemispheric basis gains little support from the findings of these studies. The exclusive activation of one or other hemisphere is not possible other than with special forms of experimental control such as lateralization of stimuli which are not directly informative with respect to higher mental processes.

9.6 Future Work

The studies reported in this dissertation provide a number of indications that particular lines of research are worthy of future exploration. Some of the specific studies have been identified in association with the section on the relevant task. In general the work could be developed immediately by further investigations of the effects of differences within task complexity. The range of results in upright and inverted conditions, and mental rotation all suggest that further exploration along these lines would be informative.

Individual differences in imagery are likely to influence performance, and the significant interaction between participant and level of task difficulty, and the one minor finding reported in the dissertation suggests that this line should be followed. This could be accomplished by selecting participants for experiments from a large but homogenous group on the basis of scores on vividness of imagery and control of imagery.

The issue of the appropriate baseline for measurement of task related changes in slow potentials is in need of urgent consideration. In particular the relationship between pre-stimulus baseline and the naive assumption that processing starts with the warning signal.

In the longer term, the question of the most informative presentation of data reflecting the dynamics of the complex processes involved in mental activity must be considered. The reliance on the single measure of the CNV as a unique reflection of brain function must be discouraged. What is needed is a way of presenting the potential changes at various scalp sites simultaneously on a time base equivalent to that for task performance. Some authors have progressed in this direction by employing isopotential mapping techniques (Lehmann, 1981). A particularly attractive resolution of this problem is suggested by Coupland (1981) who adapted cartographic techniques to provide an image in relief of the potential changes at scalp sites. It is not difficult to envisage a system in which the averages for each electrode site at each sampling point are presented simultaneously. The difficulty lies in capturing the dynamics of processing from one sampling point to the next.

Apart from the value in improving our understanding of brain-behaviour relationships the further development of this work may have practical implications for the monitoring of recovery of the brain after injury. When these results are considered in conjunction with the work of Birbaumer (1979) and his colleagues which demonstrated control over level of cortical negativity and its relationship to performance it is possible to envisage the development of a rehabilitative technique based on the systematic training of changes in cortical potential during the performance of tasks which tap the most fundamental cognitive processes.

Appendix I

Program for BBC Microcomputer (Model B)

Control of Stimulus Presentation by Kodak Carousel Projector and Inter Stimulus Intervals

```
 560DRAW 50,500
 570PRINT TAB(15,5)"Projector"
 580PRINT TAB(16,7)"Control"
 590PRINT TAB(16,8)"_______"
 600ENDPROC
 610DEFPROCdiag
 620CLS
 630GCOL0,1
 640MOVE0,625
 650MOVE0,575
 660PLOT85,50,600
 670DRAW250,600
 680MOVE0250,725
 690DRAW500,725
 700DRAW500,475
 710DRAW250,475
 720DRAW250,725
 730MOVE500,600
 740DRAW750,600
 750MOVE750,725
 760DRAW1000,725
 770DRAW1000,475
 780DRAW750,475
 790DRAW750,725
 800MOVE1000,600
 810DRAW1250,600
 820DRAW1250,200
 830DRAW200,200
 840DRAW200,600
 850MOVE75,600
 860DRAW75,200
 870MOVE100,250
 880MOVE50,250
 890PLOT85,75,200
 900MOVE900,225
 910MOVE900,175
 920PLOT85,850,200
 930MOVE600,225
 940MOVE600,175
 950PLOT85,550,200
 960MOVE750,600
 970DRAW650,500
 980DRAW650,450
 990MOVE675,450
1000MOVE625,450
1010PLOT85,650,400
1020VDU5
1030VDU19,3,7;0;
1040MOVE0,800
1050PRINT;"start"
1060MOVE8,700
1070PRINT;"delay="
1080MOVE16,650
1090PRINT;b*10;" ms"
1100MOVE0,175
1110PRINT;"A/D pulse"
1120MOVE275,825
1130PRINT;"slide 1"
1140MOVE268,650
1150PRINT;"display"
1160MOVE284,600
1170PRINT;"time="
1180MOVE284,550
1190PRINT;c*10;" ms"
1200MOVE525,700
1210PRINT;"delay="
```

```
1220MOVE535,650
1230PRINT;d*10;"ms"
1240MOVE775,825
1250PRINT;"slide 2"
1260MOVE768,650
1270PRINT;"display"
1280MOVE784,600
1290PRINT;"time="
1300MOVE784,550
1310PRINT;e*10;" ms"
1320MOVE1025,750
1330PRINT;"random"
1340MOVE1025,700
1350PRINT;"delay="
1360MOVE1025,650
1370PRINT;f/100;" to"
1380MOVE1025,575
1390PRINT;g/100;"secs"
1400MOVE475,375
1410PRINT;"timer start"
1420VDU4
1430PRINTTAB(6,29)"Press the Space Bar to Start."
1440PRINTTAB(6,30)"To Alter Times Press Return."
1450COLOUR3
1460PRINTTAB(11,2)"Slide On/Off Times."
1470*FX15,1
1480LL=GET
1490IF LL=13 THEN PROCmenu
1500IF LL=32 THEN GOTO 1510 ELSE GOTO 1480
1510CLS
1520PROCrun
1530ENDPROC
1540DEFPROCstart
1570TIME=0
1590REPEAT
1600UNTIL TIME>b
1610COLOUR1
1630ENDPROC
1640DEFPROCslide(q)
1650?&FE60=4
1660PROCtime(q-1)
1670?&FE60=0
1680ENDPROC
1690ENDPROC
1700DEFPROCchange
1710?&FE60=2
1720TIME=0:REPEAT UNTIL TIME>20
1730?&FE60=0
1740ENDPROC
1750DEFPROCbox(vpos)
1760MOVE0,vpos
1770MOVE1279,vpos
1780PLOT85,0,vpos-40
1790PLOT85,1279,vpos-40
1800ENDPROC
1810DEFPROCmenu
1820CLS
1830VDU19,3,7;0;
1840COLOUR3
1850PRINT TAB(14,1)"Select Times."
1860PROCbox(923)
1870PRINT TAB(6,6)"1 - Start Delay."
1880PRINT TAB(6,9)"2 - Slide 1 Display Time."
1890PRINT TAB(6,12)"3 - Delay Between Slides."
1900PRINT TAB(6,15)"4 - Slide 2 Display Time."
1910PRINT TAB(6,18)"5 - Minimum Random Delay Time"';SPC(10);"Between Sl
```

```
ides."
 1920PRINT TAB(6,21)"6 - Maximum Random Delay Time"';SPC(10);"Between Sl
ides."
 1930PRINT TAB(6,24)"7 - Save Data On Disc."
 1940PRINT TAB(5,28)"Enter The Number Of Your Choice."
 1950PRINT TAB(4,30)"Or Press The Space Bar To Continue."
 1960*FX15,1
 1970sel=GET-48
 1980IF sel=-16 THEN PROCdiag
 1990IF sel<1 OR sel>7 THEN GOTO1960
 2000FOR zz=0 TO 3
 2010COLOUR0
 2020PRINT TAB(6,3+(sel*3));sel
 2030PROCtime(25)
 2040COLOUR3
 2050PRINT TAB(6,3+(sel*3));sel
 2060PROCtime(25)
 2070NEXT
 2080ON sel GOTO 2090,2110,2130,2150,2170,2190,2210
 2090PROCsel("Start Delay Time.")
 2100b=tim:PROCdiag:ENDPROC
 2110PROCsel("Slide 1 Display Time.")
 2120c=tim:PROCdiag:ENDPROC
 2130PROCsel("Inter-Slide Delay Time.")
 2140d=tim:PROCdiag:ENDPROC
 2150PROCsel("Slide 2 Display Time.")
 2160e=tim:PROCdiag:ENDPROC
 2170PROCsel("Minimum Random Delay Time.")
 2180f=tim:PROCdiag:ENDPROC
 2190PROCsel("Maximum Random Delay Time.")
 2200g=tim:PROCdiag:ENDPROC
 2210PROCsave
 2220ENDPROC
 2230DEFPROCsel(r$)
 2240CLS
 2250PROCbox(1023)
 2260PROCbox(983)
 2270COLOUR3
 2280PRINT TAB(20-(LEN(r$)/2),3);r$
 2290PROCbox(883)
 2300PROCbox(843)
 2310PRINT TAB(7,15)"Enter Time In Milliseconds,"'';SPC(12);"And Press R
eturn."
 2320PRINT TAB(4,20)"Maximum Resolution=10 Milliseconds."
 2330*FX15,1
 2340PRINT TAB(0,22)" "
 2350INPUT as
 2360 IF as=0 THEN GOTO 2370 ELSE GOTO 2390
 2370PRINT TAB(0,23)"                "
 2380GOTO2340
 2390tim=as/10
 2400CLS
 2410ENDPROC
 2420DEFPROCchoose
 2430VDU19,3,7;0;
 2440GCOL0,3
 2450PROCbox(1023)
 2460PROCbox(983)
 2470COLOUR3
 2480PRINT TAB(9,3)"Please Enter Filename,"';SPC(11);"and Press Return."
 2490PROCbox(843)
 2500PROCbox(803)
 2510PRINTTAB(6,15)"Filename must be less than-"''SPC(10);"7 characters
long."
 2520*FX15,1
 2530INPUT NM$
```

```
2540IF LEN(NM$)>7 THEN GOTO 2550 ELSE GOTO 2570
2550VDU7:CLS
2560GOTO2450
2570CLS
2580PROCbox(1023)
2590PROCbox(983)
2600COLOUR3
2610PRINT TAB(6,3)"Do You Want To Change Times?"
2620PROCbox(883)
2630PROCbox(843)
2640PRINT TAB(6,18)"Enter Y For Yes, Or N For No."
2650*FX15,1
2660get=GET
2670IF get=89 THEN GOTO 2700
2680IF get=78 THEN GOTO 2730
2690GOTO 2650
2700PROCmenu
2710*FX15,1
2720ENDPROC
2730PROCdiag
2740*FX15,1
2750ENDPROC
2760DEFPROCrun
2770COLOUR3
2780PROCstart
2790PRINT TAB(2,28)"To Change Any Times,Press Return."
2800PRINT TAB(1,30)"To Start Again Press The Space Bar."
2810x=0:QQ=1
2820x=x+1
2830?&FE60=32
2850*FX5,2
2860*FX8,7
2870VDU2
2880VDU1,65
2890VDU3
2900COLOUR3
2910PROCslide(c):PRINT TAB(17,16)"SLIDE ";x
2920x=x+1
2930PROCchange
2940PROCtime(d-21)
2950?&FE60=0
2960PROCslide2(e):PRINT TAB(17,16)"SLIDE ";x
2970?&FE60=2
2980IF ?&FE60=130 THEN PROCstore("Same      ",TIME)
2990IF ?&FE60=66 THEN PROCstore("Different",TIME)
3000in=INKEY(0)
3010IF in=32 THEN GOTO 250
3020IF in=13 THEN GOTO 260
3030IF TIME>70+(q-1) THEN GOTO 3040 ELSE GOTO 2980
3040?&FE60=0
3050IF ?&FE60=128 THEN PROCstore("Same      ",TIME)
3060IF ?&FE60=64 THEN PROCstore("Different",TIME)
3070in=INKEY(0)
3080IF in=13 THEN GOTO 260
3090IF in=32 THEN GOTO 250
3100IF TIME>(RND(g-f)+f)+(20+(q-1)) THEN GOTO 3110 ELSE GOTO 3050
3110IF x=size THEN PROCend
3120?&FE60=0
3130QQ=QQ+1
3140GOTO2820
3150ENDPROC
3160DEFPROCsave
3170NO(1)=a:NO(2)=b:NO(3)=c:NO(4)=d:NO(5)=e:NO(6)=f:NO(7)=g
3180A%=OPENOUT"DATA"
3190PRINT£A%,7
3200FOR I%=1 TO 7
```

```
3210PRINT£A%,NO(I%)
3220NEXT
3230CLOSE£A%
3240PROCmenu
3250ENDPROC
3260DEFPROCload
3270A%=OPENIN"DATA"
3280INPUT£A%,X
3290FOR I%=1 TO 7
3300INPUT£A%,NO(I%)
3310NEXT
3320CLOSE£A%
3330ENDPROC
3340DEFPROCslide2(q)
3350?&FE60=20
3360TIME=0
3370IF ?&FE60=148 THEN PROCstore("Same     ",TIME)
3380IF ?&FE60=84 THEN PROCstore("Different",TIME)
3390in=INKEY(0)
3400IF in=32 THEN GOTO 250
3410IF in=13 THEN GOTO 260
3420IF TIME>(q-1) THEN GOTO 3430 ELSE GOTO 3370
3430?&FE60=0
3440ENDPROC
3450DEFPROCend
3460CLS
3470VDU19,0,1;0;
3480PRINTTAB(10,16)"Saving data on disc."
3490MOVE300,475
3500DRAW975,475
3510E%=OPENOUT NM$
3520PRINT£E%,size/2
3530FOR AW%=1 TO size/2
3540PRINT£E%,YORN$(AW%),TIM(AW%)
3550NEXT
3560CLOSE£E%
3570END
3580ENDPROC
3590DEFPROCstore(A$,B)
3600YORN$(QQ)=A$
3610TIM(QQ)=B
3620ENDPROC
```

```
>LIST
   10DIM YORN$(80),TIM(80)
   20MODE7
   30PRINTTAB(3,13)"Enter the filename to be printed."
   40INPUT NM$
   50PROCload
   60PROCPRINT
   70END
   80DEFPROCPRINT
   90*FX5,1
   92*FX6,0
   94WIDTH72
   96VDU2
  100PRINT"                 ";NM$
  110PRINT'"Slide     Decision               Time"''
  120FOR I%=1 TO X
  130@%=10
  140N=(TIM(I%)*7)/100
  150PRINT;I%*2,YORN$(I%);"         ";:@%=&20208:PRINT;(TIM(I%)-N)/100" .
.........secs."'
  160NEXT
  165VDU3
  168@%=10
  170ENDPROC
  180END
  190DEFPROCload
  200A%=OPENIN NM$
  210INPUT£A%,X
  220FOR I%=1 TO X
  230INPUT£A%,YORN$(I%),TIM(I%)
  240IF YORN$(I%)="" THEN YORN$(I%)="Dont know"
  250NEXT
  260CLOSE£A%
  270ENDPROC
```

```
LIST
   10REMpb1=slide change.pb2=slide on/off.pb4=timer start.pb5=timer stop
.pb6=same.pb7=different.
   20size=80:REM Max Number Of Slides...
   30*DISC
   40DIM NO(7),YORN$(size),TIM(size)
   50PROCload
   60a=NO(1):b=NO(2):c=NO(3):d=NO(4):e=NO(5):f=NO(6):g=NO(7)
   70PROCload
   80MODE4
   90?&FE62=63
  100?&FE60=0
  110VDU 23;8202;0;0;0;
  120VDU 19,0,4;0;19,3,2;0;
  130PROCtitle
  140PROCtime(200)
  150CLS
  160PROCchoose
  170END
  180DEFPROCtime(t)
  190TIME=0:REPEAT
  200in=INKEY(0)
  210IF in=32 THEN GOTO 250
  220IF in=13 THEN GOTO 260
  230UNTIL TIME>t
  240ENDPROC
  250x=1:PROCdiag:ENDPROC
  260PROCmenu:ENDPROC
  270DEFPROCtitle
  280GCOL0,1
  290MOVE 550,400
  300DRAW 750,400
  310DRAW 850,200
  320DRAW 450,200
  330DRAW 550,400
  340MOVE 450,200
  350DRAW 450,50
  360DRAW 850,50
  370DRAW 850,200
  380DRAW 950,200
  390DRAW 950,50
  400DRAW 850,50
  410MOVE 950,200
  420DRAW 875,300
  430DRAW 800,300
  440MOVE 50,1000
  450DRAW 1200,1000
  460DRAW 1200,500
  470DRAW 50,500
  480DRAW 50,1000
  490MOVE 650,400
  500DRAW 50,1000
  510MOVE 650,400
  520DRAW 1200,1000
  530MOVE 650,400
  540DRAW 1200,500
  550MOVE 650,400
```

```
 560DRAW 50,500
 570PRINT TAB(15,5)"Projector"
 580PRINT TAB(16,7)"Control"
 590PRINT TAB(16,8)"_______"
 600ENDPROC
 610DEFPROCdiag
 620CLS
 630GCOL0,1
 640MOVE0,625
 650MOVE0,575
 660PLOT85,50,600
 670DRAW250,600
 680MOVE0250,725
 690DRAW500,725
 700DRAW500,475
 710DRAW250,475
 720DRAW250,725
 730MOVE500,600
 740DRAW750,600
 750MOVE750,725
 760DRAW1000,725
 770DRAW1000,475
 780DRAW750,475
 790DRAW750,725
 800MOVE1000,600
 810DRAW1250,600
 820DRAW1250,200
 830DRAW200,200
 840DRAW200,600
 850MOVE75,600
 860DRAW75,200
 870MOVE100,250
 880MOVE50,250
 890PLOT85,75,200
 900MOVE900,225
 910MOVE900,175
 920PLOT85,850,200
 930MOVE600,225
 940MOVE600,175
 950PLOT85,550,200
 960MOVE750,600
 970DRAW650,500
 980DRAW650,450
 990MOVE675,450
1000MOVE625,450
1010PLOT85,650,400
1020VDU5
1030VDU19,3,7;0;
1040MOVE0,800
1050PRINT;"start"
1060MOVE8,700
1070PRINT;"delay="
1080MOVE16,650
1090PRINT;b*10;" ms"
1100MOVE0,175
1110PRINT;"A/D pulse"
1120MOVE275,825
1130PRINT;"slide 1"
1140MOVE268,650
1150PRINT;"display"
1160MOVE284,600
1170PRINT;"time="
1180MOVE284,550
1190PRINT;c*10;" ms"
1200MOVE525,700
1210PRINT;"delay="
```

```
1220MOVE535,650
1230PRINT;d*10;"ms"
1240MOVE775,825
1250PRINT;"slide 2"
1260MOVE768,650
1270PRINT;"display"
1280MOVE784,600
1290PRINT;"time="
1300MOVE784,550
1310PRINT;e*10;" ms"
1320MOVE1025,750
1330PRINT;"random"
1340MOVE1025,700
1350PRINT;"delay="
1360MOVE1025,650
1370PRINT;f/100;" to"
1380MOVE1025,575
1390PRINT;g/100;"secs"
1400MOVE475,375
1410PRINT;"timer start"
1420VDU4
1430PRINTTAB(6,29)"Press the Space Bar to Start."
1440PRINTTAB(6,30)"To Alter Times Press Return."
1450COLOUR3
1460PRINTTAB(11,2)"Slide On/Off Times."
1470*FX15,1
1480LL=GET
1490IF LL=13 THEN PROCmenu
1500IF LL=32 THEN GOTO 1510 ELSE GOTO 1480
1510CLS
1520PROCrun
1530ENDPROC
1540DEFPROCstart
1570TIME=0
1590REPEAT
1600UNTIL TIME>b
1610COLOUR1
1630ENDPROC
1640DEFPROCslide(q)
1650?&FE60=4
1660PROCtime(q-1)
1670?&FE60=0
1680ENDPROC
1690ENDPROC
1700DEFPROCchange
1710?&FE60=2
1720TIME=0:REPEAT UNTIL TIME>20
1730?&FE60=0
1740ENDPROC
1750DEFPROCbox(vpos)
1760MOVE0,vpos
1770MOVE1279,vpos
1780PLOT85,0,vpos-40
1790PLOT85,1279,vpos-40
1800ENDPROC
1810DEFPROCmenu
1820CLS
1830VDU19,3,7;0;
1840COLOUR3
1850PRINT TAB(14,1)"Select Times."
1860PROCbox(923)
1870PRINT TAB(6,6)"1 - Start Delay."
1880PRINT TAB(6,9)"2 - Slide 1 Display Time."
1890PRINT TAB(6,12)"3 - Delay Between Slides."
1900PRINT TAB(6,15)"4 - Slide 2 Display Time."
1910PRINT TAB(6,18)"5 - Minimum Random Delay Time"':SPC(10):"Between Sl
```

```
ides."
 1920PRINT TAB(6,21)"6 - Maximum Random Delay Time"';SPC(10);"Between Sl
ides."
 1930PRINT TAB(6,24)"7 - Save Data On Disc."
 1940PRINT TAB(5,28)"Enter The Number Of Your Choice."
 1950PRINT TAB(4,30)"Or Press The Space Bar To Continue."
 1960*FX15,1
 1970sel=GET-48
 1980IF sel=-16 THEN PROCdiag
 1990IF sel<1 OR sel>7 THEN GOTO1960
 2000FOR zz=0 TO 3
 2010COLOUR0
 2020PRINT TAB(6,3+(sel*3));sel
 2030PROCtime(25)
 2040COLOUR3
 2050PRINT TAB(6,3+(sel*3));sel
 2060PROCtime(25)
 2070NEXT
 2080ON sel GOTO 2090,2110,2130,2150,2170,2190,2210
 2090PROCsel("Start Delay Time.")
 2100b=tim:PROCdiag:ENDPROC
 2110PROCsel("Slide 1 Display Time.")
 2120c=tim:PROCdiag:ENDPROC
 2130PROCsel("Inter-Slide Delay Time.")
 2140d=tim:PROCdiag:ENDPROC
 2150PROCsel("Slide 2 Display Time.")
 2160e=tim:PROCdiag:ENDPROC
 2170PROCsel("Minimum Random Delay Time.")
 2180f=tim:PROCdiag:ENDPROC
 2190PROCsel("Maximum Random Delay Time.")
 2200g=tim:PROCdiag:ENDPROC
 2210PROCsave
 2220ENDPROC
 2230DEFPROCsel(r$)
 2240CLS
 2250PROCbox(1023)
 2260PROCbox(983)
 2270COLOUR3
 2280PRINT TAB(20-(LEN(r$)/2),3);r$
 2290PROCbox(883)
 2300PROCbox(843)
 2310PRINT TAB(7,15)"Enter Time In Milliseconds,"'';SPC(12);"And Press R
eturn."
 2320PRINT TAB(4,20)"Maximum Resolution=10 Milliseconds."
 2330*FX15,1
 2340PRINT TAB(0,22)" "
 2350INPUT as
 2360 IF as=0 THEN GOTO 2370 ELSE GOTO 2390
 2370PRINT TAB(0,23)"                "
 2380GOTO2340
 2390tim=as/10
 2400CLS
 2410ENDPROC
 2420DEFPROCchoose
 2430VDU19,3,7;0;
 2440GCOL0,3
 2450PROCbox(1023)
 2460PROCbox(983)
 2470COLOUR3
 2480PRINT TAB(9,3)"Please Enter Filename,"';SPC(11);"and Press Return."
 2490PROCbox(843)
 2500PROCbox(803)
 2510PRINTTAB(6,15)"Filename must be less than"'' SPC(10);"7 characters
long."
 2520*FX15,1
 2530INPUT NM$
```

```
2540IF LEN(NM$)>7 THEN GOTO 2550 ELSE GOTO 2570
2550VDU7:CLS
2560GOTO2450
2570CLS
2580PROCbox(1023)
2590PROCbox(983)
2600COLOUR3
2610PRINT TAB(6,3)"Do You Want To Change Times?"
2620PROCbox(883)
2630PROCbox(843)
2640PRINT TAB(6,18)"Enter Y For Yes, Or N For No."
2650*FX15,1
2660get=GET
2670IF get=89 THEN GOTO 2700
2680IF get=78 THEN GOTO 2730
2690GOTO 2650
2700PROCmenu
2710*FX15,1
2720ENDPROC
2730PROCdiag
2740*FX15,1
2750ENDPROC
2760DEFPROCrun
2770COLOUR3
2780PROCstart
2790PRINT TAB(2,28)"To Change Any Times,Press Return."
2800PRINT TAB(1,30)"To Start Again Press The Space Bar."
2810x=0:QQ=1
2820x=x+1
2830?&FE60=32
2850*FX5,2
2860*FX8,7
2870VDU2
2880VDU1,65
2890VDU3
2900COLOUR3
2910PROCslide(c):PRINT TAB(17,16)"SLIDE ";x
2920x=x+1
2930PROCchange
2940PROCtime(d-21)
2950?&FE60=0
2960PROCslide2(e):PRINT TAB(17,16)"SLIDE ";x
2970?&FE60=2
2980IF ?&FE60=130 THEN PROCstore("Same      ",TIME)
2990IF ?&FE60=66 THEN PROCstore("Different",TIME)
3000in=INKEY(0)
3010IF in=32 THEN GOTO 250
3020IF in=13 THEN GOTO 260
3030IF TIME>70+(q-1) THEN GOTO 3040 ELSE GOTO 2980
3040?&FE60=0
3050IF ?&FE60=128 THEN PROCstore("Same      ",TIME)
3060IF ?&FE60=64 THEN PROCstore("Different",TIME)
3070in=INKEY(0)
3080IF in=13 THEN GOTO 260
3090IF in=32 THEN GOTO 250
3100IF TIME>(RND(g-f)+f)+(20+(q-1)) THEN GOTO 3110 ELSE GOTO 3050
3110IF x=size THEN PROCend
3120?&FE60=0
3130QQ=QQ+1
3140GOTO2820
3150ENDPROC
3160DEFPROCsave
3170NO(1)=a:NO(2)=b:NO(3)=c:NO(4)=d:NO(5)=e:NO(6)=f:NO(7)=g
3180A%=OPENOUT"DATA"
3190PRINT£A%,7
3200FOR I%=1 TO 7
```

```
3210PRINT£A%,NO(I%)
3220NEXT
3230CLOSE£A%
3240PROCmenu
3250ENDPROC
3260DEFPROCload
3270A%=OPENIN"DATA"
3280INPUT£A%,X
3290FOR I%=1 TO 7
3300INPUT£A%,NO(I%)
3310NEXT
3320CLOSE£A%
3330ENDPROC
3340DEFPROCslide2(q)
3350?&FE60=20
3360TIME=0
3370IF ?&FE60=148 THEN PROCstore("Same      ",TIME)
3380IF ?&FE60=84 THEN PROCstore("Different",TIME)
3390in=INKEY(0)
3400IF in=32 THEN GOTO 250
3410IF in=13 THEN GOTO 260
3420IF TIME>(q-1) THEN GOTO 3430 ELSE GOTO 3370
3430?&FE60=0
3440ENDPROC
3450DEFPROCend
3460CLS
3470VDU19,0,1;0;
3480PRINTTAB(10,16)"Saving data on disc."
3490MOVE300,475
3500DRAW975,475
3510E%=OPENOUT NM$
3520PRINT£E%,size/2
3530FOR AW%=1 TO size/2
3540PRINT£E%,YORN$(AW%),TIM(AW%)
3550NEXT
3560CLOSE£E%
3570END
3580ENDPROC
3590DEFPROCstore(A$,B)
3600YORN$(QQ)=A$
3610TIM(QQ)=B
3620ENDPROC
```

```
>LIST
   10DIM YORN$(80),TIM(80)
   20MODE7
   30PRINTTAB(3,13)"Enter the filename to be printed."
   40INPUT NM$
   50PROCload
   60PROCPRINT
   70END
   80DEFPROCPRINT
   90*FX5,1
   92*FX6,0
   94WIDTH72
   96VDU2
  100PRINT"                    ";NM$
  110PRINT'"Slide     Decision                 Time"''
  120FOR I%=1 TO X
  130@%=10
  140N=(TIM(I%)*7)/100
  150PRINT;I%*2',YORN$(I%);"          ";:@%=&20208:PRINT;(TIM(I%)-N)/100" .
.........secs."'
  160NEXT
  165VDU3
  168@%=10
  170ENDPROC
  180END
  190DEFPROCload
  200A%=OPENIN NM$
  210INPUT£A%,X
  220FOR I%=1 TO X
  230INPUT£A%,YORN$(I%),TIM(I%)
  240IF YORN$(I%)="" THEN YORN$(I%)="Dont Know"
  250NEXT
  260CLOSE£A%
  270ENDPROC
```

```
LIST
   10REMpb1=slide change.pb2=slide on/off.pb4=timer start.pb5=timer stop
.pb6=same.pb7=different.
   20size=80:REM Max Number Of Slides...
   30*DISC
   40DIM NO(7),YORN$(size),TIM(size)
   50PROCload
   60a=NO(1):b=NO(2):c=NO(3):d=NO(4):e=NO(5):f=NO(6):g=NO(7)
   70PROCload
   80MODE4
   90?&FE62=63
  100?&FE60=0
  110VDU 23;8202;0;0;0;
  120VDU 19,0,4;0;19,3,2;0;
  130PROCtitle
  140PROCtime(200)
  150CLS
  160PROCchoose
  170END
  180DEFPROCtime(t)
  190TIME=0:REPEAT
  200in=INKEY(0)
  210IF in=32 THEN GOTO 250
  220IF in=13 THEN GOTO 260
  230UNTIL TIME>t
  240ENDPROC
  250x=1:PROCdiag:ENDPROC
  260PROCmenu:ENDPROC
  270DEFPROCtitle
  280GCOL0,1
  290MOVE 550,400
  300DRAW 750,400
  310DRAW 850,200
  320DRAW 450,200
  330DRAW 550,400
  340MOVE 450,200
  350DRAW 450,50
  360DRAW 850,50
  370DRAW 850,200
  380DRAW 950,200
  390DRAW 950,50
  400DRAW 850,50
  410MOVE 950,200
  420DRAW 875,300
  430DRAW 800,300
  440MOVE 50,1000
  450DRAW 1200,1000
  460DRAW 1200,500
  470DRAW 50,500
  480DRAW 50,1000
  490MOVE 650,400
  500DRAW 50,1000
  510MOVE 650,400
  520DRAW 1200,1000
  530MOVE 650,400
  540DRAW 1200,500
  550MOVE 650,400
```

Appendix II

Change in CNV Amplitude between Simple RT and VSRT

(Electrode site, Responding Hand and Participant)

Change in Contingent Negative Variation (microvolts) from Simple to Visuospatial Task

Left Hand Response

Electrode	Participant	Value	Electrode	Participant	Value
F3	1	+1.95	F4	1	+1.49
	2	-5.01		2	-10.39
	3	+2.19		3	-0.72
	4	-3.93		4	-8.19
	5	+4.48		5	+2.02
	6	+5.15		6	+4.13
	7	+1.45		7	+17.76
	8	+0.23		8	+2.68
	9	-7.67		9	+1.91
	10	+8.15		10	+3.30
C3	1	-7.02	C4	1	-1.09
	2	-2.02		2	-3.05
	3	-0.70		3	+2.02
	4	-5.57		4	-6.46
	5	+0.34		5	+3.39
	6	-0.67		6	+3.61
	7	+17.07		7	+16.77
	8	+0.71		8	-0.18
	9	+7.64		9	+8.04
	10	-0.82		10	-1.73
P3	1	+1.93	P4	1	+4.88
	2	+3.95		2	+0.58
	3	+1.53		3	+1.09
	4	-7.72		4	-7.09
	5	-5.84		5	-
	6	+3.48		6	+2.94
	7	+2.49		7	+0.30
	8	+6.81		8	+2.95
	9	+0.26		9	+2.52
	10	-18.90		10	+0.68

Right Hand Responses

Electrode	Participant	Value	Electrode	Participant	Value
F3	1	+5.70	F4	1	+6.62
	2	-7.81		2	-6.87
	3	+0.71		3	+4.67
	4	-8.26		4	-8.41
	5	-9.26		5	-4.67
	6	+4.00		6	+6.25
	7	+6.84		7	+9.70
	8	-3.59		8	+0.15
	9	-2.80		9	+10.92
	10	+6.32		10	+3.64

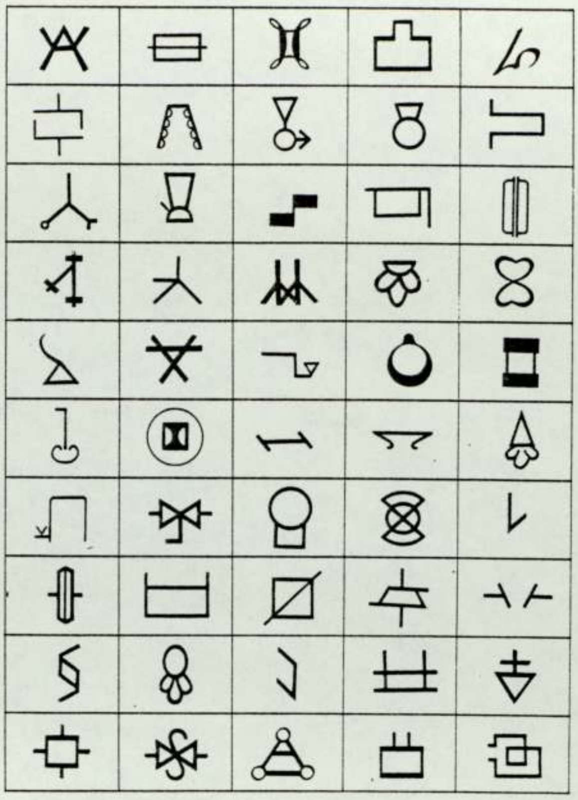
Electrode	Partici- pant	Value	Electrode	Partici- pant	Value

Right Hand Responses cont/d...

Electrode	Partici- pant	Value	Electrode	Partici- pant	Value
C3	1	+6.54	C4	1	+6.82
	2	-7.17		2	-3.39
	3	+1.58		3	+2.17
	4	-1.89		4	-5.38
	5	-4.94		5	-7.22
	6	+8.07		6	+4.32
	7	+2.23		7	+2.76
	8	+8.64		8	+4.60
	9	-0.32		9	+0.05
	10	+2.91		10	-1.52
P3	1	-7.71	P4	1	-5.36
	2	+4.22		2	-0.55
	3	-0.57		3	+1.63
	4	-2.31		4	-3.34
	5	-0.64		5	+2.41
	6	-1.45		6	+3.46
	7	+8.06		7	+4.45
	8	-1.58		8	-4.30
	9	+6.44		9	+8.75
	10	+7.27		10	+5.36

Appendix III

Meaning and the CNV in Recognition Memory
Stimuli used in Experiment on the Encoding of Meaningfulness and the CNV



senate	royal	unknown	product	locate
treasure	surround	progress	congress	scarcely
describe	besides	district	portion	oppose
castle	judgement	murmur	ancient	appeal
excuse	chamber	servant	message	whisper
conclude	somewhere	respect	decline	reader
leather	devote	throughout	fifteen	kingdom
friendship	struggle	worship	border	approach
witness	northern	herald	combine	virtue
furnish	creature	empire	household	inquire

sceerpt	ocrupdt	veodte	cnneait	nuccdole
rentrohn	ceuesx	retvui	rguhuotoht	parcpoah
qrniiue	aehbcmr	riohwsp	dmtgejenu	kwnounn
oepgsrrs	peierm	neaset	feieftn	eucrrtea
rooiptn	mnoicbe	iehpwsr	aeehltr	necgsors
rdahle	yraol	cealto	peoosp	aesriccy
idirnhfesp	seedbis	rsuifnh	noidkgm	tsiewns
setcla	sidcbere	mheeeowrs	cneidle	pleaap
rusrnudo	sidtcirt	eutarrse	ardree	rrdbeo
sgeamse	uhdsohelo	rnesvta	rgsultge	rrmmuu

Meaning and the CNV in Recognition Memory
Stimuli : words, non-words and symbols

Appendix IV

CNV Amplitudes : Meaning of Stimuli

Meaning and the CNV in Recognition Memory
CNV Measurements (all negative)

		Words						Non Words			
F3	1	1.281	F4	1	0.919	F3	1	1.070	F4	1	1.404
	2	1.660		2.	1.342		2	1.203		2	0.792
	3	1.332		3	1.378		3	1.665		3	1.438
	4	2.273		4	1.768		4	2.790		4.	1.273
	5	1.853		5	2.226		5	1.148		5	2.316
	6	1.748		6	1.515		6	1.200		6	1.569
	7	1.435		7	1,636		7	2.172		7	2.580
	8	1.556		8	1.582		8	1.247		8	1.099
	9	1.179		9	1.575		9	2.242		9	2.017
		1.60			1.73			1.79			1.79
		0.34			0.47			0.69			0.67
C3	1	1.014	C4	1	0.998	C3	1	1.587	C4	1	1.659
	2	1.539		2	1.636		2	1.149		2	0.819
	3	1.566		3	1.157		3	1.851		3	1.376
	4	2.280		4	1.841		4	2.169		4	1.292
	5	1.458		5	1.318		5	0.810		5	1.726
	6	1.306		6	0.926		6	1.040		6	1.278
	7	1.470		7	1.814		7	1.792		7	1.042
	8	1.270		8	1.747		8	1.088		8	1.516
	9	1.239		9	1.688		9	2.230		9	2.098
		1.64			1.61			1.73			1.62
		0.45			0.47			0.63			0.52
P3	1	1.943	P4	1	1.612	P3	1	1.755	P4	1	2.346
	2	0.908		2	1.149		2	1.338		2	1.280
	3	0.943		3	1.009		3	1.225		3	1.362
	4	1.729		4	1.784		4	1.729		4	1.328
	5	0.928		5	1.039		5	0.806		5	1.038
	6	1.002		6	0.728		6	1.014		6	1.194
	7	1.099		7	1.159		7	1.862		7	1.057
	8	-		8	-		8	-		8	-
	9	0.858		9	0.972		9	1.632		9	1.506
		1.39			1.38			1.63			1.59
		0.54			0.49			0.54			0.54

CNV Values : Experiment 6.1

Recognition Memory, Stimuli and Low Imagery

Symbols - Meaningful						Symbols - Non Meaningful					
F3	1	1.220	F4	1	1.603	F3	1	0.347	F4	1	1.222
	2	1.210		2	1.588		2	1.186		2	1.442
	3	1.638		3	1.628		3	1.249		3	1.072
	4	2.060		4	1.461		4	1.647		4	2.048
	5	1.754		5	1.666		5	1.542		5	1.530
	6	1.003		6	1.063		6	1.158		6	1.067
	7	4.305		7	2.529		7	1.818		7	2.912
	8	1.628		8	2.202		8	0.838		8	0.503
	9	2.707		9	2.537		9	1.574		9	1.114
		2.12			2.0			1.46			1.60
		1.07			0.63			0.60			0.77
C3	1	1.295	C4	1	1.908	C3	1	1.003	C4	1	1.427
	2	1.927		2	1.733		2	1.354		2	1.211
	3	1.843		3	1.166		3	1.740		3	1.021
	4	1.598		4	1.396		4	1.387		4	1.324
	5	1.677		5	1.543		5	1.530		5	1.649
	6	0.922		6	0.767		6	0.898		6	0.692
	7	-		7	-		7	-		7	-
	8	1.508		8	2.232		8	0.504		8	0.455
	9	1.535		9	2.020		9	1.684		9	1.578
		1.80			1.85			1.43			1.34
		0.58			0.63			0.51			0.54
P3	1	1.533	P4	1	2.123	P3	1	2.525	P4	1	2.326
	2	1.217		2	1.395		2	1.222		2	1.218
	3	1.056		3	0.928		3	1.010		3	0.921
	4	1.627		4	1.434		4	1.167		4	1.586
	5	1.408		5	1.372		5	1.562		5	1.586
	6	0.652		6	0.638		6	0.775		6	0.638
	7	3.038		7	3.107		7	1.418		7	2.302
	8	-		8	-		8	-		8	-
	9	1.117		9	1.582		9	1.043		9	1.078
		1.68			1.80			1.52			1.44
		0.80			0.85			0.63			0.64

Appendix V

CNV Scores (transformed)

Memory for High and Low Imagery Words

Experiment 6.2., Low Imagery Value (LI), High **Imagery Value (HII)** and Participants **using Imagery** Strategy (HI2) Transformed to equivalent to DC amplication

added CNV && CNV																
LI	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4
(F2	15.82	29.94	19.53	8.58	30.71	17.46	2.00	17.74	4.68	27.74	16.42	11.15	8.59	13.76	17.49	9.47
(C2	25.53	34.77	14.63	9.86	25.32	16.99	3.85	22.46	12.49	21.03	23.98	19.70	12.54	21.13	22.55	11.62
BP (P2	26.63	16.78	8.20	7.39	17.88	7.34	6.75	13.40	8.69	15.41	11.27	19.18	11.90	16.82	18.28	6.82
(P3	22.51	16.50	7.78	4.52	20.16	7.72	5.32	13.74	8.71	15.21	12.62	17.12	12.38	10.33	17.36	9.46
(P4	20.24	16.27	9.71	4.00	22.83	11.30	6.28	9.87	9.86	15.45	18.87	14.76	9.21	13.05	20.00	7.57
HI1	5	6	5	6	5	6	5	6	5	6	5	6	5	6	5	6
(F2	22.49	16.57	5.83	34.40	31.07	11.23	0.00	11.53	7.49	9.49	18.05	8.52	15.32	9.68	8.79	8.14
(C2	28.94	25.53	3.66	22.13	22.92	12.03	3.07	16.16	12.94	10.42	17.43	21.07	7.01	10.76	16.72	4.58
BP (P2	15.91	21.98	5.22	17.33	13.76	10.10	2.70	14.45	10.28	11.69	8.46	17.27	5.58	5.40	10.11	5.30
(P3	16.44	10.47	5.06	13.20	7.55	8.92	4.99	13.49	9.17	9.12	10.21	15.18	5.79	6.89	11.61	3.40
(P4	14.70	20.69	5.50	18.53	14.21	7.66	0.00	11.95	12.62	13.28	13.10	15.10	4.37	3.04	11.02	5.29
HI2	7	8	7	8	7	8	7	8	7	8	7	8	7	8	7	8
(F2	17.02	32.26	67.30	10.60	46.00	10.53	8.40	8.55	13.41	14.73	6.18	12.60	7.37	15.77	0.00	1.01
(C2	14.30	31.69	39.87	8.24	21.92	14.60	11.34	19.03	15.44	17.91	13.93	16.67	8.91	21.28	11.87	4.00
BP (P2	17.36	24.78	18.53	4.16	12.36	6.38	9.80	5.48	10.42	16.79	16.36	11.82	4.30	10.53	13.84	10.86
(P3	15.01	26.24	6.98	2.61	5.21	11.22	13.45	5.92	8.66	16.39	15.14	12.99	6.77	9.77	15.09	2.37
(P4	12.44	13.94	18.45	0.00	12.91	2.82	11.17	8.00	12.45	16.08	14.54	9.43	5.90	8.24	8.17	3.69
		+12.29		+2.61		+8.39		+3.07		-0.30		+3.56		+1.51		-1.31

added CNV & CNV																		
LI	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4
(F2	2.92	16.04	6.77	9.27	5.75	9.13	12.64	16.97	63.45	18.24	16.67	16.40	10.67	20.70	16.43	11.05	19.53	18.71
(C2	16.84	24.14	0.00	10.28	15.20	13.28	10.30	24.81	26.48	5.26	19.73	21.85	23.92	21.28	20.32	14.62	13.85	20.30
BP (P2	0.00	18.77	25.23	2.52	15.27	0.00	14.83	22.44	17.22	6.69	10.70	14.24	13.66	12.28	16.74	18.71	18.53	10.08
(P3	11.38	12.01	3.43	7.30	7.74	8.06	10.30	21.78	11.92	11.54	11.09	15.09	21.51	8.95	12.95	16.45	19.62	12.66
(P4	8.57	15.99	5.30	0.00	5.18	8.81	12.65	23.17	11.85	5.25	19.22	14.87	12.65	10.80	13.80	13.05	14.87	10.21
HI1	5	6	5	6	5	6	5	6	5	6	5	6	5	6	5	6	5	6
(F2	28.07	10.01	12.61	14.59	16.74	11.94	3.25	12.17	23.63	9.50	18.16	22.98	26.88	16.67	12.32	21.36	22.75	15.38
(C2	22.18	14.14	20.34	12.69	11.81	11.98	6.49	11.89	7.06	8.57	20.04	33.44	15.90	22.35	12.69	21.32	13.33	21.84
BP (P2	11.31	9.36	11.15	9.77	8.27	13.77	11.90	9.40	23.76	3.93	6.26	11.48	15.26	14.57	7.58	23.76	8.11	12.90
(P3	15.96	2.20	19.30	6.67	9.40	11.78	10.18	10.38	31.53	10.03	19.20	18.87	20.29	20.69	7.45	16.57	6.05	14.99
(P4	10.31	19.52	7.09	3.98	11.23	11.42	7.22	5.01	24.54	8.69	14.49	17.58	19.31	11.88	4.57	19.19	12.85	14.02
HI2	7	8	7	8	7	8	7	8	7	8	7	8	7	8	7	8	7	8
(F2	22.12	11.48	0.00	5.50	0.00	15.31	13.45	18.37	26.84	11.43	13.01	-	27.56	19.74	7.80	2.33	24.88	13.00
(C2	13.67	16.14	0.00	0.00	6.63	27.46	18.42	19.99	26.53	7.71	23.42	20.48	31.54	29.05	20.35	12.98	25.53	25.14
BP (P2	9.03	10.52	-	-	8.69	19.84	11.27	14.43	9.60	12.84	7.17	7.88	21.70	15.81	20.08	15.40	19.06	12.18
(P3	4.54	9.70	11.99	-	15.85	-	12.73	9.00	12.05	0.00	12.08	11.40	20.73	15.54	18.88	18.25	17.02	13.34
(P4	14.40	16.09	8.22	0.00	0.00	17.79	10.52	9.08	10.53	11.37	13.12	13.78	13.78	12.09	13.53	14.09	28.16	9.87
		-6.39		?		?		-0.08		-11.37		-2.37		+3.45		+4.16		+3.47

added CNV & CNV																
LI	3	4	3	4	3	4	3	4	3	4	3	4	3	4	3	4
(F2	19.37	16.58	9.12	14.29	12.25	12.91	6.60	4.02	6.43	-	16.27	16.24	29.46	14.41	25.27	0.00
(C2	27.81	23.64	14.39	8.13	16.92	25.73	5.88	7.82	0.00	-	17.60	14.36	20.45	16.30	22.62	11.57
BP (P2	16.38	10.55	14.73	6.89	14.22	20.68	12.32	6.55	0.00	-	-	-	15.28	5.69	11.92	4.70
(P3	22.93	10.97	10.96	8.17	11.96	10.58	14.71	2.04	0.00	-	13.53	12.13	17.37	17.95	12.07	3.48
(P4	11.72	10.27	10.93	8.58	9.35	15.99	8.67	0.00	0.00	-	19.43	8.91	9.89	10.61	11.68	5.57
HI1	5	6	5	6	5	6	5	6	5	6	5	6	5	6	5	6
(F2	18.02	11.08	39.15	7.23	17.56	14.39	7.37	0.00	14.42	2.61	2.77	14.05	29.93	8.20	24.08	21.04
(C2	22.29	10.96	36.54	12.82	18.73	21.00	4.58	7.85	10.93	7.77	6.73	15.33	31.02	7.05	25.81	15.87
BP (P2	8.46	7.41	35.83	12.21	13.46	9.93	2.35	5.72	2.67	0.00	-	-	18.93	0.00	7.33	5.36
(P3	22.62	11.26	27.38	13.27	13.33	9.84	2.01	5.35	5.76	4.06	10.97	12.32	14.56	5.98	7.01	7.69
(P4	9.15	8.36	28.24	16.37	12.07	8.93	0.00	4.23	2.38	2.01	4.24	16.28	18.10	0.00	7.26	6.57
HI2	7	8	7	8	7	8	7	8	7	8	7	8	7	8	7	8
(F2	10.57	12.82	2.89	11.41	9.85	15.97	11.27	20.33	14.67	6.33	5.28	11.97	16.31	12.12	20.81	23.67
(C2	12.09	14.19	15.26	7.59	22.17	31.93	9.15	20.70	13.65	9.95	10.46	9.64	16.21	10.89	19.15	21.64
BP (P2	11.75	11.60	6.27	3.58	17.27	21.33	6.13	7.91	6.02	3.57	-	-	8.75	3.33	10.19	7.68
(P3	11.20	13.06	16.65	13.84	15.25	16.56	3.65	9.62	12.27	9.26	10.77	8.99	5.02	5.94	14.02	16.27
(P4	12.72	11.74	14.20	10.25	10.56	14.25	0.00	11.13	4.07	2.67	6.71	7.59	7.49	-	13.06	11.14
		-1.32		-3.58		+2.31		-1.51		+6.59		+1.40		?		+0.13

Appendix VI

Mean Response Times (Experiment 6.4)

Low and High Imagery Stimuli
Set Sizes 1, 2 and 4 words

Mean Response Times (Experiment 6.4)
Low (L) and High (H) Imagery Stimuli
Set Sizes 1, 2 and 4 words

Participants		Set Size		
		1	2	4
1	L	964	913	841
	H	946	994	844
2	L	723	948	813
	H	788	863	825
3	L	1007	1182	1785
	H	1062	1197	1582
4	L	698	782	842
	H	658	793	802
5	L	942	1061	919
	H	852	1071	984
6	L	1062	1008	1066
	H	1064	1027	865

Appendix VII

CNV Data (Experiment 6.4)

Low and High Imagery Stimuli
Set Sizes 1, 2 and 4 words

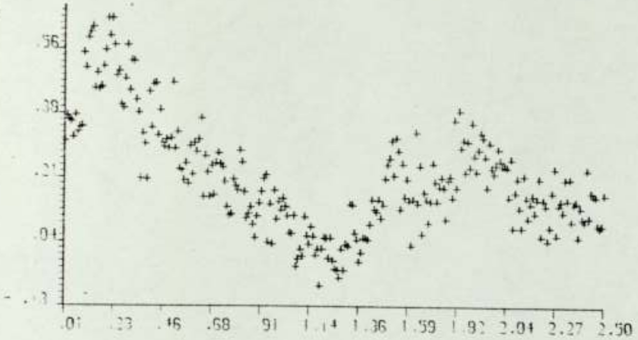
CNV Data (Experiment 6.4)
Low (L) and High (H) Imagery Stimuli
Set Sizes 1, 2 and 4 words

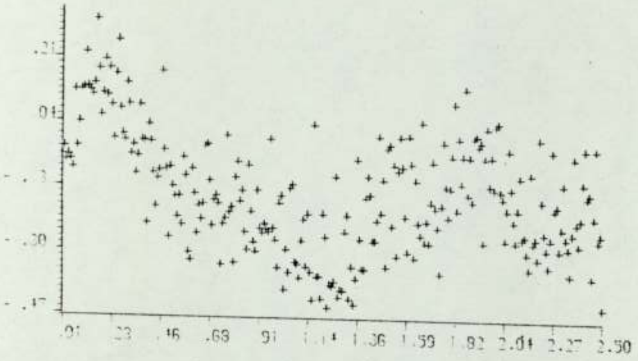
		Electrode			
		F3	F4	P3	P4
1	1L	-1.23	2.51	0.64	1.96
	1H	-1.79	2.34	1.306	2.63
	2L	1.59	-1.83	0.89	3.7
	2H	-2.27	-1.10	2.49	2.68
	4L				
	4H				
2	1L	1.57	0.5	-1.0	0.05
	1H	+5.3	+0.965	+0.94	+3.04
	2L	-7.2	-5.3	-3.6	1.6
	2H	-0.74	-0.60	-0.32	-0.16
	4L	-1.55	-1.96	+0.95	-0.13
	4H	-1.26	+1.8	+2.00	+0.81
3	1L	-1.48	6.76	-4.8	-1.48
	1H	0.08	3.35	-1.16	-1.57
	2L	0.65	7.0	0.66	30.13
	2H	2.35	1.33	1.84	-6.52
	4L	4.7	7.86	11.98	12.7
	4H	-2.48	+9.10	-8.25	-7.0
4	1L	-2.06	-1.27	-0.46	-2.36
	1H	-0.38	0.852	-0.38	-1.23
	2L	+0.38	+5.63	-0.40	+0.74
	2H	-1.56	0.543	-1.89	-0.75
	4L	+2.61	+7.50	+1.67	-0.60
	4H	+2.84	+6.52	-0.12	-0.30
5	1L	-3.94	-3.46	-0.94	-0.75
	1H	-1.9	+0.54	-2.62	-0.40
	2L	-7.04	-6.23	-4.48	+1.40
	2H	-7.4	-6.16	-3.20	-1.60
	4L	+0.18	+1.8	+2.82	+0.61
	4H	+3.11	+4.37	-0.7	+3.11

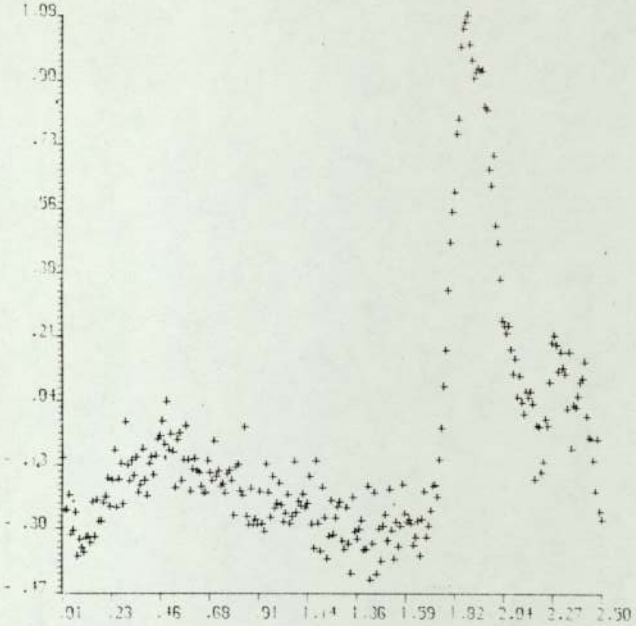
Appendix VIII

An Example of CNV Record (Experiment 6.4)
High Imagery Stimuli

Set Sizes 1, 2 and 4 words


.56
.39
.21
.04
-.13
.01
.23
.46
.68
.91
1.14
1.36
1.59
1.82
2.04
2.27
2.50


.21
.04
-.13
-.30
-.47
.01
.23
.46
.68
.91
1.14
1.36
1.59
1.82
2.04
2.27
2.50


1.09
.90
.73
.56
.39
.21
.04
-.13
-.30
-.47
.01
.23
.46
.68
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1.36
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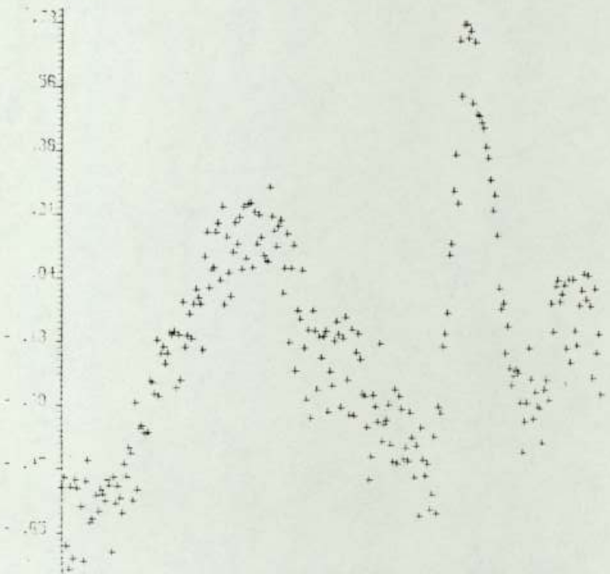
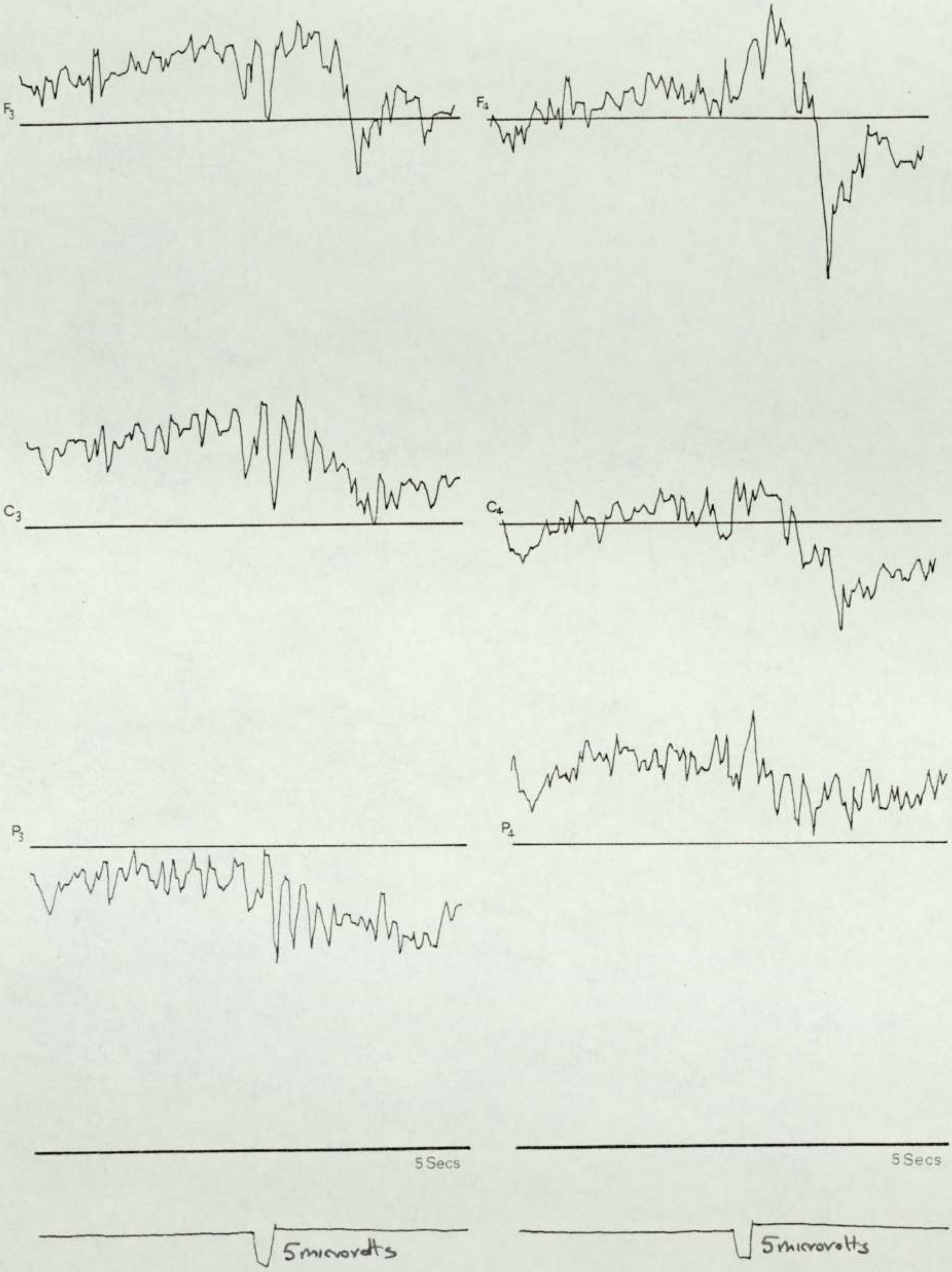
1.82
2.04
2.27
2.50

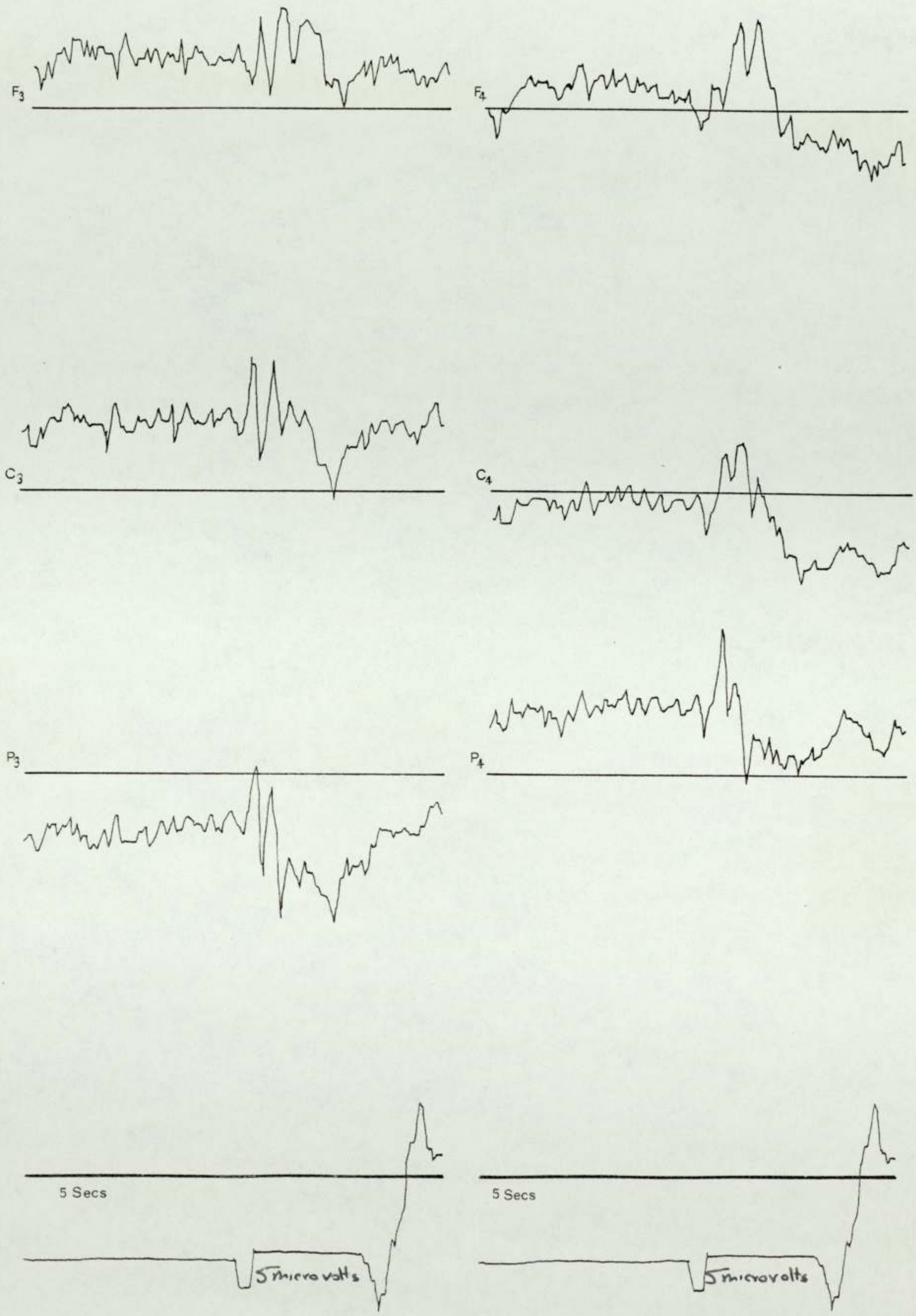

.73
.56
.39
.21
.04
-.13
-.30
-.47
-.63

Appendix IX

Face Recognition Task

Sample of CNV Record from One Participant (MT) Encoding and Recognition Phases


F$_3$
F$_4$
C$_3$
C$_4$
P$_3$
P$_4$
5 Secs
5 Secs
5 microvolts
5 microvolts


F3
F4
C3
C4
P3
P4
5 Secs
5 microvolts
5 Secs
5 microvolts

Appendix X

CNV Values : Face Recognition Task

(Experiment 7.1)

CNV Values

Face Recognition Task Experiment 7.2

Final Values with respect to Baseline & Point (3) at 4.75 secs

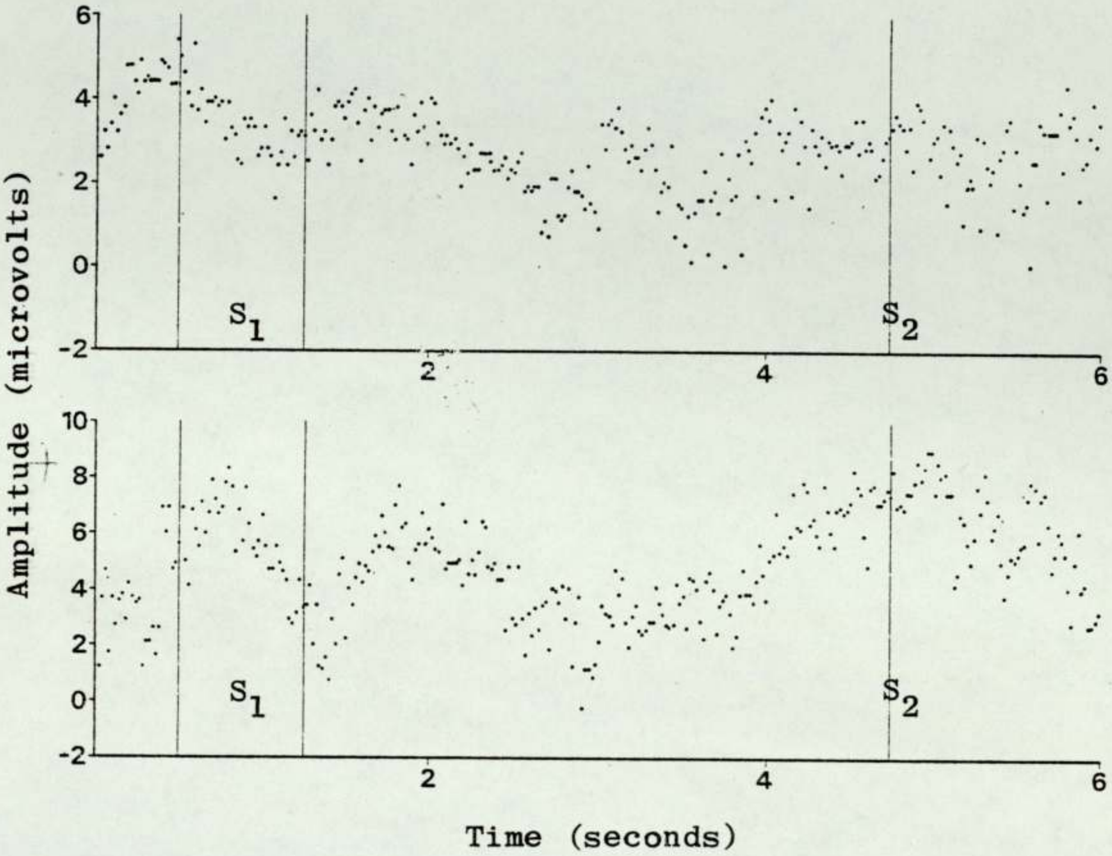
Subject	Channel	Upright	Inverted	Upright-Same	Upright-Diff	Inverted-Same	Inverted-Diff	Inverted Incorrect
1	P3	+ 0.036	+ 0.098	+ 0.081	+ 0.152	+ 0.080	+ 0.136	+ 0.044
	PZ	+ 0.168	+ 0.159	+ 0.254	+ 0.326	+ 0.266	+ 0.050	+ 0.402
	P4	+ 0.380	+ 0.436	+ 0.508	+ 0.542	+ 0.398	+ 0.336	+ 0.585
2	P3	- 0.720	- 0.666	- 0.689	- 0.873	- 0.716	- 0.806	
	P2	- 1.556	- 1.449	- 1.621	- 1.857	- 1.487	- 1.686	
	P4	- 0.937	- 0.780	- 1.008	- 1.369	- 0.768	- 0.852	
3	P3	+ 0.288	+ 0.280	+ 0.288	+ 0.355	+ 0.255	+ 0.246	
	P2	+ 0.119	+ 0.068	+ 0.094	+ 0.123	+ 1.080	+ 0.149	
	P4	+ 0.394	+ 394	+ 0.378	+ 0.467	+ 0.450	+ 0.449	
4	P3	+ 0.229	+ 0.178	+ 0.216	+ 0.224	+ 0.169	+ 0.111	
	P2	+ 0.504	+ 0.352	+ 0.542	+ 0.528	+ 0.288	+ 0.233	
	P4	+ 0.648	+ 0.526	+ 0.674	+ 0.683	+ 0.564	+ 0.488	
5	P3	- 0.161	- 0.119	- 0.204	- 0.173	- 0.144	+ 0.182	+ 0.093
	P2	- 0.335	- 0.289	- 0.360	- 0.407	- 0.022	- 0.217	- 0.127
	P4	- 0.513	- 0.420	- 0.551	- 0.581	- 0.149	- 0.339	- 0.172

Appendix XI

CNV : Sample Response from One Participant
(Experiment 7.2)

Face Recognition : Upright and Inverted Condition

CNV Data : Face Recognition in Upright and Inverted Conditions



Appendix XII

Face Recognition (Experiment 7.3)

Mean Response Times

Face Recognition : Experiment 3
Mean Reaction Time

Upright/Same	Inverted/Same
833.8	880.8
925.5	1028.4
1047.3	1860.5
1269.2	1281.2
928.4	1049.6
920.5	977.7
799.2	860.6
603.8	723.3

Upright/Different	Inverted/Different
934.4	1039.3
1424.5	1136.9
2234.1	2817.9
1442.1	1647.5
1279.9	1170.7
1235.7	1007.5
909.8	832.3
766.4	758.2

Appendix XIII

The Difference in Performance and CNV Amplitude between Upright and Inverted Conditions

The Differences in Performance and CNV Amplitude at all Electrode Sites between Upright and Inverted Conditions

Response (milli-seconds)	Amplitude (microvolts X10^{-2})			
	F3	F4	P3	P4
-470	8	188	30	258
-1029	270	464	130	-201
-8132	158	220	-16	-4
-120	72	100	202	-94
-975	58	-40	2	-142
-572	68	51	146	-164
-614	916	1594	2052	856
-1195	12	-60	28	32
-1049	42	-26	0	392
+287.6	298	142	28	390
-583.8	-30	50	88	-36
-2047	-120	-90	-84	-48
+1092	-28	-22	-18	128
+2282	50	32	1134	73
+82	316	-6	-40	-74
	0.358	0.150	0.116	0.223

Appendix XIV

CNV Values : Mental Rotation Task

(Experiment 8.1)

CNV Values
Mental Rotation Task Experiment 8.1

	F3	F4	C3	C4	P3	P4		F3	F4	C3	C4	P3	P4
HK$_1$	44.28	22.14	56.86	39.34	61.24	49.03	DB$_{10}$	6.42	6.48	4.54	13.32	4.19	9.08
	42.92	38.91	46.88	42.29	38.36	37.66		8.16	12.64	7.17	6.32	5.96	7.16
	40.15	38.60	47.99	44.15	49.73	43.87		10.79	15.13	13.12	19.16	12.74	17.61
KL$_2$	36.60	23.04	27.09	22.62	27.28	25.44	DR$_{11}$	4.75	4.55	7.58	4.12	10.64	10.71
	27.10	18.76	14.63	15.19	17.21	14.77		6.89	3.09	7.73	4.94	9.48	8.67
	25.88	21.23	16.15	21.55	18.94	16.23		7.16	6.96	14.29	11.90	16.33	16.02
JE$_3$	19.23	21.20	18.60	15.05	15.50	13.10	SB$_{12}$	6.92	11.59	15.98	21.31	18.53	19.47
	10.54	10.11	14.62	10.31	2.67	9.79		5.09	2.52	6.07	7.84	6.01	9.48
	27.38	28.63	18.00	21.53	2.81	14.49		4.62	12.68	7.78	9.74	7.95	10.34
JP$_4$	9.18	16.32	15.17	15.64	12.42	11.25	DW$_{13}$	12.31	0.00	26.20	15.06	24.52	20.77
	20.25	13.82	14.64	11.57	9.32	8.84		16.92	15.62	22.01	13.25	10.66	7.32
	15.59	18.89	23.48	18.02	23.31	19.75		0.97	3.14	13.03	11.35	8.62	4.36
EB$_5$	10.37	12.78	4.15	6.64	3.23	5.02	RW$_{14}$	13.34	16.06	12.74	8.43	8.27	3.95
	5.0	11.21	5.70	8.80	6.57	5.55		6.05	13.60	11.53	7.86	7.08	5.75
	2.27	5.02	12.49	3.85	7.01	4.85		22.62	28.14	19.20	16.64	19.30	12.72
HW$_6$	8.95	11.78	9.48	13.77	23.55	11.89	AM$_{15}$	12.07	15.62	8.79	17.24	11.66	13.72
	34.39	34.97	28.90	34.04	48.94	29.36		16.83	11.72	12.49	10.28	17.78	17.17
	8.40	5.89	5.79	5.87	14.79	9.57		10.9	12.89	16.05	15.09	20.09	21.71
JL$_7$	45.08	51.29	32.64	53.72	48.10	53.51	TH$_{16}$	9.79	18.00	11.70	14.63	18.51	12.30
	11.24	9.70	17.22	10.51	+4.63	16.67		10.67	13.88	12.26	7.40	9.53	6.90
	42.67	48.02	-	48.18	39.31	41.49		18.29	12.45	11.97	6.54	11.36	8.41
PS$_8$	36.58	+32.75	42.74	+2.54	46.05	40.04	DT$_{17}$	17.4	12.9	18.1	16.45	10.65	13.6
	18.6	30.3	14.58	10.57	11.73	14.24		8.3	11.0	11.35	10.65	9.35	8.55
	21.14	27.12	20.08	17.27	20.69	20.86		8.2	9.65	7.65	4.5	6.95	6.85
LG$_9$	26.29	12.41	13.35	13.80	21.84	15.78	JC$_{18}$	10.26	6.54	8.95	5.79	7.69	7.12
	30.91	17.31	11.74	15.11	18.5	12.32		15.88	17.93	13.30	17.44	7.43	12.53
	31.18	15.08	8.54	6.91	+2.73	+4.71		13.22	13.98	9.5	11.07	6.75	10.30

Appendix XV

Mental Rotation : Amplitudes of the CNV

Electrodes P3 and P4

Mental Rotation : CNV Values for Different Degree of Rotation at P3 and P4

P3	P4
14.89	11.59
7.51	3.77
9.56	8.60
12.32	11.58
5.07	8.82
16.54	10.48
8.12	10.27
14.45	15.7
26.08	24.07
14.35	15.19
4.08	6.36
5.82	8.08
8.73	5.83
11.62	12.71
9.21	7.86
18.68	18.72
14.22	12.47
7.97	11.30
13.71	11.76
9.73	6.69
11.35	13.86
15.67	12.82
6.06	9.17
11.52	13.88
32.13	23.07
10.68	14.82
18.50	14.81
10.98	8.73
16.86	13.31
10.0	13.4
13.27	9.23
11.62	11.59
12.62	15.73
11.05	9.11
20.22	26.49
15.9	12.63

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